SHIP-BUILDING

AND

STEAM SHIPS.

THE
THEORY AND PRACTICE
OF
SHIP-BUILDING

BY

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WITH PORTIONS OF THE TREATISE ON NAVAL ARCHITECTURE

BY

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STEAM-SHIPS

BY

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EDINBURGH
ADAM AND CHARLES BLACK
MDCCCLXI

PREFACE.

THE proprietors of the Encyclopædia Britannica having determined on printing the article SHIP-BUILDING as a separate treatise, it is proposed to say a few words explanatory of its tenor and scope. The article in the previous edition was written by Mr Creuze, a member of the School of Naval Architecture, which formerly existed at Portsmouth under the late Dr Inman. His death at a comparatively early age, while it was a source of great regret to a numerous circle of friends, was at the same time a serious loss to the profession of which he formed so distinguished an ornament. His work was received with the greatest favour as a valuable addition to the works on Ship-building in the English language. Since it was written, however, great changes have taken place. The researches of Canon Moseley, and the still more important researches and works of the Rev. Dr Woolley, have added to the theoretical knowledge of the subject, and the rapid extension of Steam-Shipping, the general increase in the size of vessels, the introduction, or perhaps, to speak more correctly, the now general adoption of Iron as a material for the construction of Ships, and latterly the use of a casing of thick armour-plates of iron for the protection of men-of-war, all called for special notice, and for a revisal, and in some respects a renewal, of the article.

To follow Mr Creuze was felt to be assuming no light responsibility; but, as it was specially desired to produce a work which should be of a nature to be useful to practical ship-builders, and as iron ships had assumed so important a position in the shipping of the country, it became imperative that the work should be undertaken by one possessed of a practical knowledge of this branch of the subject, the more so as it was felt that the previous article by Mr Creuze afforded so good a groundwork for the portion on wooden ship-building which would still be required. The writer was employed by Mr Fairbairn of Manchester, in 1834, upon two iron steamers constructed by him to run upon the Humber between Selby and Hull. In 1836 he entered into partnership with Mr Fairbairn, for the purpose of commencing Iron Ship-building on the Thames; and works for this purpose were erected at Millwall, where he was for some years the sole and resident partner, actively engaged in superintending the construction, both theoretically and practically, of the iron vessels built there. In 1843 he entered the service of the Admiralty, and since then he has carefully watched the progress of iron vessels, and, while he has been in a position to do so, he has at the same time also had opportunities of seeing the construction of some of the finest specimens of wooden ships that the world has ever seen, or probably now will ever see.

The history of Naval Architecture, as given in the previous article, has been retained with but little change; from that period it has been continued up to the present time. Since the text was written, however, another change has taken place in the history of Ship-building in the Royal Navy by the retirement of Sir B. W. Walker from the position of Controller. The period of his career was an eventful one. Many beneficial changes in the administration of his office were introduced by him, and many fine ships were built during the time of his holding the office of Surveyor, and subsequently of Controller, of the Navy, a change of name with apparently but little change in power or responsibility. It is perhaps too early a date, after his retirement, to write an impartial history of the occurrences of his time; but it is to be feared that it has already become apparent that his term of office was at first a period of retrogression, and subsequently of only forced, and therefore slow, advancement in the direction to which everything in ship-building was tending. On those slipways on which the Arrogant, the first attempt at a Screw Frigate in the Navy, and the Plumper, a forerunner of the class of Screw Sloops or small corvettes, were built, three-decked sailing ships were laid down, and on the outbreak of the Russian war the British Navy was consequently found deficient in those classes of small vessels which would have proved the most useful in any war. If the classes of Minx and Teazer, Rifleman and Sharpshooter, Reynard and Plumper, Arrogant, Dauntless, Simoom, and Agamemnon, not to mention Blenheim, Hogue, &c., as forerunners of Screw Line-of-Battle Ships, all laid down, and many tried and proved before this period, had been followed up and improved upon, spending the same amount of money, the British Navy would have been in a position to have earned more honour in that war. If men have not narrowly watched the progress of events, it cannot possibly happen that if suddenly put into places of active responsibility, they can be such good judges of what is likely to be most beneficial as others whose minds have been directed for years to the one branch placed under their control. It is to be hoped that the change in the constitution of the Board of Admiralty now (1861) under the consideration of a Select Committee of the House of Commons, will lead to this most important matter being put upon a proper footing.

The changes that have taken place in the art of gunnery, and in the nature of the projectiles used, and the present position of this country behind France, in regard to the introduction of the system of covering vessels with thick iron plates, to make them impenetrable to shell and solid shot from the ordinary previously existing guns, or in regard to the construction of any vessels specially prepared to meet opponents so protected, seem both to indicate that whatever may be the views entertained, or whatever may be the decision finally come to, as to the proper classes of vessels hereafter to be built, the construction of the ordinary classes of wooden vessels has been continued too long. Doubts may be felt, and they have been strongly expressed by Sir Howard Douglas, the greatest authority of the present day on naval gunnery, whether these armour-clad vessels are judicious, and will continue hereafter to be built, and in these doubts the writer fully agrees. It seems, however, to be generally admitted, and Sir Howard Douglas himself concurs, though unwillingly, in believing that vessels of this class must at present be built by us to put the nation on an equality, or rather to keep up our superiority on the seas over France. From the complete revolution, as before said, that is now taking place in gunnery, it would seem more especially imperative that the whole subject of the structure of the future vessels of war should also be taken into immediate and serious consideration. The dangerous and destructive nature of the shells now in use would lead to the opinion that a man-of-war should hereafter be built in such a manner that her sides and upper deck would be impenetrable by them, especially when it is considered that iron of a thickness of two inches is understood to be sufficient for this purpose. With respect to rendering vessels proof against solid shot, or even altogether against shells of the heaviest nature, the utmost that the advocates for armour-clad ships have claimed for these vessels which are now being built cased with iron 4½ inches thick, backed by timber 18 inches thick, is, that they are impenetrable to 68-pounder shot; and this seems to be the greatest thickness or weight of side that they have ventured to propose for any vessel. Now, when it is considered that, according to the present system of gunnery, there is no limit to the weight of a projectile, except, perhaps, the facility of handling it by two men, and that this would permit a bolt-formed projectile of as great a weight as 400 lbs. to be used, it would appear to be out of the question to attempt to construct ships absolutely, or, practically speaking, even generally impenetrable. The subject is a serious one, when it is considered that such projectiles might be fired against a vessel costing a sum approaching to half a million sterling by a tiny and swift gunboat.

In 1854, during the Russian war, the subject of rifled mortars for throwing conical shot or shell of great weight was brought forward and strongly advocated by Lieutenant Palliser of the 60th Rifle Brigade, and in 1855 the writer saw one of his mortars tried by the Excellent at Portsmouth, with great success for a first experiment. It is also well known that at that time the Russians were turning their attention most seriously to the subject of mortar firing, with a view to meeting the floating batteries which were then being constructed in this country and in France, with their sides protected by 4-inch plates of iron, while their decks were left unprotected. In the event of a war, it is not likely that such means of destroying these vessels would be left untried, and certainly on our side many of the young officers commanding these small vessels, and anxious to distinguish themselves, even at a probable risk of their own destruction, would only be too eager to make the attempt.

After completing the history, the theory of naval architecture was treated of by Mr Creuze, and the same arrangement has been continued. This portion of the present article has been rewritten, and is entirely the production of Mr Robinson, Head-master of the school for apprentices in Chatham Dockyard. The writer believes that he could not have obtained the assistance of any one more competent to do justice to the subject, knowing that Mr Robinson's knowledge and acquirements in this respect have been highly considered by both Canon Moseley and Dr Woolley, the two highest authorities of the present day upon this branch of mathematical research.

For the investigations respecting the effects of the forces which act upon a ship when in motion, and the strains to which she is liable under different circumstances, the writer is himself answerable, as well as for the portions upon the materials used in ship-building, upon the forms and the construction of the bodies of ships, and upon the practical operations required therein. On all these points, occasional remarks from Mr Creuze's previous work, which was placed by the proprietors at the disposal of the writer, have been introduced, but they are so mixed up with the general reasoning, that it was found impossible to separate them, or to give them entire as extracts from his work, without hurting the continuity of the argument, and rendering the illustrations aimed at obscure. The desire throughout has been to produce, in the simplest possible form, a work which may be useful to the practical ship-builders of this country.

To naval officers, it is at the same time believed that much of the article will be found useful; because, while it must be beneficial to them to understand the principles on which the ships in which they are serving are constructed, they ought also, certainly, to understand those principles which regulate the strains to which their ships are exposed under different circumstances, and how these may be modified and lessened by their management.

In conclusion, the writer desires to express his thanks to the managing Directors of the Peninsular and Oriental Company, and to the Practical Builders to whom he applied; and who, in the most kind and ready manner, furnished him with the valuable specimens of their works which appear in the plates.

PORTSMOUTH, *April* 15, 1861.

CONTENTS.

SHIP-BUILDING.

STEAM SHIP.

TIMBER.

TONNAGE.

SHIP-BUILDING.

To a people whose power is essentially maritime it is not necessary to use any arguments in proof of the importance of ship-building. Without pausing to dwell on the various struggles by which England has maintained her position amongst nations, it must be seen by all who study her history, that it has been by keeping invaders from her shores, by means of her wooden bulwarks, that she has withstood the repeated attacks of the powerful nations of the continent. And whilst the navy must be looked upon as the proper means of defence to this sea-girt land, who can visit the docks of London, Liverpool, the Clyde, or any of her other commercial ports, and not feel that her very heart's strength lies in those forests of masts which bring wealth to her merchants and manufacturers, and the means of employment to her artisans, forming, at the same time, a nursery and a reserve of seamen, who will be ready in the hour of need to vindicate her claim to pre-eminence on the ocean? Who, it may also be asked, can look upon the changes effected by her instrumentality in all quarters of the globe, and not own that her winged messengers have, under God's blessing, been the means of spreading civilization and truth through a large portion of the world?

The love of a sailor's life, common to all ranks amongst her sons, owes perhaps its origin to their Norman forefathers; but, however begotten, and however fostered, England owes much to it, and to the spirit of adventure which it has engendered amongst them. Individual enterprise has led to national achievements, till the name and power of Great Britain have been so extended that the sun never sets upon her possessions.

In an age when science is lending its mighty aid to every peaceful and warlike art, when mighty armies may be suddenly concentrated by railroads, and a nation's fate may hang on the electric wire, England must not trust in the multitude alone of her ships. Every fresh struggle for wealth or power proves that it is the amount of mind and intellect put forth in that struggle, and the amount of energy, and of means used to effect the end desired, which, humanly speaking, ensure success; and, as knowledge is always increasing, nations or individuals must not rest upon what has been done, if they desire to keep pace with the world in its eager rush of advancement and improvement. With regard to ship-building, not only must ingenuity and skill be brought to bear to assist the artisan in the practical construction of the fabric, but men of science must lend their aid, and use their powers of investigation, to assist in designing a complete whole, adapted to meet the ever-increasing competition for mastership on that element on which not only the welfare of England but of the whole world seems to hang.

The limits of a treatise of this nature are such that a very general view only of the many branches of inquiry involved in this important subject can be given. It could not, however, be considered complete without a short outline of the rise and progress of the art, or without some reference to the authors from whose works further information may be obtained. It is always interesting and instructive in every art to trace the various stages it has gone through before arriving at its existing state. The retrospect of the art of ship-building shows that there has been no standing still in its course without corresponding injury to the prosperity and power of the nation which has neglected it, and that there must be no relaxation of exertion to meet the demands of a commercial and warlike people.

RISE AND PROGRESS OF NAVAL ARCHITECTURE.

Marine architecture divided into epochs by Charnock.

In tracing the progress of naval architecture among the nations of antiquity, in order to connect it with its advance in more modern times, the chronological divisions adopted by that indefatigable investigator, Charnock, in his valuable *History of Marine Architecture*, present a very succinct idea of the probable rise, progress, decline, and revival of the art, and therefore offer a valuable guide for investigation. It would not be consistent with the purpose of this article to enter into the detail that would be necessary to ascertain the state of naval architecture during the periods embraced in each of the sections he has assigned to this subject. Some few facts only will be collected from various authors in illustration of the probable size and nature of the shipping of the ancient world, with an outline of what little is known of the rude vessels which, during the darkness of the middle ages, bore the marauders of the northern nations on their predatory excursions. Charnock divides maritime history into seven sections. The first comprehends the time previous to the foundation of Rome, until which he considers that all history is founded on surmise. The second section comprises a period somewhat less obscure, in which the collateral testimony of various authors may be examined and compared; and therefore there certainly appears less difficulty in ascertaining facts. It extends from the foundation of Rome to the destruction of her rival, Carthage. The termination of the third is at the conversion of the Republic into an empire. The death of Charlemagne ends the fourth epoch. The fifth extends from this period to the discovery of the mariner's compass. The sixth ends with the discovery of cannon, and with their adaptation to naval warfare commences the seventh epoch.

The Ark.

The first vessel of which we have any description is the ark as built by Noah under the directions of the Almighty. Its proportions possess some interest, because, though not intended for a voyage, it may be inferred that it was constructed to float with as little motion as possible, considering that it "went upon the face of the waters" for about five months. It was no doubt exposed to the action of the winds and waves during that period, for before it rested "a wind was made to pass on the earth, and the waters asswaged." Assuming a cubit to be about 18 inches of our measure, its length was about 450 feet, its breadth about 75 feet, and its depth about 45 feet, with an arch or round-up of the upper deck of about 18 inches. Its draught of water must have varied greatly during the period of its occupation, as twelve months' provisions must have formed a very large proportion of the original weight, and these must have been gradually consumed. Its length is thus seen to have been six times its breadth, and it is perhaps curious that ship-builders should not sooner have given this, or a greater proportion of length to their vessels; seeing that these were intended for locomotion, with as much speed as possible, and consequently that an increase of length must have been proportionally advantageous to them, by giving them a finer form. The remembrance of this huge vessel, or floating house, would remain long on the minds of Noah's posterity; but it was not likely to influence them in the construction of petty floating vessels, to meet any of their limited requirements. Wickerwork frames of rushes, or reeds, or of the rind of the papyrus, smeared with mud or pitch, similar to the ark in which Moses was exposed, appear to have been at a very early age brought into use, and basketwork, covered with skin, has continued in constant use among many nations, even up to the present time. They are still in use in some parts of this and other countries under the name of coracles. Canoes, formed out of the trunk of a tree, require tools or implements for their construction, and were, therefore, no doubt of later introduction.

Vessel Ancie Egypt.

As early authentic records on the subject of ship-building, the paintings and sculptures of Upper and Lower Egypt may be referred to. These show regularly formed boats, constructed of sawn planks of timber, propelled by numerous rowers, and also by sails. Some are represented as formed with inclined planes, forward and aft in the same manner as the barges on the Thames, and in this respect are more correct in theory and in reality as to ease of propulsion than many canal-boats of the present day, constructed of a wedge-like form. The Hebrews in the time of Solomon must have possessed vessels of considerable size, as mention is made, in the sacred writings of that date, of "stately ships" and of voyages made to bring trees of considerable size to be used in the building of the temple. In addition to the trade in the Mediterranean from Joppa and Tarshish, it is also recorded that Solomon despatched a navy of ships from the Red Sea to fetch gold from Ophir, the position of which, though disputed, was probably on the east coast of Africa.

Phœni shippi

The Phœnicians were connected with the Hebrews in their maritime expeditions, and this people appear to have been the most enterprizing in navigation of all the nations of antiquity. There can be no doubt from the accounts given by that most pains-taking and careful historian, Herodotus, that an expedition fitted out by this people sailed round the Cape of Good Hope. They started from the Red Sea, and after passing Ophir, if situated, as previously supposed, on the east coast of Africa, and to which they were in the habit of trading, they rounded the Cape, and keeping by the shore they entered the Mediterranean through the pillars of Hercules, or Straits of Gibraltar, and arrived in Egypt in the third year of their expedition. Vessels capable of performing such a voyage must have been of considerable size. The Phœnicians were also engaged, in concert with other nations, in wars with the Greeks; and it was from them that the latter nation learned in their wars what they knew of ships and of navigation. Amongst the Grecian states, the Corinthians appear to have most distinguished themselves by improving the forms of the galleys, and increasing their size. The people of Tuscany and the Carthaginians also became important maritime powers about this time.

Grecia shippi

Roma shippi B.C.

The Romans in the earlier stage of their history paid little attention to navigation, until it was forced upon them by the necessity of competing with their great rivals the Carthagenians. The galleys of this period ranged from a single bank up to the quinquireme of five banks of oars. The oars in these large galleys being arranged in sets or *banks*, the number of these could be increased to any extent by giving additional length to the galley. The trireme, or three-banked galley, appears to have been generally open in the middle where the rowers sat, with decks or platforms at both ends for the soldiers; but this was not always the case, as in the representation of a trireme found at Pompeii, it is decked over for its whole length, and with a house or inclosed space at the stern. The galleys of greater size than the triremes appear to have been always decked-vessels, and the upper or fourth and fifth oars of each bank were probably pulled from the deck, in the same manner as the long oars of the present day, called sweeps, while the three lower oars were pulled through port-holes by men seated below the deck.

The chief information on the vessels of this period is gathered from the accounts of naval expeditions and engagements as recorded in the histories of the Peloponnesian war by Thucydides; the wars of Alexander the Great, especially the siege of Tyre, by Curtius and Arrian; the battle between Demetrius and Ptolemy, by Diodorus Siculus; the first Punic war, by Polybius, in which a very minute account is given of the engagement between the Romans and the Carthaginians; and of the battle of Actium, by Dionysius Cassius. Cæsar, in his *Commentaries*, also gives an account of the vessels used in the invasion of Britain, which seem to have been of greater draught of water than common at that period, as he considers it worthy of recording, that the men on disembarking were breast-high in the water, and that at last the galleys were ordered in between these larger vessels and the shore, to protect the disembarkation.

Classes of Roman shipping.

The Roman ships were divided into three classes: the *naves longæ*, or ships of war; the *naves onerariæ*, or ships of burthen; and the *naves liburnæ*, which were ships built expressly for great velocity, and may be supposed to have been used as despatch-boats, and for making passages with important personages. There is repeated evidence to prove that these vessels were invariably built of pine, cedar, or other light woods, excepting that the bows of those for war were of oak, strongly clamped and strengthened with iron or brass, in order to withstand the shock of opposing vessels; the tactics comprising the attempt to sink or damage the enemy's vessel, by violently propelling this armed bow against the weaker broadside of the enemy, or else endeavouring to break and cripple the oars. Oak was first applied to ship-building by the Veneti, on the testimony of Cæsar in his treatise *De Bello Gallico*, lib. iii. cap. 13. Copper or brass was introduced for fastenings, in consequence of the quick corrosion of the iron, about the time of Nero. This is stated on the authority of Vegetius, and also of Athenæus; and Pliny mentions that flax was used for the purpose of caulking the seams of the plank.

Oak first used in ship-building.

Copper.

Caulking.

Exhumation of a Roman vessel.

The following quotation is from Locke's History of Navigation:—"Sheathing of ships is a thing in appearance so absolutely new, that scarce any will doubt to assert it altogether a modern invention; yet how vain this notion is, will soon appear. Leo Baptisti Alberti, in his book of *Architecture* (lib. v. cap. 12), has these words: But Trajan's ship weighed out of the lake of Riccia at this time, while I was compiling this work, where it had lain, sunk and neglected, for above 1300 years; I observed that the pine and cypress of it had lasted most remarkably. On the outside it was built with double planks, daubed over with Greek pitch, caulked with linen rags; and over all a sheet of lead fastened on with little copper nails. Raphael Volaterranus, in his *Geography*, says this ship was weighed by the order of Cardinal Prospero Colonna. Here we have caulking and sheathing together above 1600 years ago; for I suppose no man can doubt that the sheet of lead nailed over the outside with copper nails was sheathing, and that in great perfection, the copper nails being used rather than iron, which, when once rusted in the water, with the working of the ship, soon lose their hold and drop out."

During the dark ages which followed the downfall of Rome, little progress was made in navigation, and but little is known of the vessels in which the northern hordes made their predatory and conquering excursions.

Royal Society of Northern Antiquarians.

The investigations of the Royal Society of Northern Antiquarians at Copenhagen have thrown considerable light on the subject of this early navigation, and of the discoveries of the Scandinavians in the west; and it cannot be supposed that it was in coracles that frequent voyages were made to Newfoundland, and colonies established there, which, it appears proved, were in existence as early as the tenth century. But to recur to the description given by Cæsar of the ships of the Gaulish Veneti. "Their bottoms were somewhat flatter than ours, their prows were very high and erect, as likewise their sterns, to bear the hugeness of the billows and the violence of the tempests. The body of the vessel was entirely of oak. The benches of the rowers were made of strong beams about a foot in breadth, and fastened with iron nails an inch thick. Instead of cables, they secured their anchors with chains of iron; and made use of skins and a sort of thin pliant leather, by way of sails, probably because they imagined that canvas sails were not so proper to bear the violence of tempests, the rage and fury of the winds, and to govern ships of that bulk and burthen. . . . . . Neither could our ships injure them with their beaks, so great was their strength and firmness, nor could we easily throw our darts, because of their height above us, which also was the reason that we found it extremely difficult to grapple the enemy and bring him to close fight." And again, speaking of the manner in which these ships were eventually taken possession of: "They," the Romans, "had provided themselves with long poles, armed with long scythes; with these they laid hold of the enemies' tackle, and drawing off the galley by the extreme force of oars, cut asunder the ropes that fastened the sailyards to the masts; these giving way, the sailyards came down, insomuch that, as all the hopes and expectations of the Gauls depended entirely on their sails and rigging, by depriving them of this resource, we at the same time rendered their vessels wholly unserviceable."

Gaulish Veneti. B.C. 65.

The account proceeds to state, that many attempted to escape from this unforeseen means of aggression; but that the wind falling, and a perfect calm coming on, they were obliged to remain inactive on the water, and were taken possession of, one after the other, by the simultaneous attack of several Roman galleys. It would appear from this that they were vessels only intended for sailing, and that, since oars were used, from the mention made of seats for the rowers, they could have been as very partial accessories to the sails, or probably even only for steering. Another fact is mentioned by Cæsar, that the Veneti sailed from their port to meet the Roman fleet, and several of the vessels escaped to their port from the fleet. This, though not conclusive of the fact of sailing on a wind, is worthy of notice.

Hengist and Horsa. A.D. 450

It is probable that it was ships such as these which brought Hengist and Horsa to England about the middle of the fifth century, since it is recorded that their force, which consisted of 1500 men, found accommodation in only three vessels. It is hardly to be imagined that the coracles, or skin-boats of the northern nations, were ever of sufficient dimensions to accommodate a force of 500 men, with arms and means of active aggression.

Rise of Venice.

The earlier irruptions of the northern barbarians into Italy had desolated the Roman province of Venetia, and driven a remnant of its inhabitants to the refuge afforded by the small marshy islands at the extremity of the Adriatic. There they are described by Cassiodorus, who assimilates them to water-fowl, as subsisting on fish, and steeped in poverty, their only manufacture and their only commerce being salt. From such humble beginnings arose the state destined to connect the old world with the new, and to lead the van of modern commercial and maritime enterprise. The mercantile prosperity of Venice diffused its influence throughout the shores of the Mediterranean, which thus became once again the nursery of civilization For many centuries Venice was the great school of the arts connected with navigation, and her shipwrights and seamen were long the most instructed in Europe. While the northern seas were navigated by the Scandinavian sea-kings, in their rude and frail boats, in quest of plunder or of a home, ships floated on the waters of the Mediterranean bearing the banner of St Mark, which, it is said, were, even as early as the tenth century, of the burthen of 1200 up to 2000 tons. The vessels, however, generally adopted by the Mediterranean states were either copies or modifications of the ancient galley.

Mediterranean galley.

It is a fact worth notice, that while the continuation of the use of this species of vessel in the comparatively tranquil waters of the Mediterranean fostered the arts of commerce and navigation, its introduction into the northern seas, to which it was ill adapted, appears to have checked, in a most remarkable degree, the maritime enterprise which had hitherto so characterized the population of their coasts. It is even probable that the barrier thus opposed to commerce entailed on the states of Northern and Western Europe centuries of comparative barbarism.

Alfred. A.D. 871.

Alfred was the first ruler of England who clearly understood that the policy of Britain was rather to prevent than to resist invasion; and the bygone history of his country told him plainly that its military strength was not only insufficient to awe invaders from its shores, but that all the military resources at his command were inadequate to preserve the liberties of his people. He therefore turned the energies of his mighty mind to the task of creating a naval force, which should be more powerful than that of his untiring persecutors the Danes. In this he succeeded; and at length, under the protection of the fleets which his genius had created, he was enabled to establish that framework of internal policy and government, from the wisdom of which England has even to this day benefited. It is historically certain that Alfred himself superintended the formation of his fleet, and that he gave the design of vessels to be superior to those of the Danes.

His ships.

These vessels were galleys, generally rowed with forty oars, some even with sixty, on each side; and they were twice as long, deeper, nimbler, and less "wavy" or rolling, than the ships of the Danes. The information on this subject is obtained by Selden from a Saxon chronicle of the time of Alfred, which is in the Cottonian Library.

Reasons for their introduction.

It should be remembered, that when Alfred thus introduced the Mediterranean galley into these northern seas, his object was not so much to form a vessel adapted for the purpose of navigating those seas, as to obtain one which would afford space for a large force of fighting men. For this the galley was admirably qualified; and indeed it maintained its place as the appropriate ship for the purposes of war until the invention of cannon rendered other arrangements necessary.

Their success.

The immunity which it insured from the attacks of the Danish marauders caused its general adoption along the coasts hitherto open to their incursions, on all of which it thus superseded the sailing vessels that have been already described; and voyages which, until its introduction, were boldly and successfully achieved, became of rare occurrence and of hazardous issue during the subsequent ages, until the galleys once again gave place to sailing vessels. It also gradually checked the enterprise of the Northmen, by the curb which it placed upon their successes.

Saxon rule.

It is not proposed to give more than a slight sketch of the naval history of Britain through the line of her Saxon princes; for little data can be found on which to base any speculation even, as to the progress of naval architecture during these ages. The galley of the Mediterranean continued to be used for the defence of the coasts; and the policy of Alfred appears to have been well understood by many of his successors—that England only enjoyed peace from invasion when her fleets were powerful enough to repel it from her shores. It is also to be inferred that the use of sailing vessels was not wholly abandoned; for in the reign of Athelstan, the third in descent from Alfred, as recorded by Hackluyt, it was decreed, that "if a marchant so thrived, that he passed thrise over the wide seas of his owne crafte, he was thenceforth a Thein's right worthie."

Mercantile shipping.

Decline of naval enterprise.

This establishes two rather interesting facts: one is, that at so early a period there were merchants of importance enough to engage in such a traffic; and the other is, that from the richness of the reward held out to successful enterprise, the difficulty of the task assigned must have been estimated as great. It may be assumed that these long voyages were made in ships more adapted for the purpose than galleys; in fact, in the vessels which the galleys had been intended to supersede. But the spirit of maritime enterprise had, as before observed, evidently received a check, since one of the highest rewards in the power of the monarch to bestow was held out to the merchant as an incitement to an adventure, which the vague hope of plunder would alone have been sufficient to induce that merchant's progenitors to attempt and successfully perform. However, it is probable that at no time was the art of navigating vessels, which depended principally, although perhaps not wholly, upon their sails, lost in the northern seas. Gibbon says, that at the early crusades the vessels of the "Northmanni et Gothi" (the Norwegians and Danes) differed from those of the other powers, among all of whom the ships partook of the character of the Mediterranean galley. These northern crusaders are described by him as navigating "*navibus rotundis*—that is to say, ships infinitely shorter in proportion to their length than galleys." This was not later than the beginning of the twelfth century, and therefore not so far removed from the periods in question as to render the inference proposed to be deduced from it erroneous, particularly when referring to times of such slow improvement as the middle ages.

Edgar.

Ethelred.

Canute. A.D. 1016.

The "mighty" fleets maintained by Edgar afford no information on the subject of this article, excepting that the facts connected with that monarch's annual circumnavigation of his territories prove them to have consisted of row-galleys. They must, however, have formed comparatively a "mighty" fleet; for, from a grant of land made by Edgar to Worcester cathedral, it is found that he assumed to himself the title of "Supreme Lord and Governor of the Ocean lying round about Britain." That they were but of slight construction may be inferred from the low state of the navy so shortly after the death of Edgar as the reign of Ethelred, who, in order to re-establish it, instituted a regular tax for providing and maintaining a navy. It was enacted, according to Selden, that whoever possessed "310 hides of land was charged with the building of one ship or galley; and owners of more or less hides, or part of one hide, were rated proportionally"—the hide being, according to the best authorities, as much ground as a man could turn up with one plough in a year. But this tax appears to have been inadequate to the purpose of providing a sufficient fleet, for all the exertions of Ethelred could not preserve Britain from again being ravaged by the Danes, and, after the short reign of his son Edmund Ironsides, England was ruled by Danish monarchs. From the known talent of Canute, the first of these princes, and from the crowns of Denmark, Norway, and Britain being united in his person, it may be presumed that the naval affairs of England were not suffered to retrograde. There is, indeed, a record of their advance during this second Danish rule. It may also be inferred from the present which was made by Earl Godwin to Hardicanute, the third Danish sovereign, of a galley, sumptuously gilt, and rowed by fourscore men, each of whom wore on his arm a bracelet of gold weighing sixteen ounces; not that the mere gorgeousness of the gift would prove any advance in the art of ship-building, but it may be supposed, from its nature, that naval affairs found favour in the sight of this monarch. Of this there is also other historical evidence, as Hardicanute raised L.11,048,

History.

in the first two years of his reign, for the purpose of building thirty-two ships; and the taxes he levied for the support of his navy were so grievous that, Florentius says, scarcely any man was able to pay them.

Norman conquest. A.D. 1066.

The marine of England seems to have been maintained on a comparatively powerful footing up to the period of the Norman conquest; and from the naval resources at the command of Harold the Saxon, in comparison with the insignificance of the shipping which brought William and his Normans across the channel, there can be no doubt that had Harold relied upon his naval strength, the conquest of England would never have been achieved; but, by some fatality, his fleet, which had been long stationed off the Isle of Wight, was dispersed, in consequence of a report that William had abandoned his enterprise.

Fleet of William.

The flotilla of William the Conqueror is variously stated; by some at 900, by others at 3000 vessels. Either number proves their insignificance, as the invading force consisted of about 60,000 troops, which would give in the one case about 66 men to each vessel, in the other 20 men only (figs. 1 and 2).

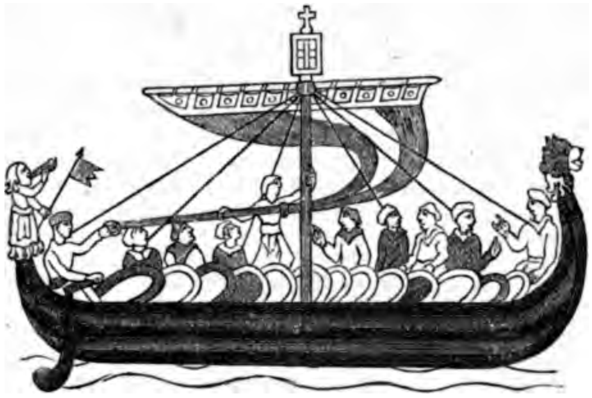

Fig. 1.

The conquest of England being completed, the shores on either side of the narrow seas between England and Normandy were under the same rule. William, therefore, claimed sovereignty over them, which right was maintained by his successors. There can be no doubt that the constant intercourse between the two portions of the empire, which continued throughout the Norman sway, and indeed for a period of upwards of three centuries, must have done much towards fostering a maritime spirit among the population of England, and accustoming it to consider that fame and fortune were the rewards of nautical adventure.

Fig. 2.

Probable size of ships.

History. A.D. 1100.

There is but slight evidence as to the state of naval architecture during the early period subsequent to the Conquest. There are a few facts scattered among the records of these times, from which some vague conclusions as to the probable size and nature of the vessels used may be drawn. When Prince William, son to Henry I., was drowned, by the loss of the vessel in which he was crossing from France to England, it is recorded that 300 souls perished with him. As of this number a large portion, historians say 140, were men of rank, and as there were many ladies, since the prince was accompanied by his sister, the vessel must have been of considerable burthen. A similar event, namely, a shipwreck, that occurred during the reign of Henry II., by which nearly the same number of persons perished, tends to prove that such was about the extent of the accommodation afforded by the shipping of this period.

State of trade.

Galleys still continued to be used for the purposes of war; but as commerce began to be extended, it became necessary to recur to the use of sails, and they were therefore gradually recovering their importance, and superseding oars. Indeed, it is difficult to conceive commerce to be profitably engaged in when attended with the immense expense of the crews necessary to propel the larger galleys. This must have had an important influence in the improvement of navigation and of naval architecture, for the commercial intercourse between the portions of the empire on either side of the channel must have been considerable. There is constant reference in the early chronicles to the great extent of the wine trade, and of the commerce in wool and woollen cloths.

The introduction of vessels propelled by sails for the purposes of commerce would necessarily cause a change in the constitution of the fleets assembled for the services of war; and this will be found to have been the case.

Richard Cœur de Lion. A.D. 1190.

The expedition of Richard Cœur de Lion, in 1190, to join the crusade to the Holy Land, consisted of nine ships, which are described as being of extraordinary size, 150 others of inferior dimensions, and only 38 galleys. After the reduction of Cyprus, and the addition of the vessels captured there, with others which he had hired at Marseilles and in Sicily, his armament consisted of 254 "tall shippes, and about three score galliots." The increase was, therefore, almost wholly in the ships. This, together with the recorded fact, that he captured a Saracenic vessel of such size as to be capable of containing 1500 Saracens, and a large quantity of military stores, destined for the relief of Achon, tends to prove that the progress of naval architecture, under the influence of the commercial powers of the Mediterranean, had been more rapid than in these northern seas, where the commerce was much more confined in its nature, and the nations bordering on which were in constant warfare with each other.

Sovereignty of the seas.

The Norman monarchs appear to have been very tenacious of their claim to the sovereignty of the narrow seas; and not only their claim, but their power to maintain their right, is admitted by the French historians. The Père Daniel sanctions the claim of Henry II. to this sovereignty.

John. A.D. 1199.

Early origin of Portsmouth dockyard.

In the reign of John the fleets of England were of such importance that the claim was extended; for it was then enacted, that if the masters of foreign ships should refuse to strike their colours, and thus pay homage to the English flag, such ships should be considered as lawful prizes. This monarch most carefully fostered the naval power of England; and it is in the records of the thirteenth year of this reign that mention is first made of any public naval establishment. There is in the close rolls, published by the Record Commission, an order, which is dated the 29th of May 1212, from the king to the sheriff of the county of Southampton, in which he is directed without delay to cause the king's docks at Portsmouth to be enclosed by a good and strong wall, in order to protect the king's galleys and ship's; and also to build storehouses against this wall, for the preservation of the fittings and equipment of the said vessels; all of which works are to be performed under the direction of William, archdeacon of Taunton, and the greatest diligence is to be used, in order that the whole may be completed during the summer.

Edward I. A.D. 1272.

Sovereignty of the sea held by England, and spontaneously abandoned.

The naval power of England appears to have continued sufficient to maintain the sovereignty assumed by John. For the occurrence of predatory excursions by some Genoese, during the reign of Edward I., caused all the nations of Europe, bordering on the sea, to appeal to the kings of England, whom they acknowledged to be in peaceable possession of the "Sovereign Lordship and Dominion of the Seas of England, and Islands of the same;" which proves that their claim was generally acknowledged. This document, Evelyn says, was still extant in his time, in the archives of the Tower. The right to the absolute sovereignty of the seas was maintained up to the reign of James I. Queen Elizabeth insisted on and maintained her power to refuse or grant passage through the narrow seas, according to her pleasure. In 1634 Charles I. asserted his right to their sovereignty; and in 1654 the Dutch were compelled, after a severe struggle, to submit to it, and consent to "strike their flags and lower their top-sails on meeting any ship of the English navy on the British seas;" which homage the commanders of English men-of-war were instructed to exact from all foreign vessels until so lately as the close of the last war, when it was judiciously abandoned, for the following reasons, as given by Sir John Barrow. In his *Life of Howe*, with reference to Trafalgar, he says, "That battle, moreover, having so completely humbled the naval powers of France and Spain, suggested to the consideration of the Board of Admiralty, with the approbation of the government, the omission of that arbitrary and offensive article which required naval officers to demand the striking of the flag and lowering of the top-sail from every foreign ship they might fall in with. That invidious assumption of a right, though submitted to generally by foreigners for some centuries, could not probably have been maintained much longer, except at the cannon's mouth; and it was considered, therefore, that the proper time had come when it might, both morally and politically, be spontaneously abandoned."

Error respecting the use of sailing vessels.

It is generally supposed that ships intended only for sailing were first built by the Genoese, and that not until the beginning of the fourteenth century. It is perhaps more probable, that in the Mediterranean they date from an earlier period than this; and that although the general adoption of the galley in Western Europe had much checked the art of navigation by means of sails, it had never been wholly lost, but that sailing vessels, though probably very few in number, and imperfect in rig, had been constantly in use. To judge from the few hints handed down to us by history, they were probably luggers, and were adopted for mercantile purposes along the coast of the Channel and the Bay of Biscay. In the north of Europe sails had never been discontinued, but the more warlike galleys of England and France prevented the incursions of the northern nations with such vessels into these more southern seas.

The beginning of the fourteenth century is decidedly an epoch in the histories both of navigation and of naval architecture, and from it may be dated the general introduction of sails and many other appliances. It is generally supposed that the "large ships" mentioned in the enumeration of the fleets of this period, were ships built only for sailing, and intended for those long voyages which the invention of the compass by Flavio Gioio, a Neapolitan, about the year 1300, had rendered of comparatively easy performance.

Mariner's compass.

It has been surmised that the compass was brought to Europe from the East about forty years previous to this date, by Paulus Venetus. It is certain that the Portuguese found the knowledge of the magnetic needle generally and long diffused among the eastern navies. Evelyn says, that "it was, near eighty years after its discovery, unknown in Britain." This is not improbable, for there does not remain much record of maritime affairs in the interval between the reigns of John and Edward III.

Edward III. A.D. 1327.

The reign of this latter monarch, however, was, after a most severe struggle with France for supremacy on the seas, the era of a series of naval triumphs, and both navigation and naval architecture made most decided advances.

Naval battle.

In an engagement which took place in 1340, the French force amounted to 400 vessels, of which 120 were "large ships," these being principally Genoese mercenaries. Edward III. commanded the English fleet in person, which consisted of but 260 sail. The French are variously reported to have lost 20,000 and 30,000 men, and 200 vessels are said to have been captured. The loss to the English was only 4000 men. Two facts are elicited by the accounts of this engagement; one is, that there is no mention of galleys as forming any part of the fleets; the other is, that in the James of Dieppe, which was captured by the Earl of Huntingdon, 400 persons were found slain; consequently the size of the vessel must have been very considerable.

Royal fleet.

Use of cannon.

In 1344 Edward summoned commissioners from all the ports, to meet in the metropolis, provided with the state of their "navies." The roll of this fleet is inserted in the first volume of Hackluyt, from a copy in the Cottonian Library. The total numbers were 710 ships, and 14,151 mariners; and there were 38 foreign ships, with 815 mariners. From this roll it will be seen that it was about this time that galleys ceased to be used by England for war or commerce, as neither among the king's ships nor among those furnished by merchants is there any mention of them. This fleet was that engaged in the celebrated siege of Calais, and it was probably at this time that cannon were first employed by the English. Camden, in his *Remains*, says, "Certain it is, that King Edward III. used them at the siege of Calais in 1347."

Sizes of Edward's ships.

Although from the fact of there being a royal dock-yard at Portsmouth so early as the reign of John, it is probable that the kings of England were possessed of a navy almost from the conquest; yet this roll of Edward's fleet contains the first enumeration of ships belonging to the sovereign, and employed in the service of the state, which occurs in English history; and consequently it is from the reign of Edward III. that the formation of a royal navy must be dated. The king's ships were 25 in number, and were manned by 419 mariners. It appears that the vessels belonging to the sovereign were inferior in force to many of those which were supplied by subjects; for the average number of the crews of the king's ships were 17 men to each vessel, while the average of the fleet was rather above 20. Of course these numbers only include the mariners employed in navigating the vessels, and not the soldiers to be afterwards embarked on board them. Considering the simplicity of the rig of these ships, in comparison to the wilderness of canvas and cordage covering the tall masts of a modern merchantman, there is more reason to be astonished at the large number of hands employed, than at the smallness of the averages, 17 and 20. There is good reason to suppose that the addition of the bowsprit to the rig of ships dates no farther back than late in the reign of Edward III., which is alone quite sufficient to prove the very imperfect state of the navigation at that period, and also to excite astonishment that, with such apparently inadequate means, so much was effected; for history would almost lead us to suppose that, for all the purposes of war and commerce, fleets as proudly or as industriously ploughed the main then as now, "with all appliances and means to boot."

Richard II.

First navigation act.

In the year 1381, the fourth of the reign of Richard II., the first navigation act was passed in England, for the encouragement of the naval interest and the augmentation of our maritime power, by discountenancing the employment of foreign shipping. It enacted, "That for increasing the

A.D. 1381.

shipping of England, of late much diminished, none of the king's subjects shall hereafter ship any kind of merchandize, either outward or homeward, but only in ships of the king's subjects, on forfeiture of ships and merchandize, in which ships also the greater part of the crews shall be of the king's subjects." This act was not, however, enforced, permission being given to hire foreign shipping when there were no English ships in readiness.

Royal ships hired by merchants.

Henry IV.

Letter to Henry V.

It has been remarked above, that the royal navy of England must date from the reign of Edward III. There is proof that it continued to be customary for the sovereign to possess ships; they were, however, used both for war and commerce. This practice, which does not at all militate against the existence of a royal navy, appears to have commenced when "large ships" were substituted for the galleys as vessels for war; and it long continued to be usual for merchants to hire shipping from the sovereign for commercial voyages. The proceedings of the privy council, which have been printed by the Record Commission, show that in June of the year 1400, Henry IV. ordered his "new ship," together with such others as were in the port of London, to proceed against the enemy. There is also a letter in the Cottonian Library, which has been printed in Ellis's *Collection of Letters*, from John Alcetre to King Henry V., concerning a ship building for that monarch at Bayonne. The letter is of the date of 1419; and as it contains more minute details than might be expected to have descended to us from such an early period, we give the following extract:—"At the makyng of this letter yt was in this estate, that ys, to wetyng xxxvj. strakys in hyth y bordyd, on the weche strakys hyth y layde xj. bemys; the mast beme ys yn leynthe xlvj. comyn fete, and the beme of the hameron afore ys in leynthe xxxix. fete, and the beme of the hameron by hynde is in leynthe xxxiij. fete; fro the onemost ende of the stemme in to the post by hynde ys in leynthe a hondryd iij$^{xx.}$ and vj. fete; and the stemme ys in hithe iiij$^{xx.}$ and xvj. fete; and the post xlviij. fete; and the kele y in leynthe a hondryd and xij. fete; but he is y rotyt, and must be chaungyd."

Libel of English Policie.

We have also evidence of the existence of ships which belonged to the monarch, in contradistinction to ships which belonged to the "commons," in the quaint rhymes of an anonymous author of the year 1433, which have been preserved by Hackluyt, termed *The Prologue of the processe of the Libel of English policie, exhorting all England to keepe the sea, and namely, the narrowe sea, showing what profite commeth thereof, and also what worship and saluation to England, and to all Englishmen.*

> "And if I should conclude all by the king
> Henrie the Fift, what was his purposing,
> Whan at Hampton he made the great dromons,
> Which passed other great ships of all the commons;
> The Trinitie, the Grace de Dieu, Holy Ghost,
> And other moe, which as nowe bee lost.
> What hope ye was the king's great intent
> Of thoo shippes, and what in minde hee meant:
> It was not ellis; but that hee cast to be
> Lorde round about environ of the sea."

The term dromond is the corruption of a Levantine term, dromones, imported probably by the crusaders. The dromonds were long row-galleys, but the adopted term dromond was applied generally to all large ships.

Henry's fleet.

There is a list of Henry's vessels in the fourth year of his reign preserved in the proceedings of the privy council. His navy then consisted of three "large ships," or "grands niefs," three "carracks," eight barges, and ten balingers. In 1417 it was augmented to three "large ships," eight "carracks," six other ships, one barge, and nine balingers.

Early tonnage.

Again, in a letter preserved among the Cottonian manuscripts, and printed in Ellis's collection, it is stated that the Spaniards offered Henry V. two carracks for sale, one of which is described as of a tonnage equal to 1400, and the other to 1000 butts. So energetical was Henry V. in all things relating to his navy, and the consequent increase in the number of the royal ships during his reign was so great, as to have led to the error that before his time the sovereigns of England were not possessed of vessels, but relied wholly upon the aid to be gathered from the different ports of England, or to be hired from foreigners. This is evidently incorrect.

Neglect of the navy.

On the death of Henry V. a different line of policy appears to have been adopted; for in May 1423 the king's ships were all sold at Southampton, under a restriction that no foreigner could be a purchaser of them. But it appears that a long period did not elapse before the depressed state of the naval resources of the kingdom, consequent on this injudicious measure, attracted the attention of parliament. The following interesting quotation from the preface of the fifth volume of the *Proceedings of the Privy Council*, printed by the Record Commission, refers to this event:—"In 1443 the attention of parliament was directed to this important part of the national defence (the naval force), and a highly curious ordinance was made for the safeguard of the sea. From February to November eight ships with forestages, or, as they were sometimes called then, as now, forecastles, armed with 150 men each, were to be constantly at sea. Every large ship was to be attended by a barge of 80 men, and a balinger of 40 men. There were also to be 'awaiting and attendant upon them' four 'spynes' or 'spinaces,' with 25 men each. The whole number of men in these 24 ships was 2240."

There is also in the same preface an account of the various kinds of ships which formed the navies of this period, a part of which we shall quote, and by the addition of some further information of the same nature, derived from Froissart, Monstrelet, and other sources, the reader will be enabled to form a tolerably correct opinion as to the state of naval architecture in England previous to and during the fifteenth century.

Ships.

Ships. "The burthen of the largest ships at that period probably did not exceed 600 tons, though some of them were certainly very large," as, for instance, the vessel built at Bayonne for Henry V., already mentioned. "One which belonged to Hull was released from arrest" (she having been pressed into the king's service), "because she drew so much water that she could not approach within two miles of the coast of Guienne, where the Duke of Somerset's army intended to disembark;" and several notices occur of ships of 300 and 400 tons and upwards. Some had three and others only two masts, with short topmasts, and a "forestage" or "forecastle," consisting of a raised platform or stage, which obtained the name of castle from its containing soldiers, and probably from its having bulwarks. In this part of the ship it appears business was transacted; and in the reign of Edward III., if not afterwards, ships had sometimes one of these stages at each end, as ships "*ove chastiel devant et derere*" are then spoken of. Lydgate, describing the fleet with which King Henry V. went to France after the battle of Agincourt, says,

> "Fifteen hundred ships ready there be found,
> With rich sails and high topcastle."

This is a confusion of terms. The "topcastles" were not the forecastles, but were castellated enclosures at the mastheads, in which the pages to the officers were stationed during an engagement, in order to annoy the enemy with darts and other missiles; as is frequently mentioned in Froissart, and is represented in the illuminations to his work.

Carracks.

Carracks "were vessels of considerable burthen, and were next in size to great ships, in which class they indeed were sometimes included. Their tonnage may be estimated by their being in some instances capable of carrying 1400 butts; and the sail of one afforded Chaucer a strange simile expressive of magnitude,

> 'And now hath Sathanas, saith he, a tayl
> Broder than of a carrike is the sayl.'

Though occasionally armed and employed against the enemy, they were more generally used in foreign trade."

Charnock says that the first carrack which was built in England was built for a merchant, John Tavenier of Hull, who was consequently honoured by Henry VI. with distinguished favour; and she was licensed in 1449 with particular privileges to trade through the Straits of Morocco. The king also ordered her to be called the "Grace Dieu Carrack." The license states her to have been built "by the help of God and some of the king's subjects."

Barges.

Barges "were a smaller kind of vessel and of different construction from ships, though, like them, they sometimes had forecastles. Those appointed to protect the seas in 1415 were of 100 tons burthen, and contained forty mariners, ten men-at-arms, and ten archers; whilst the ships employed on the same occasion were of 120 tons, and had forty-eight mariners, twenty-six men at arms, and twenty-six archers each. Four large barges and two balingers were capable of holding 120 men-at-arms and 480 archers and sailors.".

Balingers.

Balingers "were still smaller than barges, had no forecastle, and sometimes contained about forty sailors, ten men-at-arms, and ten archers." Froissart makes frequent mention of "balniers," "balleniers," which he describes "as drawing little water, and being sent in advance to seek adventures, in the same manner as knights and squires, mounted on the fleetest horses, are ordered to scour in front of an enemy, to see if there be any ambuscades." Monstrelet speaks of one vessel that was employed by Louis XI. to abduct the Count de Charolais, by the two names ballenier and balayer. It is not improbable that the name is derived from the French word *baleine*, and that its origin was similar to that of our English name whaler. The whale-fishery in Biscay was of a very early date.

Galleys.

Galleys "are frequently mentioned at a very early period; and in the 5th Rich. II., 1381, the Commons complained that no measures had been taken to resist the enemy, who had attacked the English at sea with their barges, galleys, and other vessels. In 1405 Henry IV. directed his council to apply to the King of Portugal to lend him his galleys to assist the English navy against the French."

In Sir Grenville Temple's Travels in Greece and Turkey the following description of a Maltese galley, or, more correctly, galleas, made from an old model preserved there, will be found:—"These galleys measured 169 feet 1 inch in length, and 39 feet 6 inches in breadth. They had three masts with latine sails, and were propelled by forty-nine oars, each 44 feet 5 inches long. Their armament consisted of 1 thirty-six pounder, 2 of twenty-four, and 4 of six, all on the forecastle, which in those days had in reality some appearance of a castle. On each side of the vessel, aft of the forecastle, were 4 six-pounders." The total crew, including galley-slaves, consisted of 549 persons.

Galleas.

The *Galleas* and the *Galleon* appear to have been successive improvements on the original galley, rendered necessary by the introduction of cannon into naval warfare. The artillery introduced on board the early galleys was placed either before or abaft the rowers, and to fire in the direction of the length. In the galleas, a description of vessel first used at the battle of Lepanto, guns were also placed between the rowers, to fire from the broadside. Evelyn describes the galleases he saw at Venice (1645) as being "vessels to rowe of almost 150 foote long and 30 wide, not counting prow or poop, and contain twenty-eight banks of oares, each seven men, and to carry 1300 men, with three masts." In the galleon the oars ceased to be the principal means of propulsion, and if used at all, were only so as occasional aids. The galley and galleas had overhanging topsides for the accommodation of the oars. In the galleon, on the contrary, the topsides "tumbled home" to so extraordinary an extent, that the breadth at the water was twice that at the topside, a fashion which has continued, but in a much less degree, to the present time.

Spynes or spynaces.

Spynes or *spynaces*, "now called pinnaces, seem to have been large boats, capable of holding twenty-five men, and were probably used for swiftness. To these must be added crayers, hulks, gabarres or gabbars, a kind of flat-bottomed boat, used in shallow rivers." The French still continue to apply the term "gabarre" to store-ships.

Playtes and smalle vessels.

"Playtes, cogships, whence perhaps cogs and coggles are derived; farecrofts, passagers, which were perhaps boats used between England and France; and cock-boats, a small boat which attended upon all kinds of ships. The whole of these vessels were employed in conveying goods or passengers, and most of them on rivers or in the coasting trade. The ships, carracks, barges, balingers, and galleys, were employed equally for commerce or for war. When sent against the enemy, soldiers were put on board of them; and it is most likely they were at all times partly manned by soldiers. In foreign voyages they usually sailed in convoys; and it was a very ancient custom for the masters and sailors to elect their own admiral."

Foists or foysts.

In Burchett's account of the unfortunate action in the Bay of Conquet, in 1513, in which the Lord High Admiral, Sir Edward Howard, lost his life, four *foists* are mentioned as forming a part of the French force. They were probably vessels of a similar character with the galley, but smaller in size. About the beginning of the seventeenth century, "carracks," "galleons," and "tall shippes," appear to have become synonymous terms.

Hulks.

The term hulk originally was applied in a different sense from that which is stated in the part of the foregoing remarks which we have quoted from the preface to the proceedings of the privy council. Frequent allusion is made to hulks in documents of the fifteenth and sixteenth centuries. In a letter from Sir Thomas Seymour to the privy council, dated the 13th of November 1544, when in command of the "shipes whyche was a poyntede to kepe the Narrow Sees," vindicating himself for putting back on account of a storm, there is the following passage, from which it might almost be inferred that hulk was a general name synonymous with ships:—"Thre holkes that come after me colde nott gett syght thereof (the 'Eylle of Wyght') tyll they warre in a bay on the est syde of the Eylle, of the whyche Mr Strowd, Bramston, and Battersebe of the garde, God rest their sowles, was in on of them, whyche holke brake all her ankeres and cabelles, and she brake all to peses on the shorr, and but 41 of 300 saved a lyve. The other two rode out the storme, whyche lasted all that nyght and the next day. My brother (Sir Hy Seymour) and John Roberds of the garde, tryde the sees all the first nyght, and the next day cam into Dartemouth haven, wharre my brothers holke strake on a roke and brest all to peses; but God be praysede, all the men warre savede, savying thre; and a nother new holke that tryde the sees that nyght brake thre of her bemes, and with moche ado came into the Wyght."

Again, in a letter from Lord Viscount Lisle, Baron Malpas, the Lord High Admiral of England, to Henry VIII., there is an announcement, that "their is cum into the Downes 30 sayle of hulkses, whereof sum be tall shipes." And again, in a letter from the same to the Lord Chamberlain, Lord St John, he speaks of having detained "3 grate hulkes bound, as they say, for Lusshborne, the leste of y^{m} 500 tunnes." And again, from the same to the same, he speaks of his former letter and the "goodly hulkes," and says, "sithens that tyme I have stayed other too, which in beautye and well appoynting are beyond the others. That I have last stayed ys a shipe of 600 at the least, and hath

5 toppes, and she ys of the town of Dansick, and ladon in Flanders for Lusshbourne."

A.D. 1450. State of mercantile shipping. William Canyne.

The importance of the mercantile shipping of England during the fifteenth century must have been considerable. About the middle of it flourished the celebrated William Canynge, a merchant of Bristol, who built the church of St Mary's, Redcliff, in that city, in which church he was buried in 1474. This man appears to have been much in advance of the rude times in which he lived. His mercantile transactions were on so extensive a scale, and carried on in vessels of such large size, that they must have had an important influence in improving the navies of the period. The information which has descended to us respecting him is therefore not only a fact of much historical interest, but is one which is intimately connected with, and most materially affects, our subject. He was a great patron of the arts, a friend and protector of genius, and eminent for his virtue and piety. From an inscription upon his tomb, a tradition has become current, that Edward IV. took 2470 tons of shipping from him, he having "forfeited the king's peace;" and for the obtaining of which again, it is stated that Edward accepted these ships instead of a fine of 3000 marks. The *Itinerary* of William of Worcester, preserved in the library of Bennett College, Cambridge, gives the names of Canynge's vessels, among which are the Mary and John of 900 tons, Mary Redcliff of 500 tons, and Mary Canynge of 400 tons. The same authority gives the names and tonnage of other large ships belonging to Bristol merchants, among which are the John of 511 tons, and the Mary Grace of 300 tons. If there be any truth in the tradition of the confiscation of the shipping, it is probable that the inscription on the tomb may refer to some act of Canynge's in favour of the house of Lancaster, as he appears to have enjoyed the favourable opinion of Henry VI. Another account, which, it is said, is authenticated by the original instrument in the Exchequer, states that this Canynge assisted Edward IV. with a loan, and received in return a license to have 2470 tons of shipping free of imposts. In Corry's *History of Bristol* it is said, "the commerce and manufactures of Bristol appear to have made considerable progress during the fifteenth century, about the middle of which flourished the celebrated Canynge. This extraordinary man employed 2853 tons of shipping, and 800 mariners, during eight years. Two recommendatory letters were written by Henry VI. in 1449, one to the master-general of Prussia, and the other to the magistrates of Dantzic, in which the king styles Canynge his beloved eminent merchant of Bristol."

)oubts as o accuracy n estimat-ng size of hips.

Some doubt must always remain as to the actual size of the shipping of this remote period, as we cannot ascertain the bulk that was then considered as equivalent to a ton. It is probable that the tonnage was estimated according to the number of butts of wine that a vessel could carry. For we find references to ships sometimes by tonnage, and sometimes by the "portage" of so many butts.

This, however, is only a question as to exactness of size. In whatever way measured, Canynge's ships must have been of very considerable dimensions. It is rather extraordinary, that at the unsettled period in question Bristol should have enjoyed such a state of commercial prosperity as the ownership of such shipping as that enumerated by William of Worcester necessarily involves. Bristol, for many centuries, was only second in mercantile importance to London; but the civil wars which distracted the kingdom during a great part of the fifteenth century must have much retarded the increase both of the military and the mercantile navy of England; and only when order was again re-established by the accession of Henry VII. to the throne, in 1485, could men's minds revert from the internal excitement of party strife to external affairs.

Ienry VII.

In this interval, in which England was torn by the wars of the houses of York and Lancaster, naval science had made more rapid strides than in any previous period of similar duration. The compass was not only known but was generally adopted. Navigators could take observations by the use of an instrument called the astrolabe, invented by the Portuguese. The Spaniards and Portuguese were sufficiently advanced in the art of navigation to sail on a wind, and their smaller vessels, at least, were adapted for this manœuvre. New maritime states had started into existence. The Netherlands, until then scarcely known, was, under the Duke of Burgundy, the most formidable naval power in the north of Europe. "His navy," says Philip de Commines, "was so mighty and strong, that no man durst stir in those narrow seas for fear of it, making war upon the king of France's subjects, and threatening them everywhere; his navy being stronger than that of France and the Earl of Warwick joined together." Venice, in 1420, according to Denina, in his *Revolutions of Italy*, supported 3000 merchant-ships, on board of which were 17,000 seamen. They employed 300 sail of superior force, manned by 8000 seamen; had forty-five carracks, with 11,000 men to navigate them; and her arsenals employed 16,000 carpenters. Portugal had pushed her discoveries round the Cape, and Spain had added America to the world.

Progress of naval improvement. Compass. Astrolabe. Netherlands. Venice.

Portugal. Spain.

The progress of discovery by the Portuguese to the south and east, and by the Spaniards to the west, in the voyages of Columbus, with the consequent rapid increase in the importance of these two powers, and the influence of their discoveries on the state of Europe, renders the fifteenth century probably the most important of modern history. In it was given the death-blow to the increase of the Saracenic power, and to that of the Mediterranean states. The Turk, the Venetian, and the Genoese, had hitherto been the monopolizers of the commerce of the east. The discovery of the passage round the Cape of Good Hope opened this trade to all nations. The commercial sceptre, and consequently the military sceptre, hitherto shared by the Turk, passed wholly from the infidel to the believer. The crescent sank before the cross.

Passage round the Cape of Good Hope.

Its influence on naval architecture.

There can be no doubt, also, that the "*tormentas*" of the "*grão Cabo de boa Esperāça*," were a means of great improvement in naval architecture; for, in consequence of the representations of Bartholomew Diaz, John II. of Portugal ordered ships to be constructed for the especial purpose of contending with the stormy seas of the Cape of Good Hope. The ships were built to form the squadron of Vasco de Gama, and were of small tonnage, from the very proper idea that small vessels were more adapted to prosecute researches in unknown seas than those of a large size, and consequent increased draught of water.

Squadron of Vasco de Gama.

The squadron of Vasco de Gama consisted of three ships and a caravella. One of the ships was of the burthen of 200 tons, another 120, and the third 100; the caravella was of 50 tons. The largest of the ships was a victualler; the smallest was intended to prosecute discovery up creeks and shallows; and the other was for a display of force. As it is evident that it was not increase of dimensions which was to be the object in designing new vessels, the direction of improvement must have been towards perfecting their forms, strengthening their frames, and adding to the efficiency of their *materiel*. Portugal by these means became the most advanced state of Europe in knowledge of the art of ship-building; for it was long supposed that the passage to India required ships such as the Portuguese alone could build. Spain, in her career of discovery, conquest, and colonization across the mighty waters of the Atlantic, as if to assimilate the means to the vastness of her achievements, rapidly acquired the art of constructing ships of very large dimensions; and as long as she possessed a marine, her ships maintained this superiority.

A.D. 1500. State of naval affairs in England.

There is a curious instance of the light in which naval enterprises were considered in England at this time, notwithstanding the earnest desire of the monarch to re-establish his navy, which had necessarily suffered from the long civil wars. A letter from Henry VII. to the Pope is preserved in the Cottonian Library, excusing himself from sending succour against the Turk, from which the following is a quotation:—"The Galees commying from Vennest o England be commonly vij. monethes sailying, and sometimes more;" and again, "it should be May or they should be ready to saill, and it shall be the last end of September or the said shippes shuld passe the Streits of Marrok; and grete difficultie to fynde any Maryners hable to take the rule and governance of the said shippes sailying into so jeopardous and ferre parties."

Henri Grace à Dieu.

There is a drawing extant in the Pepysian Library in Magdalen College, Cambridge, of the Henri Grace à Dieu, built by the order of Henry VII., which Charnock has engraved in his *History of Marine Architecture*, and argues as to the general authenticity of the representation. He says, "this vessel may be termed the parent of the British navy. This celebrated structure, the existence of which is recorded in many of the ancient chronicles, cost the king, by report, nearly 14,000 pounds."

Early origin of naval terms.

From this drawing may be traced the derivation of one or two names which have been preserved even to the present hour; as, for instance, the "yard-arm," no doubt from the ends of the yards being armed with an iron hook. The castellated work from which has arisen the term "forecastle" is earlier than this; and the buckler-ports are most probably derived from a yet earlier period, when the bucklers of the knights were ranged along the sides of the ship, as they are represented in the illustrations of Froissart, and of the early chroniclers, and even in the Bayeux Tapestry.

"The masts were five in number, inclusive of the bowsprit, an usage which continued in the first-rates without alteration till nearly the end of the reign of King Charles I.; they were without division, in conformity with those which had been in unimproved use from the earliest ages. This inconvenience it was very soon found indispensably necessary to remedy, by the introduction of separate joints, or top-masts, which could be lowered in case of need."

The drawing shows two tiers of ports. The introduction of port-holes is said to be an improvement due to a French ship-builder of Brest, named Descharges, in the reign of Louis XII., and about the year 1500. If the drawing be authentic, the correctness of this appropriation of the merit of the introduction of port-holes may be questionable.

Again, if the drawing be a correct representation of the vessel, she would have been in danger of upsetting, excepting in calm weather, and when her course was with the wind. In fact, as yet the large ships of war of England were not at all adapted to sail on a wind, and were very ill provided with such sails as would enable them to do so; they had therefore nothing to fear from the result of a measure which could not be put into execution. The fleets of war seldom ventured out of port excepting in the summer months, and then only when the wind was favourable to their intended course. But very shortly after the date of the building of the Henri Grace à Dieu, great improvement took place, and in the reign of Henry VIII. there is evidence to prove that sailing on a wind formed one of the qualities of the vessels composing his fleets. This fact appears to throw some doubt upon the correctness of the drawing, for it must have required ships widely different from any of which that would at all give an idea, to have performed the evolution of tacking or wearing; and as the Henri Grace à Dieu was in all probability the same ship that on the accession of Henry VIII. was called the Regent, she must have formed one in fleets which were capable of performing these manœuvres. It is true that she may have been altered to adapt her to these new requirements of an improved system of seamanship; and it must also be said, that she was burned in an action with the French fleet, which occurred as early as the fourth year of the reign of Henry VIII.

Though it is out of the question that ships with the enormous top-hamper which, on the evidence of all the drawings extant, still continued to be the fashion, could have made much progress in sailing on a wind, the letters of the time extant corroborate the statement made; for they begin to contain references to this improvement in navigation. In a letter from Sir Edward Howard, "Lord Admiral," to King Henry VIII., upon the state of the fleet, A.D. 1513, preserved in the Cottonian Library, and published in Ellis's collection, the following passage occurs:—"Ye commanded me to send your grace word how every shipp dyd sail; and this same was the best tryal that cowd be, for we went both slakyng and by a bowlyn, and a cool acros and abouet in such wyse that few shippes lakkyd no water in over the lee wales." The Lord High Admiral Lisle, in one of his letters (1545), says the small vessels of his fleet could "lye best by a wynde;" and in 1567 we have conclusive proof that there were "fore and aft," indeed "cutter-rigged" vessels on the British seas; as in a map of Ireland of that date, published in the state-papers, two such vessels are represented, for the purpose, apparently, of indicating regular packets from England to Ireland.

It has been very generally supposed, on the authority of Sir Walter Raleigh, that the "knowledge of the bowline" was a discovery in navigation made shortly before his time; but is is probable that there were, even from the time of the Northmen, craft so rigged as to be capable of sailing on a wind. Froissart mentions, in several instances, "a vessel called a Lin, which sails with all winds, and without danger;" and again, "a vessel called a Lin, which keeps nearer the wind than any other." Boats with a rig adapted for this manœuvre are also represented in engravings of a very early date. In the plates of Breydenbach's *Voyage to Palestine*, which was published in 1483, boats and small vessels are represented with lateen sails; and in Braun's *Civitates Orbis Terrarum*, published in 1572, sprit-sails are met with. It is quite certain, however, that sailing on a wind was by no means a general quality possessed by the ships of war, or to any extent even by the greater portion of the larger shipping, until about the reign of Henry VIII. One other instance may be adduced in the account of the loss of the Mari Rose, a ship of the "portage of 500 tons," not so much to corroborate the fact of sailing on a wind as to show that the two innovations, the introduction of port-holes and the "knowledge of the bowline," were in advance of the qualities of the large ships of war of the time. Sir Walter Raleigh says that, "in King Henry VIII.'s time, at Portsmouth, the Mari Rose, by a little sway of the ship in casting about, her ports being within sixteen inches of the water, was overset and lost."

The loss of this ship has been the means of giving another interesting insight into the comparatively low state of nautical skill in England at this period, namely, the middle of the sixteenth century. In a letter among the state-papers published under the direction of the Record Commission, addressed by the Duke of Suffolk to Sir William Pagett, "chief secretary to the kinge's highnes," dated the 23d of July 1545, and containing a schedule of things necessary to be had for the raising of the Mari Rose, one item is "fifty Venyzian maryners and one Venyzian carpenter;" the next item is "sixty Englisshe maryners to attende upon them." It would also appear that the attempt was to be made under the direction of an Italian, as the conclusion of the schedule is, "Item, Symond, petrone and master in the Foyst, doth aggrie that all thyngs must be had for the purpose aforesaid." The attempts, however, all failed; the wreck of the Mari Rose remains to this day at Spithead, and so lately as August 1836, several of her brass cannon, of most exquisite workmanship, were recovered from the sea by the enterprise and ability of an Englishman of the name of Deane.

inutiæ of ip-building at this eriod.

Some idea of the detail of ship-building rather before this period may be obtained from an account of a vessel built by James IV. of Scotland, at the close of the fifteenth or the beginning of the sixteenth century. The extract is from Charnock, but he has not mentioned his authority. "The king of Scotland rigged a great ship, called the Great Michael, which was the largest and of superior strength to any that had sailed from England or France; for this ship was of so great stature, and took so much timber, that, except Falkland, she wasted all the woods in Fife which were oakwood, with all timber that was gotten out of Norway; for she was so strong, and of so great length and breadth, all the wrights of Scotland, yea, and many other strangers, were at her device by the king's command, who wrought very busily in her; but it was a year and a day ere she was completed. To wit, she was twelve score feet of length, and thirty-six foot within the sides; she was ten foot thick in the wall and boards, on every side so slack and so thick that no cannon could go through her. This great ship cumbered Scotland to get her to sea. From that time that she was afloat, and her masts and sails complete, with anchors offering thereto, she was counted to the king to be thirty thousand pounds expense, by her artillery, which was very great and costly to the king, by all the rest of her orders. To wit, she bare many cannon, six on every side, with three great bassils, two behind in her dock and one before, with three hundred shot of small artillery, that is to say, myand and batterd falcon, and quarter falcon, flings, pestilent serpentens, and double dogs, with hagtor and culvering, corsbows and handbows. She had three hundred mariners to sail her, she had six score of gunners to use her artillery, and had a thousand men of war, by her captains, shippers, and quarter-masters."

arge Swe- sh ship.

Several of the writers of this period mention the fact of a Swedish ship of extraordinary dimensions being built in the middle of the sixteenth century, and which was burned in an action between the Swedes and Danes in 1564. Chapman has given an estimate of the dimensions of this vessel. She was called the Makalos (by Charnock, Megala). According to Chapman, she was 168 English feet in length and 43 English feet in breadth, an immense vessel for that period. Her armament was 173 guns, 67 only of which could be considered as cannon, the remainder being merely swivels.

oyal ›ckyards.

Henry VIII. was deeply sensible of the necessity of a permanent and powerful naval force, and established the navy office, and also several dockyards for building and repairing the ships of the royal navy. Among these were Woolwich, Deptford, and Chatham. He also greatly added to and improved the dockyard at Portsmouth. He invited from foreign countries, particularly from Italy, the commercial cities of which were still in advance of the rest of Europe in the maritime arts, as many skilful foreigners as he could allure, either by the hope of gain or by the honours and distinguished countenance he paid to them. The following extract is from a report made to James I. in the year 1618, and published in the *Archæologia*. It was made in answer to a commission issued by that monarch to the several master-builders.

dward I.

The minority of Edward VI., and the civil and religious strife which distracted the kingdom during the reign of Mary, depressed the resources of the state, and evidently much checked the progress of its maritime strength. The report says, "In former times our kings have enlarged their dominions rather by land than sea forces, whereat even strangers have marvelled, considering the many advantages of a navy; but since the change of weapons and fight, Henry VIII., making use of Italian shipwrights, and encouraging his own people to build strong ships of war, to carry great ordnance, by that means established a puissant navy, which in the end of his reign consisted of 70 vessels, whereof 30 were ships of burthen, and contained in all 10,550 tons, and 2 galleys. The rest were small barques and row-barges, from 80 tons downwards to 15 tons, which served in rivers and for landing of men. Edward VI., in the sixth year of his reign, had but 53 ships, containing in all 11,005 tons, with 7995 men, whereof only 28 vessels were above 80 tons each. Queen Mary had but 46 of all sorts."

A.D. 1547. Report of of master builders.

Peculiar defect of ships of war up to this period.

There is one peculiarity of ships of war up to this time, which exemplifies the defects of their design in a remarkable feature. It is, that the ships built for the royal navy appear only to have been adapted for the lodgment of the soldiers and mariners, with their implements of war, and the necessary stores for navigation. The provisions were carried in an attendant vessel, called a "victualler," of which there was one attached to each of the large ships of war in the fleet, or to several of the smaller size. The hold appears to have been principally occupied by the "cook-room," the inconvenience of which arrangement, though much complained of, was general when Sir Walter Raleigh, in his *Discourse on the Royal Navy and Sea Service*, recommended that it should be removed to the forecastle; and even so lately as 1715, several men of war had "cook-rooms" in their holds. There is also no doubt that the enormous quantity of ballast which was rendered necessary by the immense top-hamper of these ships, and the space which it occupied, from being shingle, left but little room for the stowage of any quantity of provisions. In the ships built for commerce, this defect does not appear to have existed, as in fleets composed of the king's and of private shipping, those ships only which belonged to the royal navy had these attendant victuallers. The cook-rooms in the merchant shipping were under the forecastle; and they had less top-hamper, as less accommodation was required for officers.

Epoch in naval architecture.

Although the comparative inefficiency of the vessels may be commented on, it will be apparent that that period in the history of naval architecture and of navigation has now been entered on in which, though still in their infancy, these arts may be considered as perfect in all but the maturity to be acquired by the experience of years. The mariner's compass was known; the theory of taking observations was understood, and the practice of it in the course of being perfected; and therefore the longest voyages could be undertaken with comparative certainty and safety. Besides this, the ships, though still imperfect, were becoming gradually manageable machines, and had ceased to be the cumbrous masses of the preceding ages, which, with few exceptions, were capable of little more than of being driven before the wind.

Three epochs in the maritime history of England.

If the contents of the foregoing pages be considered, there will appear to be three epochs in the maritime history of England; the first commencing with the introduction of galleys by Alfred, and ending with the reign of Edward III., before whose time these galleys and vessels, propelled by oars, were the chief instruments of navigation; the second ending with the reign of Henry VII., during which period, though sailing vessels were used for the purposes both of war and commerce, they were comparatively at the mercy of the winds, and, speaking generally, could sail only when they blew both fairly and gently; the third epoch has been already noticed.

From the extract of the report of the builders, the state of the navy during the reigns of Edward VI. and of Mary

A.D. 1558. Elizabeth. Action with Spanish Armada.

will be seen. It is known, therefore, that when Elizabeth ascended the throne, the marine of England, both military and mercantile, was in a very depressed state. The successful enterprise of Drake, and the fear of the Spanish Armada, aroused the energies of the country, and the force collected to resist the invasion amounted to 197 vessels of various descriptions, of the aggregate burthen of nearly 30,000 tons, 34 of which, measuring together 12,600 tons, composed the royal navy. It is true, that by far the larger portion were of small force. One only, the Triumph, was of 1100 tons; another, the White Bear, was of 1000 tons; two were of 800 tons, 3 of 600, six of 500, and five of 400; sixty-six were under 100 tons; and fifteen were victuallers, of which the tonnage is not mentioned. There are also seven other vessels included in the 197 which have no tonnage assigned them; but they must have been of small size, the number of mariners on board the whole seven being only 474. We have very conclusive means of comparing the Spanish with the English ships, and also of judging how very little naval arrangements were then understood, from their imperfect state even on board a fleet which had occupied the whole attention of the Spanish authorities for a space of three years, exemplified in the following anecdote. Burchett, in his account of the action of the 23d of July 1588, says, "The great guns on both sides thundered with extraordinary fury, but the shot from the high-built Spanish ships flew over the heads of the English without doing any execution; one Mr Cock being the only Englishman who fell, while he was bravely fighting against the enemy in a small vessel of his own."

Three-decked ships.

The Spaniards appear to have been the first to introduce a third tier of guns, the earliest mention of a three-decker being the Philip, a Spanish ship engaged in the action off the Azores in 1591, with the Revenge, commanded by Sir Richard Greenvil. The following armament of the Philip is extracted from a most spirit-stirring account of this tremendous action, which was written by Sir Walter Raleigh, and has been preserved by Hackluyt. "The Philip carried three tire of ordnance on a side, and eleven pieces in euerie tire. She shot eight forth right out of her chase, besides those of her stern portes."

The English do not appear to have followed the example set by the Spaniards; for, during the long reign of Elizabeth, the ships of the royal navy were not much, if at all, increased in their dimensions, which was probably owing to the triumphant successes of her fleets, though they were composed of ships generally much smaller in size than those opposed to them. From the list of the royal navy at the time of her death, in 1603, given by Sir William Monson in his tracts, of 42 ships composing the navy, there were then only two ships of 1000 tons, three of 900, three of 800, two of 700, four of 600, four of 500, and there were eight under 100 tons burthen. Two of these ships, the Triumph and the White Bear, are rated in this list each at 100 tons less burthen than in the list of the fleet in the year 1588, already noticed.

The mercantile marine was also greatly improved and increased during the reign of Elizabeth. This wise monarch did all in her power to encourage foreign trade; and she honoured Drake by knighting him on board his own vessel at Deptford, after his return from circumnavigating the globe. The celebrated Sir Walter Raleigh, under a charter granted by her in 1584, commenced trading with America, and his successes, with those of others, in trade, as well as in the capture of richly laden Spanish merchantmen, prove the superiority of the English ships of this period. In 1600 the East India Company obtained their charter from Elizabeth, and merchant-ships, which proved the precursors of a fleet of the finest merchantmen, were immediately built by them for this distant traffic.

A.D. 16
James I.
Report
commission.

Shortly after the accession of James to the throne, several commissions were appointed to inquire into the state of the navy. From that of the year 1618 a very voluminous report emanated, of which the following is an extract, that affords an example of the state of knowledge on naval architecture at that time:—"The next consideration is the manner of building, which in shipps of warr is of greatest importance, because therein consists both their sayling and force. The shipps that can saile best can take or leave (as they say), and use all advantages the winds and seas does afford; and their mould, in the judgment of men of best skill, both dead and alive, should have the length treble to the breadth, and breadth in like proportion to the depth, but not to draw above 16 foote water, because deeper shipps are seldom good saylers, and ever unsafe for our rivers, and for the shallow harbours, and all coasts of ours, or other seas. Besides, they must bee somewhat snugg built, without double gallarys, and too lofty upper workes, which overcharge many shipps, and make them coeme faire, but not worke well at sea.

"And for the strengthening the shipps, wee subscribe to the manner of building approved by the late worthy prince, the lord adm^{ll}., and the officers of the navy (as wee are informed), on those points.

"1. In makeing 3 orlopes, whereof the lowest being placed 2 foote under water, both strengtheneth the shipp, and though her sides bee shott through, keepeth it from bildgeing by shott, and giveth easier meanes to finde and stopp the leakes.

"2. In carrying their orlopes whole floored throughout from end to end, without fall or cutting off y^{e} wast, which only to make faire cabbins, hath decayed many shipps.

"3. In laying the second orlope at such convenient height that the portes may beare out the whole fire of ordinance in all seas and weathers.

"4. In placeing the cooke roomes in the forecastle, as otherr war shipps doe, because being in the midshipps, and in the holds, the smoake and heate soe search every corner and seame, that they make the okam spew out, and the shipps leaky, and soone decay; besides, the best roome for stowage of victualling is thereby soe taken up, that transporters must be hyred for every voyage of any time; and, which is worst, when all the weight must bee cast before and abaft, and the shipps are left empty and light in the midst, it makes them apt to sway in the back, as the Guardland and divers others have done."

This commission was followed by several others during this and the succeeding reign, and from their reports arose many regulations tending much to the improvement of the navy, although the expenses incurred were, ostensibly at least, in part the means of causing the subsequent revolution.

Mercant shipping this period.

In the early part of the reign of James I. the mercantile navy of England was reduced to a very low state, most of the commerce being carried on in foreign bottoms. The incitement offered by the advantageous trade which the Dutch had long engaged in to India at length aroused the nation, and the formation of the East India Company, which was the act of James, was followed by the building of the largest ship that had yet been constructed for the purposes of commerce, at least in England. The king dined on board of her, and gave her the name of the Trade's Increase. She is reported to have been of the burthen of 1200 tons. The impetus once given, before the end of the reign of James an important mercantile navy was owned by British merchants.

Trade's I crease.

Shipwrights' Company

Another interesting fact connected with this reign is the founding of the Shipwrights' Company, in the year 1605, and which was incorporated by a charter granted to the "Master, Warden, and Commonality of the Art or Mystery of Shipwrights," in May 1612. Mr Phineas Pett was the first master. The draughts for the ships of the royal navy were subsequently ordered to be submitted to this company for approval previously to being built from. They also had jurisdiction over all builders, whether of the royal navy or of merchant-shipping.

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In 1610 the Royal Prince was launched; she was the largest ship which at that time had been built in England, and was also a most decided improvement in naval architecture. The great projection of the prow, a remnant of the old galley, was for the first time discontinued, and the stern and quarters assimilated more to those of a modern ship than to any which had preceded her. She is thus described in Stow's *Chronicles*:—"A most goodly ship for warre, the keel whereof was 114 feet in length, and the cross-beam was 44 feet in length; she will carry 64 pieces of ordnance, and is of the burthen of 1400 tons. The great workmaster in building this ship was Master Phineas Pett, Gentleman, some time master of arts at Emanuel College, Cambridge."

hineas ett.

The same gentleman, Mr Phineas Pett, continued the principal engineer of the navy during the reign of Charles. The family of the Petts were the great instruments in the improvement of the navy, and, if the term may be allowed, of modernizing it, by divesting the ships of much of the cumbrous top-hamper entailed on them from the castellated defences which had been necessary in, and which yet remained from, the hand-to-hand encounters of the middle ages; and it is probable that, but for the taste for gorgeous decoration which prevailed during the seventeenth century, this ingenious family would have been able to effect much more; as it was, they decidedly rendered England pre-eminently the school for naval architecture during the time they constructed its fleets. This family can be traced as principal engineers for the navy from about the middle of the fifteenth century to the end of the reign of William III.

he Petts.

irst fri- ate.

Evelyn, in his *Diary*, relating a conversation, says, "Sir Anthony Deane mentioned what exceeding advantage we of this nation had by being the first who built frigates, the first of which ever built was that vessell which was afterwards called the Constant Warwick (built in 1646), and was the work of Pet of Chatham, for a trial of making a vessell that would sail swiftly. It was built with low decks, the guns lying near the water, and was so light and swift of sailing, that in a short time she had, ere the Dutch war was ended, taken as much money from privateers as would have laden her." The dimensions of this vessel are given in Pepys's *Miscellanies* as follows: length of the keel 85 feet, breadth 26 feet 5 inches, depth 13 feet 2 inches, and 315 tons burthen; her highest number of guns" 32, and of crew 140.

eter Pett.

Peter Pett, who built the Constant Warwick, was the son of Phineas Pett. He caused the fact of his being the inventor of the frigate to be recorded on his tomb. He was also the builder of the Sovereign of the Seas, in 1637, which was the first three-decker built in England. Her length over all is stated to have been 232 feet, her length of keel 128 feet, her main breadth 48 feet, and her tonnage 1637. Heywood describes her in the following terms:—"She hath three flush deckes and a forecastle, an halfe decke, a quarter decke, and a round-house. Her lower tyre hath thirty ports, which are to be furnished with demi-cannon and whole cannon throughout, being able to beare them. Her middle tyre hath also thirty ports for demi-culverin and whole culverin. Her third tyre hath twentie-sixe ports for other ordnance. Her forecastle hath twelve ports, and her halfe decke hath fourteene ports. She hath thirteene or foureteene ports more within board for murdering peeces, besides a great many loope-holes out of the cabins for musket shot. She carrieth, moreover, ten peeces of chase ordnance in her right forward, and ten right aff; that is, according to land service, in the front and the reare. She carrieth eleaven anchors, one of them weighing foure thousand foure hundred, &c.; and according to these are her cables, mastes, sayles, cordage, which, considered together, seeing Majesty is at this infinite charge, both for the honour of his nation, and the security of his kingdome, it should bee a spur and encouragement to all his faithful and loving subjects to bee liberall and willing contributaries towards the ship money."

irstthree- ecker.

Of this ship, Fuller, in his *Worthies*, says, "The Great Sovereign, built at Woolwich, a leiger ship for state, is the greatest ship our island ever saw; but great medals are made for some grand solemnity, while lesser coin are more current and passable in payment." She was afterwards cut down one deck, and remained in the service, with the character of the best man-of-war in the world, until the year 1696, when she was accidentally burnt at Chatham.

Sir Walter Raleigh's works: *Invention of Shipping; Concerning the Royal Navy and Sea-Service.*

About this time, 1650, appeared the first work connected with naval improvement ever written in this country, and by no less celebrated an author than Sir Walter Raleigh. It is very probable that his two discourses, the one on the *Invention of Shipping*, the other *Concerning the Royal Navy and Sea-Service*, had great influence in creating the interest which was evidently taken about this period in the improvement of the navy. Sir Walter says, "Whosoever were the inventors, we find that every age had added somewhat to ships and to all things else. And in my owne time the shape of our English ships hath been greatly bettered. It is not long since the striking of the top-mast (a wonderfully great ease to great ships both at sea and harbour) hath been devised. Together with the chaine-pumpe, which takes up twice as much water as the ordinary did, we have lately added the bonnett and the drabler. To the courses we have devised studding-sayles, top-gallant-sayles, sprit-sayles, top-sayles. The weighing of anchors by the capstane is also new. We have fallen into consideration of the length of cables, and by it we resist the malice of the greatest winds that can blow; witnesse our small Milbroke men of Cornewall, that ride it out at anchor half seas over betweene England and Ireland all the winter quarter; and witnesse the Hollanders that were wont to ride before Dunkirke with the wind at north-west, making a lee-shore in all weathers; for true it is that the length of the cable is the life of the ship in all extremities; and the reason is, because it makes so many bendings and waves as the ship riding at that length is not able to stretch it, and nothing breaks that is not stretched. In extremity, we carry our ordnance better than we were wont, because our nether-overloops are raised commonly from the water, to wit, betweene the lower part of the port and the sea. We have also raised our second decks, and given more vent thereby to our ordnance, tying in our nether-overloope.

"We have added crosse pillars in our royall ships to strengthen them, which being fastened from the kelson to the beames of the second decke, keep them from settling or from giving away in all distresses.

"We have given longer floares to our ships than in elder times, and better bearing under water, whereby they never fall into the sea after the head, and shake the whole body, nor sinck sterne, nor stoope upon a wind, by which the breaking loose of our ordnance, or the not use of them, with many other discommodities, are avoided. And to say the truth, a miserable shame and dishonour it were for our shipwrights, if they did not exceed all other in the setting up of our royall ships, the errors of other nations being farre more excusable than ours. For the kings of England have for many years been at the charge to build and furnish a navy of powerfull ships for their owne defence, and for the wars only; whereas the French, the Spainards, the Portugalls, and the Hollanders (till of late), have had no proper fleete belonging to their princes or states.

"Only the Venetians for a long time have maintained their arsenal of gallyes, and the kings of Denmark and

Sweden have had good ships for these last fifty years. I say that the forenamed kings, especially the Spainards and Portugalls, have ships of great bulke, but fitter for the merchant than the man of warre, for burthen then for battaile. . . . . Although we have not at this time 135 ships belonging to the subjects of 500 tuns each ship, as it is said we had in the 24th yeare of Queen Elizabeth, at which time also, upon a generall view and muster, there were found in England, of all men fit to beare arms, eleaven hundred and seventy-two thousand; yet are our merchants' ships now farre more warlike and better appointed than they were, and the royal navy double as strong as then it was. . . . . We have not, therefore, lesse force than we had, the fashion and furnishing of our ships considered; for there are in England at this time 400 saile of merchants fit for the wars, which the Spainards would call gallions; to which we may add 200 saile of crumsters or hoyes, of Newcastle, which each of them will beare six demi-culverins, and four sakers, needing no other addition of building than a slight spar-decke fore and afte, as the seamen call it, which is a slight decke throughout. The 200 which may be chosen out of 400, by reason of their ready staying and turning, by reason of their windwardnesse, and by reason of their drawing of little water, and they are of extreame vantage neere the shoare, and in all bayes and rivers to turn in and out; these, I say, alone, well manned and well conducted, would trouble the greatest prince in Europe to encounter in our seas; for they stay and turn so readily as, ordering them into small squadrons, three of them at once may give their broad-sides upon any one great ship, or upon any angle or side of an enemy's fleet. They shall be able to continue a perpetuall volley of demi-culverins without intermission, and either sink or slaughter the men, or utterly disorder any fleete of crosse sailes with which they encounter.

"I say, then, if a vanguard be ordained of these hoyes, who will easily recover the wind of any other ships, with a battaile of 400 other warlike ships, and a reare of thirty of his majestie's ships to sustaine, relieve, and countenance the rest (if God beat them not), I know not what strength can be gathered in all Europe to beat them. And if it be objected that the states can furnish a farre greater number, I answer, that his majestie's forty ships, added to 600 before named, are of incomparable greater force than all that Holland and Zeeland can furnish for wars."

Ships of royal navy inferior to merchant-ships.

In the foregoing extract there is strong evidence that the ships of the royal navy were generally inferior to those employed by the merchant-service, in the essential qualifications of being weatherly. This is exactly the conclusion that might be arrived at from the consideration, that a private individual would dispense with all that superabundance of top-hamper which was entailed on the ships of the royal navy, by the accommodation required for the numerous officers and gentlemen generally embarked on board them, and also by the mania for gorgeous decorations. This mania is well exemplified by the fact, that of the Sovereign of the Seas it is stated, "She beareth five lanthornes, the biggest of which will hold ten persons to stand upright, and without shouldering one another."

Sir Walter Raleigh, in his *Discourse on the Royal Navy and Sea-Service*, adverts to the same subject. He says, "We find by experience, that the greatest ships are lesse serviceable, goe very deep to water, and of marvellous charge and fearefull cumber, our channells decaying every yeare. Besides, they are lesse nimble, lesse maineable, and very seldome imployed. *Grande navio, grande fatica*, saith the Spainard; a ship of 600 tons will carry as good ordnance as a ship of 1200 tons; and though the greater have double the number, the lesser will turn her broadsides twice before the greater can wend once; and so no advantage in that overplus of ordnance. And in the building of all ships, these six things are principally required:—

1. First. that she be strong built; 2. Secondly, that she b swift; 3. Thirdly, that she be stout sided; 4. Fourthl that she carry out her guns all weather; 5. Fifthly, th she hull and try well, which we call a good sea ship; Sixthly, that she stay well when bourding and turning o a wind is required.

"1. To make her strong, consisteth in the truth of th workeman and the care of the officers.

"2. To make her sayle well, is to give a long run forwar and so afterward done by art and just proportion. For, in laying out of her bows before, and quarters behind, s neither sinck into nor hang in the water, but lye cleare and above it; and that the shipwrights be not deceive herein (as for the most part they have ever been), the must be sure that the ship sinck no deeper into the wat than they promise, for otherwise the bow and quarter w utterly spoile her sayling.

"3. That she be stout, the same is provided and perform by a long bearing floore, and by sharing off above wat even from the lower edge of the ports.

"4. To carry out her ordnance all weather, this lo bearing floore, and sharing off from above the ports, is chiefe cause, provided alwayes that your lowest tyre of or nance must lye foure foot cleare above water when loading is in, or else those your best pieces will be of sm use at the same in any growne weather that makes t billoe to rise, for then you shall be enforced to take in your lower ports, or else hazard the ship.

"5. To make her a good sea ship, that is to hull a trye well, there are two things specially to be observe the one that she have a good draught of water, the oth that she be not overcharged, which commonly the king ships are, and therefore in them we are forced to lye trye with our maine course and missen, which, with a de keel and standing streake, she will performe.

"6. The hinderance to stay well is the extreame leng of a ship, especially if she be floaty and want sharpnesse way forwards; and it is most true, that those over-lon ships are fitter for our seas than for the ocean; but on hundred foot long, and five and thirty foot broad, is a goo proportion for a great ship. It is a speciall observation that all ships sharpe before, that want a long floore, will fa roughly into the sea, and take in water over head and ears.

"So will all narrow quartered ships sinck after the tayle The high charging of ships is it that brings them all il qualities, makes them extreame leeward, makes them sinc deep into the water, makes them labour, and makes them overset. Men may not expect the ease of many cabbins and safety at once, in sea-service. Two decks and a half i sufficient to yield shelter and lodging for men and mariners and no more charging at all higher, but only one low cabbi for the master. But our marriners will say, that a shi will beare more charging aloft for cabbins, and that is true if none but ordinary marryners were to serve in them, wh are able to endure, and are used to, the tumbling and rowl ing of ships from side to side when the sea is never so littl growne; but men of better sort and better breeding woul be glad to find more steadinesse and lesse tottering cadg work. And albeit, the marriners doe covet store of cabbin yet indeed they are but sluttish dens, that bread sicknes in peace, serving to cover stealths, and in fight are dange ous to teare men with their splinters."

In Fuller's *Worthies*, there is also a short summary the comparative qualities of the ships of different nations the middle of the seventeenth century. It is as follow "First, for the Portugal, his cavils and carracts, where few now remain (the charges of maintaining them far e ceeding the profit they bring in); they were the verie drones on the sea, the rather because formerly their seelin was dam'd up with a certain kind of mortar to dead t shot, a fashion now by them disused.

A.D. 1650.

"The French, however dexterous in land-battles, are left-handed in sea-fights, whose best ships are of Dutch building. The Dutch build their ships so floaty and buoyant, they have little hold in the water in comparison to ours, which keep the better winde, and so outsail them.

"The Spanish pride hath infected their ships with loftiness, which makes them but the fairer markes to our shot. Besides the winde hath so much power of them in bad weather, so that it drives them two leagues for one of ours to the leeward, which is very dangerous upon a lee-shore.

"Indeed the Turkish frigots, especially some thirty-six of Algier, formed and built much nearer the English mode, and manned by renegadoes, many of them English, being already too nimble heel'd for the Dutch, may hereafter prove mischievous to us, if not seasonably prevented."

Rise of Dutch naval power.

During the early part of the seventeenth century, the Dutch navy rapidly increased in importance. Their success in having wrested from the Portuguese a share of the commerce of the east, emboldened them, in the then depressed state of the Spanish marine, to make a similar attempt on the west, and endeavour to establish settlements in South America.

The wars with Spain, in which they were consequently engaged, had such an important effect in establishing their maritime power, that in 1650 their navy consisted of 120 vessels fitted for war, seventy of which had two tiers of guns; and their fleet was in all respects the most efficient in Europe.

Evelyn's *Navigation and Commerce*.

Evelyn, in his tract on Navigation and Commerce, speaking of the fisheries, says "Holland and Zeeland alone should, from a few despicable boats, be able to set forth above 20,000 vessels of all sorts, fit for the rude seas, of which more than 7000 are yearly employed upon this occasion. 'Tis evident that by this particular trade they are able to breed above 40,000 fishermen and 116,000 mariners, as the census (1639) has been accurately calculated."

The tremendous struggle in which they were enabled by these means to engage with us shortly after this period, in consequence of the injurious operation of the navigation act on their commerce, had a most influential effect on the improvement of our navy, which at the commencement of the contest was very unequal to that of the Dutch; and it is probable that this war was the means of enabling us to contend triumphantly against the immense and unexpected attempts of Louis XIV. to wrest the sceptre of the seas from our grasp.

Charles I.

The sovereigns of the house of Stuart, without exception, appear to have devoted much attention to the improvement of the navy. Charles I. may be almost said to have lost both crown and life in consequence of these efforts; nor would it be doing justice to Cromwell to omit mention of the energy with which he took advantage of the all but despotic power which he possessed to increase his naval force. For this purpose not only many ships were built during the protectorate, but numbers of merchant-vessels were bought for the service of the state.

Charles II. His personal attention to ship-building and naval affairs.

After the Restoration, Charles II. paid great personal attention even to the minutiæ of his navy, as shown by the following curious extract from a letter of his to Prince Rupert, preserved in the state-papers, and also by continual references to his naval predilections in Evelyn's and Pepys's memoirs and writings. The letter is dated 4th August 1673. It says, "I am very glad the Charles does so well; a gerdeling this winter when she comes in will make her the best ship in England; next summer, I believe, if you try the two sloops that were builte at Woolidge that have my invention in them, they will outsail any of the French sloops. Sir Samuel Mooreland has now another fancy about weighing anchors; and the resident of Venice has made a model also to the same purpose. We have not yet consulted them with Mr Tippet nor Mr Deane; but hope when they are well considered, we may find one out of them that will be good."

A.D. 1666. Sir Anthony Deane.

In Pepys's *Diary*, 19th May 1666, there is the following notice relating to one of the gentlemen mentioned in the above letter:—"Mr Deane and I did discourse about his ship the Rupert, which succeeds so well, as he has got great honor by it, and I some by recommending him. The king, duke, and everybody, say it is the best ship that was ever built. And then he fell to explain to me his manner of casting the draught of water which a ship will draw beforehand, which is a secret the king and all admire in him; and he is the first that hath come to any certainty beforehand of foretelling the draught of water of a ship before she be launched." This gentleman appears therefore to have been the first who applied mathematical science to naval architecture in this country. Pepys also says, "another great step and improvement to our navy, put in practice by Sir Anthony Deane," was effected in the Warspight and Defiance, which were "to carry six months' provisions, and their guns to lie 4½ feet from the water." This was in 1665.

First application of mathematical calculation to naval architecture.

The foregoing extract probably indicates the date of the first practical application to a useful purpose in this country of the famous discovery of Archimedes. It is well known that he was called upon by his king to test the purity or the adulteration of the gold of the royal crown, and the displacement of the water of his bath by his own immersion therein suggested to his mind the means of solving the problem. He saw that a body immersed in water displaced its own bulk of water, and that by immersing the crown, which was correct in weight, and measuring the water displaced by it, the increased bulk necessary to make up the weight, if the gold had been adulterated by any lighter metal, could be detected. After this the knowledge followed that a body floating in a fluid displaced its own weight of that fluid.

Sir Robert Slingeby.

In this historical sketch the probability that the merchant-shipping of England were superior in their sea-going qualities to those composing the royal navy, has been adverted to in a *Discourse touching the Past and Present State of the Navy*, by Sir Robert Slingeby, knight-baronet, and comptroller of the navy, dated 1669, there is the following interesting statement, which points to a reason why this superiority of the merchant-shipping may have existed. "But since these late distractions began at home" (the Commonwealth), "forraigne trade decayed, and merchants so discouraged from building, that there hath been scarce one good merchant-ship built these twenty years past, and of what were then in being, either by decayes or accident, there are very few or none remaining. The merchants have found their private conveniences in being convoyed att the publick charge; they take noe care of making defence for themselves if a warr should happen." Yet he says, in the time of Charles I., "the merchants continued their trade during the wars with France and Spain, if there could but two or three consort together, not caring who they met," they being little inferior in strength or burthen to the ships of the royal navy.

Decay of mercantile navy during the Commonwealth.

Its subsequent improvement.

Sir Richard Haddock.

About 1684 Sir Richard Haddock, comptroller of the navy, adopted the recommendation of Mr, afterwards Sir Anthony Deane, at that time surveyor of the navy, and directed an inquiry to be made as to "the number of cube feet that are contained in the bodyes of several draughts to their main water-line, when all materialls are on board fitt for saileing." The result of this inquiry was a very voluminous statement of the weights which made up the whole displacement of the fourth, fifth, and sixth rate ships, including minute details of their masts, yards, armament, &c., accompanied by perfect drawings of each ship. The following table contains the dimensions and displacements, &c., of each class:—

First analysis of the royal navy.

A.D. 1684.

Table of Dimensions, from a Manuscript dated 1684.

	A First Fourth-rate near the largest dimensions.	A Second Fourth-rate near the dimensions of the Adventure.	A Fifth-rate of the largest dimensions.	A First Sixth-rate.	A Second Sixth-rate.	A Sixth-rate of the largest dimensions.	A Sixth-rate of the old fashion.
	Feet. In.	Feet. In.	Feet. In.	Feet. In.	Feet. In.	Feet. In.	Feet. In.
Length on the gun-deck from the rabbitt of the stem to the rabbitt of the post	124 6	116 6	103 9	87 8	70 0	92 6	93 0
Maine breadth to the outside of the outboard planke........	35 0	32 9	28 8	23 6	21 6	23 6	22 9
Depth in hold from the seeling to the upper side of the beame................	14 0	13 2	11 4	10 9	9 10	11 9	10 0
Breadth at the afte side of the maine transome	21 0	18 4	18 0	14 0	13 0	14 0	15 0
Height on the gun-deck from planke to planke............ afore.......	5 9	6 0	5 9	5 7	5 6	...	...
midships...	6 0	6 0	6 0	...	...	...	...
abafte	6 6	6 3	6 7	6 3	6 2	...	...
The center of the.... fore.... mast from the rabbitt of the stern..........	13 6	12 9	9 10	7 6	6 6	10 0	9 6
maine..	69 0	62 0	54 6	45 0	36 0	50 0	49 6
mizion.	102 0	96 9	84 0	71 0	57 0	73 0	74 0
Draft of water.................... afore....	14 6	13 6	12 0	9 8	8 6	10 0	8 0
abaft...	15 10	15 0	13 0	10 8	9 6	11 0	9 0
Number of tuns, tunage.........................	885	580	362	...	...	230	220
Number of men (in warr)	260	180	135	85	70	90	29
Number of guns..............................	50	44	34	24	18	22	24
Cube feet in the several draughts to their main water line....................	29,814	22,346	13,195	8906	6790	...	...
	Ts. cwt. qr. lb.	Ts. cwt. qr. lb.	Ts. cwt. qr. lb.	Ts. cwt. qr. lb.	Ts. cwt. qr. lb.	Ts.	Ts.
Weight of each ship's hull, and all manner of materials on board.............	851 16 2 8	638 9 0 16	377 0 0 3	254 9 0 16	194 0 0 0	...	...
Each ship's hull at first launching........	418 0 0 0	314 0 0 0	160 0 0 0	120 0 0 0	98 0 0 0	...	...
Burthen in tuns, what she will really carry......................	433 16 2 8	324 9 0 16	216 0 0 0	134 9 0 16	...	135	130
No. of months' provisions and water.......	4	3	3	2	2	...	...

James II.

James II., from having so long and so gloriously filled the office of Lord High Admiral while Duke of York, was perfectly aware of the requirements of the navy; and during his short reign he paid great attention to increasing its efficiency. He also especially directed inquiries into the question of the durability of timber for the construction of it, and carefully accumulated both materials and stores for its maintenance. It is not a little curious that it was probably the attention which the monarchs of the line of Stuart had bestowed on the naval service, which enabled it so triumphantly to resist the persevering attempts of Louis XIV. to recover for them the throne of their ancestors.

The Revolution.

Though England was at the Revolution possessed of an efficient fleet, manned by experienced seamen, who had all the confidence arising from a series of naval triumphs, it must be remembered that for a long period no opposition to her naval superiority had been anticipated from any other power than Holland; and consequently the fleets of England were composed of ships which had many of them been built to adapt them to this service, for which small dimensions and light draughts of water were essential qualifications, on account of the shoalness of the Dutch coast.

William III.

William was too cautious a monarch to have neglected so important a means of national defence as was the navy, when engaged with such an ambitious and energetic opponent as Louis XIV.; and we find that the naval force was considerably increased, both numerically and in dimensions, during his reign. But the triumphs of our armies under Marlborough having for a time diverted the attention of the nation from naval affairs, it fell into decay during the reign of his successor.

Louis XIV.

When Louis XIV. determined to dispute with England the sovereignty of the seas, he was not only without a navy, but without the means of forming one. The military and commercial marine of France had ceased to exist. The sanguine temperament of the monarch, and the wisdom of his minister Colbert, removed all obstacles; commerce began to flourish on the quays, merchant-vessels to crowd the ports; dockyards, harbours, and shipping appeared simultaneously to start into existence; and the nation, which almost for centuries had been essentially military, felt constrained to turn its energies to commerce and to the sea. A navy which, in 1661, consisted of some four or five small vessels, in little more than ten years bearded and baffled the combined fleets of Holland and of Spain, and asserted the sovereignty of the Mediterranean. In 1681 her fleets consisted of 115 line-of-battle ships, manned by 36,440 men, with 179 smaller ships, the crews of which amounted to 3037 men; and in 1690 a fleet of eighty-four vessels of war, out of which three were of a hundred guns and upwards, and ten others were above eighty-four guns, with twenty-two fire ships, was cruising in the British seas. It is true that these mighty armaments failed in fulfilling the ambitious designs of Louis. But the severity of the struggle, which at length ended in the annihilation of his hopes, and in our triumphant assertion of our naval superiority, must always serve as an example of the danger we may incur by too great confidence in that superiority.

Rise of French val powe

The following comparison between the French and British ships of about this period, is from an official contemporary paper, by a gentleman of the name of Gibson :—

Comparison between English and Fre ships.

"Our guns being for the most part shorter, are made to carry more shott than a French gunn of like weight, therefore the French guns reach further, and ours make a bigger hole. By this the French has the advantage to fight at a distance and wee yard-arm to yard-arm. The like advantage wee have over them in shipping; although they are broader and carry a better saile, our sides are thicker, and better able to receive their shott; by this they are more subject to be sunk by gunn shott than wee."

Injudici management of royal na

The paper also complains much of the injudicious management of our shipping, by which it says, "many a fast sayling shipp have come to loose that property, by being over-masted, over-rigged, over-gunned (as the Constant Warwick, from twenty-six gunns, and an incomparable sayler, to forty-six gunns and a slugg), over-manned (vide all the old shipps built in the parliament time now left), over-built (*vide* the Ruby and Assurance), and haveing great tafferills, gallarys, &c., to the making many formerly a stiff, now a tender-sided shipp, bringing thereby their head and tuck to lye too low in the water, and by it takeing away their former good property, in steering, sayling, &c. The French by this defect of ours make war with the sword (by sending no small shipps of warr to sea, but clean), and wee, by cruseing in fleetes, or single shipps foule, with bare threates."

Lord Rodney.

In a letter from Sir George (afterwards Lord) Rodney, dated the 31st May 1780, to Mr Stephens, the secretary of the Admiralty, is a passage which goes to prove the truth of the above statement. "Nothing could induce them (the French fleet) to risk a general action, though it was in their power daily. They made, at different times, motions which indicated a desire of engaging, but their resolution failed them when they drew near; and as they sailed far better than his majesty's fleet, they with ease could gain what distance they pleased to windward."

Cause of inferiority of English ships.

One great cause of the inferiority of our ships arose from the practice which prevailed during the first half of the eighteenth century, through a mistaken idea of economy, of "rebuilding" old ships, without reference to the opinions of practical men, so that the forms and dimensions of the previous century passed down, in many instances, into the succeeding one, and justice was not done to the ship-building knowledge of the surveyors.

A.D. 1745.

French system followed by Spain.

The French system of improvement was followed by the Spaniards, and the capture of the Princessa, in 1740, of 70 guns, 165 feet in length, and 49 feet 8 inches in breadth, when our ships of the same force then building were only 151 feet long and 43 feet 6 inches broad, caused an appeal to be made by the Admiralty to Admiral Sir John Norris. The surveyors of the navy of that date who had succeeded Sir A. Deane were men of no note, because no opportunity of showing their powers had been allowed them.

Improvements attempted by the Admiralty.

In consequence of the inquiries then made, the several master-shipwrights of the dockyards were directed to send in proposals for the future established dimensions of the navy; and, in 1745, Sir Jacob Attwood being surveyor of the navy, the Admiralty issued a new establishment for the dimensions of the several ratings of ships. The following table, taken from Derrick's *Memoirs of the Royal Navy*, contains the various established alterations from time to time, from the reign of Charles II. to this of 1745, which was the last:—

An Account showing the Dimensions established, or proposed to be established, at different times, for Building of Ships. Extracted from Derrick's Memoirs of the Royal Navy.

	Establishment of				Proposed in		Establishment of 1745.
	1677.	1691.	1706.	1719.	1733.	1741.	
Ships of 100 Guns.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.
Length on the gun-deck	165 0	...	...	174 0	174 0	175 0	178 0
Length of the keel, for tonnage	137 8	...	...	140 7	140 7	142 4	144 6½
Breadth, extreme	46 0	...	...	50 0	50 0	50 0	51 0
Depth in hold	19 2	...	...	20 0	20 6	21 0	21 6
Burthen in tons	1550	...	...	1869	1869	1892	2000
90.							
Length on the gun-deck	158 0	...	162 0	164 0	166 0	168 0	170 0
Length of the keel, for tonnage	...	...	132 0	132 5	134 1	137 0	138 4
Breadth, extreme	44 0	...	47 0	47 2	47 9	48 0	48 6
Depth in hold	18 2	...	18 6	18 10	19 6	20 2	20 6
Burthen in tons	1307	...	1551	1566	1623	1679	1730
80.							
Length on the gun-deck	...	156 0	156 0	158 0	158 0	161 0	165 0
Length of the keel, for tonnage	...	...	127 6	128 2	127 8	130 10	134 10¾
Breadth, extreme	...	41 0	43 6	44 6	45 5	46 0	47 0
Depth in hold	...	17 4	17 8	18 2	18 7	19 4	20 0
Burthen in tons	...	1100	1283	1350	1400	1472	1585
70.							
Length on the gun-deck	150 0	...	150 0	151 0	151 0	154 0	160 0
Length of the keel, for tonnage	...	...	122 0	123 2	122 0	125 5	131 4
Breadth, extreme	39 8	...	41 0	41 6	43 5	44 0	45 0
Depth in hold	17 0	...	17 4	17 4	17 9	18 11	19 4
Burthen in tons	1013	...	1069	1128	1224	1291	1414
60.							
Length on the gun-deck	...	144 0	144 0	144 0	144 0	147 0	150 0
Length of the keel, for tonnage	...	...	119 0	117 7	116 4	119 9	123 0½
Breadth, extreme	...	37 6	38 0	39 0	41 5	42 0	42 8
Depth in hold	...	15 8	15 8	16 5	16 11	18 1	18 6
Burthen in tons	...	900	914	951	1068	1123	1191
50.							
Length on the gun-deck	...	...	130 0	134 0	134 0	140 0	144 0
Length of the keel, for tonnage	...	...	108 0	109 8	108 3	113 9	117 8½
Breadth, extreme	...	...	35 0	36 0	38 6	40 0	41 0
Depth in hold	...	...	14 0	15 2	15 9	17 2½	17 8
Burthen in tons	...	...	704	755	853	968	1052
40.							
Length on the gun-deck	...	...	118 0	124 0	124 0	126 0	133 0
Length of the keel, for tonnage	...	...	97 6	101 8	100 3	102 6	108 10
Breadth, extreme	...	...	32 0	33 2	35 8	36 0	37 6
Depth in hold	...	...	13 6	14 0	14 6	15 5½	16 0
Burthen in tons	...	...	531	594	678	706	814
20.							
Length on the gun-deck	...	...	...	106 0	106 0	112 0	113 0
Length of the keel, for tonnage	...	...	...	87 9	85 8	91 6	93 4
Breadth, extreme	...	...	...	28 4	30 6	32 0	32 0
Depth in hold	...	...	...	9 2	9 5	11 0	11 0
Burthen in tons	...	...	...	374	429	498	508

History.

A.D. 1746.

The ships built after the establishment of 1745 are reported to have been stiff, and to have carried their guns well, but were still inferior to those of the French; and, consequently, about ten years afterwards an alteration was made in the draughts for the several ratings, and the dimensions were also slightly increased. It may not be uninteresting to remark, that the proportional breadths in the establishment of 1745 considerably exceeded those of more modern ships. Their length varied from 3·49 to 3·85 of their breadth; while the lengths of most of our line-of-battle ships, built shortly afterwards, are within the limits of 3·61 and 3·83 of their breadths.

Royal George.

The Royal George was the first ship built on the increased dimensions, which were the result of the beforementioned inquiry. She was laid down in 1746, and launched in 1756; and rather more than ten years afterwards, that is, in 1758, Thomas Slade and William Bateley being the surveyors of the navy, the Triumph and Valiant of 74 guns were built on the lines of the Invincible, a French 74 gun-ship, captured in 1747.

Triumph and Valiant.

The dimensions of these ships are given below, as they were manifestations of an improved system, which, however, was not persevered in; for, with the exception of occasionally building after a French or Spanish model, the English ships were scarcely altered from those built at the commencement of the century.

	Royal George.	Triumph and Valiant.
	Feet. In.	Feet. In.
Length on the gun-deck	178 0	171 3
Length of the keel, for tonnage	143 5½	138 8
Breadth, extreme	51 9½	49 9
Depth in hold	21 6	21 3
Burthen in tons	2047	1826

History.

A.D. 1763.

Grand distinction between English and foreign navies.

There was still a very essential distinction between the navy of England and of either France or Spain, which was this, that until after 1763 neither of these nations had any three-deckers in their fleets. Their largest armament appears to have been eighty-four guns on two decks, while we had third-rates which were three-deckers, as the Cambridge and Princess Amelia, launched in 1754 and 1757, and carrying only eighty-four guns, our naval officers of that period having advocated a high battery, and the naval architects having designed some very fine ships of this new class. The capture of the Foudroyant, a French eighty-four on two decks, in 1758, caused a change in this respect, by furnishing the English with a model for a very superior class of men-of-war, which was adopted. Derrick, in his *Memoirs of the Royal Navy*, says, that "no eighty-gun ship with three decks was built after the year 1757, no seventy-gun ship after 1766, nor any sixty-gun ship after 1759."

French-built three-deckers.

During the peace that preceded the war with America, which commenced in the year 1768, the French had introduced three-deckers into their fleets, having found their eighty-fours on two decks to be no match for the more powerful of our three-deckers. Their first-rates were at this time generally of 110 guns on three decks. The Bretagne, one of these ships, was, according to Charnock, 196 feet 3 inches long on the water-line; and her moulded breadth was 53 feet 4 inches. Her displacement, it is stated in Sewell's *Collection of Papers on Naval Architecture*, was 4640 English tons.

Establishment of French fleets.

In 1786 the establishment of the French fleet was fixed by an ordinance of the government, as according to the following table, which is extracted from Charnock, and some very fine vessels of each class were built upon these dimensions:—

	Ships of 120 Guns.	Ships of 110 Guns.	Ships of 80 Guns.	Ships of 74 Guns.	Ships of 64 Guns.	Frigates carrying 18 Pounders.	Frigates carrying 12 Pounders.	Corvettes of 20 Guns.	Advice-boats, carrying four 4 Pounders.
	Feet. In.	Feet.	Feet.	Feet. In.	Feet. In.	Feet. In.	Feet. In.	Feet. In.	Feet. In.
Length from head to stern	196 6	186—185	184—180	170 0	156 0	144 0	136 0	112 0	80 0
Breadth from outside to outside of the frame	50 0	49 6 in.	48 0 in.	44 6	41 0	36 6	34 6	28 4	24 0
Depth in hold	25 0	24 6	23 9	22 0	20 0	18 0	17 6	14 4	12 0
Draught of water abaft when light	17 6	17 4	17 0	15 8	14 6	12 6	11 3	9 6	8 4
Draught of water forward when light	14 0	13 8	12 0	10 10	11 1	8 7	8 6	8 5	8 0
Draught of water abaft when laden	25 0	24 8	22 6	21 6	19 9	16 0	15 4	13 3	11 6
Draught of water forward when laden	22 8	22 2	21 0	19 10	18 9	15 2	13 9	11 9	10 0
Total weight of the ship and stores when victualled and furnished for a six months' cruise	Tons. 5246	Tons. 4910	Tons. 3825	Tons. 3548½	Tons. 2300	Tons. 1479	Tons. 1162	Tons. 546	Tons. 266
Weight of the hull and masts	2500	2400	1804	1437	1120	665	583	266	141

George III. and George IV.

The ships of England continued throughout the wars of the reign of George III. inferior to those of France and Spain. The skill of our commanders, and the indomitable courage of our seamen, eventually succeeded in these, as in all former contests, in annihilating opposition, and in triumphantly asserting our naval supremacy. It cannot be denied that their task would have been comparatively easy, accompanied with less loss of life and expenditure of treasure, had their ships been more upon a par with those of their opponents. The French officers, however, after the war, to save their vanity, attributed our successes at sea to the superiority of our ships, and they commenced building after our models.

Reasons for the continued inferiority of British shipping.

Although so much attention appears to have been directed at various times to the improvement of the navy, not only by the servants of the crown officially connected with it, but by the sovereigns themselves, we have seen that an inferiority of our ships in sailing to those of our opponents has been repeatedly asserted on undoubted testimony. The reason that all the attention thus bestowed failed in producing a corresponding beneficial effect appears to have been that in England the speculative ideas of men, undoubtedly of sense and judgment, as may be seen from the quotations of their opinions which have been given, but men uninformed as to principles, were taken as the rules for guidance. In France, on the contrary, the aid of science was called in, and some of the greatest mathematicians of the time turned their attention to the improvement of the shipping of that country, and worked harmoniously with the naval officers who were to use the ships, as well as with the practical men who were to construct them, modifying their theories by the practice and experience of the others. Colbert employed an engineer of the name of Rénau d'Elisagary, a protégé of the Count de Vermandois, whose first essay was in the adaptation of ships to carry bombs, to be used in the then projected armament against the piratical states of the Mediterranean. Under the enlightened direction of Colbert, the French ships which, by the ordinance of 1688, were much restricted in dimensions, were increased nearly one-fourth in size, and every means taken which the then state of knowledge could suggest to insure a proportionate improvement in their qualities; while a corresponding increase in size was not made in English ships till the commencement of the energetic surveyorship of Sir William Symonds in 1830. Rénau was, we believe, the first French author who wrote on the theory of ships. He was followed by the Bernoullis, by Père La Hoste, by Bouguer, Euler, Don Jorje Juan, Romme, and a host of others, the effects of whose writings may be traced in the progress of the improvements introduced into the navies of France and Spain, and which the navy of England was forced to imitate. The only English treatise of that period on ship-building that can lay any claim to a scientific character was published by Mungo Murray in 1754; and he, though his conduct was irreproachable, lived and died a working shipwright in Deptford dock-yard.

Instance of ignorance.

A palpable instance of the ignorance or neglect of all the principles of naval architecture among the authorities who were charged with designing our royal navy, even up to the close of the last century, may be quoted from an article in the Papers on Naval Architecture, as given by Mr Wilson then of the Admiralty.

Razee of the Anson.

Mr Wilson, speaking of the cutting down of the Anson, a sixty-four-gun ship, to a frigate of thirty-eight guns, says, "she was cut down in the year 1794; and although in all other maritime states the science of naval construction was well understood, yet so culpably ignorant were the English constructors, that this operation, so well calculated, when properly conducted, to produce a good ship, was a complete failure. Seven feet of the upper part of the top sides, together with a deck and guns, making about 160 tons, were removed, by which her stability was greatly increased; but, by a complete absurdity, the sails were reduced one-sixth in area. In her first voyage the rolling was so excessive that she sprung several sets of top-masts. To mitigate this evil, in 1795, her masts and yards were increased to their original size; but as there were no decrease of ballast, she was still a very uneasy ship, and, as a necessary result, her wear and tear were excessive.

"Other sixty-fours were cut down, masted, and ballasted in exactly the same manner, and, it need scarcely be added, experienced similar misfortunes; and although they were improved by enlarging their masts and yards, they were still bad ships. Had their transformations been scientifically conducted, a class of frigates would have been continued in the navy, capable, from their size, of coping with the large American frigates; and thus the disasters we experienced in the late war, from the superior force of that nation, would, without doubt, have been not merely avoided, but turned into occurrences of a quite opposite character."

Improvements in naval architecture in this country.

The subject, however, of the improvement of ship-building was by no means lost sight of in this country at that period. The investigations and experiments which were made were, as usual in England in comparison with France and other continental nations, more of a practical than of a theoretical nature. Attwood's papers, read before the Royal Society in 1796 and 1798, form almost a solitary exception to this remark. In 1785, and subsequent years, Mr Miller of Dalswinton, in Dumfriesshire, made many experiments, expending as much as L.30,000 of his own private fortune for the advancement of naval architecture. In 1788 he was induced, by a Mr Taylor, to allow Symington, a working-engineer, to place a steam-engine on board a pleasure-boat on his lake at Dalswinton, for the purpose of propelling it by a paddle-wheel, and he thus became the originator of steam-navigation.[1]

Beaufoy's experiments.

In 1791, "a Society for the Improvement of Naval Architecture" was instituted, mainly by the exertions of Colonel Beaufoy. This society numbered amongst its members the then Duke of Clarence, afterwards William IV., and many noblemen and gentlemen of great influence. They conducted a most valuable series of experiments between 1793 and 1798, but a first report only of the results was ever published by the society. The funds at their disposal became exhausted, and the experiments were thus terminated, the interest of the public having flagged on account of the necessarily tedious nature of the proceedings. A detailed account of the whole of the experiments was subsequently published, in a most patriotic spirit, by Mr Henry Beaufoy, at his own private expense, and presented gratuitously to scientific societies and parties connected with naval architecture. Some valuable practical results were deduced from them, and these will be discussed hereafter, when treating of the resistances and other qualities of differently formed vessels.

Increase of merchant-shipping.

At the commencement of the present century the merchant-shipping of this country had increased to such an extent as to be of great importance. From the returns prepared by the Registrar-General of the Board of Trade, the total number of British merchant-vessels in the year 1801 was 19,711, with an aggregate registered tonnage of 2,038,253 tons, employing 149,766 men. In 1811 the total number of merchant-vessels was 24,106, with an aggregate registered tonnage of 2,474,784 tons, employing 162,547 men.

East India Company's shipping.

In the Honourable East India Company's service there were at this period 67 ships, each carrying 30 to 38 guns, 31 ships of 20 to 28 guns, and 52 ships of 10 to 19 guns, thus forming a powerful addition to the warlike resources of the country. Additional attention was also attracted to the subject of ship-building in the early part of this century by the institution of the Royal Yacht Club. It was joined by many influential and wealthy noblemen and gentlemen, and they gave much encouragement to the production of superior fast-sailing yachts.

School of Naval Architecture at Portsmouth.

Another important effort to improve the scientific knowledge of naval architecture, was the establishment, in 1811, of a school for naval architecture in Her Majesty's Dockyard at Portsmouth. This school was the result of the statements and recommendations contained in the report of a commission of naval revision, appointed in 1806, to examine into the management of the dockyards. The commissioners found that the practice of permitting the master shipwrights and their assistants to take private apprentices, receiving high fees with them, had been at that time disallowed and discontinued. By this system young men of superior early education, and of superior standing to the ordinary shipwright apprentices, had been trained in the higher branches of the profession, and their further scientific and theoretical education had been attended to, while at the same time they had acquired a knowledge of practical shipbuilding by being employed amongst the workmen. The commissioners therefore considered it expedient that some means should be adopted to supply the future demand for such men to fill those higher civil situations in which scientific knowledge is indispensable for the due performance of the duties. The school was accordingly instituted, but upon

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[1] *Sketch of the Origin and Progress of Steam Navigation*, Bennet Woodcroft, 1848.

History.

A.D. 1813.

so large a scale, and with so little consideration of the real requirements of the service, that in a very few years 42 students were educated there, while the whole number of places in the Admiralty service, requiring such education and training, did not exceed 25 or 26. The necessary result of this was, that they were put into inferior positions for which their previous standing and training had not adapted them, they failed in the duties of men required in these positions, and the school was considered to have been a failure. Much increase, however, of sound scientific knowledge resulted from the labours of the principal of the school, the late Dr Inman, though he confined his labours to too limited a sphere, and did not follow out the investigations of the French mathematicians. Many valuable papers on naval architecture have also been published by different members of the school, and the article Ship-building, in the previous edition of this work, and from which much of the present article is taken, was written by the late Mr Creuze, one of its most talented and distinguished members.

History.

A.D. 1832.

The following table, taken from the navy list of 1813, will show the force of the royal navy at that period, distinguishing the number of ships in each class:—

Extent and Disposition of the British Naval Force in 1813.

Stations.		Line.	50-44	Frigates.	Sloops and Yachts.	Bombs, Fire-ships.	Brigs.	Cutters.	Schooners, Gun-ves., Lug., &c.	Total.
Downs		4	0	1	4	0	20	5	6	40
North Sea and Baltic		12	2	8	5	3	50	11	9	100
English Channel and coast of France		15	0	16	15	0	23	7	13	89
Irish station		0	0	5	3	0	5	1	7	21
Jersey, Guernsey, &c		0	0	1	0	0	2	2	2	7
Spain, Portugal, and Gibraltar		15	0	11	6	2	14	4	1	53
Mediterranean and on passage		27	5	33	10	2	26	1	2	106
Coast of Africa		0	0	0	1	0	0	0	0	1
Halifax, Newfoundland, &c		9	2	23	13	0	23	1	6	77
West Indies	Leeward Islands	2	1	10	8	0	6	2	4	33
	Jamaica and on passage	5	1	11	7	0	8	0	0	32
South America		4	1	8	7	0	4	0	2	24
Cape of Good Hope and southward		1	0	3	3	0	2	0	0	9
East Indies and on passage		4	0	16	3	0	4	0	0	27
Total at sea		98	12	146	85	7	187	34	52	619
In port and fitting		24	9	24	21	0	25	9	9	121
Guard-ships		5	1	4	5	0	0	0	0	15
Hospital ships, prison ships, &c		32	1	3	2	0	0	0	0	38
Total in commission		159	23	177	111	7	212	43	61	793
Ordinary, and repairing for service		72	11	80	37	4	12	1	3	220
Building		28	4	25	9	0	7	0	0	73
Totals		259	38	282	157	11	231	44	64	1086

In 1832 the Navy Board was abolished, and it was determined to place the construction of ships under one head, continuing the name of surveyor of the navy, but altering the nature of the office by the appointment of a naval officer instead of a naval architect and ship-builder. Captain (afterwards Rear-Admiral Sir) William Symonds was the officer selected. He had early distinguished himself amongst his brother-officers by the attention he had paid to the sailing properties of boats and vessels. It was said of him that he could take any one of the boats in turn, of the vessel to which he was attached, and make her beat any of the others. His habit of observing the peculiarities of the different ships, whose properties he had an opportunity of witnessing, led him to draw certain conclusions respecting the forms of vessels; and, while holding a civil appointment in Malta, he built a yacht called the Nancy Dawson, in accordance with these preconceived views. The great speed of this yacht gained him notoriety, and procured for him the patronage and support of several influential and patriotic noblemen. Through their influence he obtained the sanction of the Board of Admiralty to build a corvette, the Columbine, and as this vessel was very favourably reported of, his character as a designer was proportionally raised. These successes led to his appointment as surveyor of the navy. It is not proposed here to discuss the propriety or otherwise of this office being filled by a naval officer, though in Sir William Symonds' case it led to important changes in the construction of the ships of the royal navy, and to much acrimony of feeling on the part of the shipwright officers of the service. One point is quite certain, that no man can be qualified to control the different forms of the various classes of ships, more especially of new classes that may be required in the navy, without long and careful study of the subject of naval architecture, both practically and theoretically. It is equally certain that a naval officer of experience is the most competent judge of the general proportions and qualities of the ships that will be most useful in the service, and that he is best able to point out the faults at sea of any ships that have been so tested.

Sir William Symonds was the first constructor of the English navy whose standing enabled him to claim the power legitimately due to his position, that he should be left unrestricted as to dimensions, and he was consequently enabled to introduce into the service ships which undoubtedly bore very high characters as men-of-war. He also practically demonstrated the possibility of ships of war obtaining sufficient stability without the aid of ballast—a very important advantage, and one which has been productive of much benefit. He was in error, however, as to the true principles on which the stability of floating bodies is dependent, in order to secure as great freedom from rolling and as great ease of motion as possible. His ships had great statical stability, and therefore great power of carrying sail, and hence were generally very successful in trials of speed in sailing. But this advantage was not obtained without, in many instances, incurring a compensating disadvantage from uneasiness of motion. This appears to have been a very general fault in ships of his construction, some of them being marked examples of the uneasiness attendant on a stability which depends almost wholly on breadth at the load-water section and above it, to the neglect of the form of the solids of immersion and emersion. His ships, however, were very general favourites in the service amongst the officers in command of them, who in their reports made light of any faults, and bore any personal inconvenience and want of comfort cheerfully and willingly, on account of the speed of their ships and their success in the sailing matches. The country is much indebted to Sir William Symonds for many improvements which he introduced into the navy, especially at the commencement of his tenure of office. He failed, however, to keep pace with the improvements of his time, his want of scientific education and of enlarged views rendering him unable to go beyond or apply to steamers, or any new class of vessels, the ideas which he had imbibed in his earlier years, and to which he adhered with a pertinacity amounting to obstinacy.

The following table contains the dimensions of the various classes of ships which Sir William Symonds introduced into the British navy, as well as of one or two other English ships built to compete with those of his construction. The dimensions according to which the ships of the French navy were at that time built are also given:—

Dimensions of English Ships of War at the period when Sir W. Symonds was Surveyor of the Navy.

	Names of Ships and of their Designers.	Guns.	Length of				Extreme Breadth.		Depth in Hold.		Burden in Tons.
			Gun-Deck.		Keel for Tonnage.						
			Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	
Designs of Sir William Symonds.	First Rate.										
	Queen	110 on 3 decks	204	0	166	5	60	0	23	9	3099
	Second Rate.										
	Vanguard	80 on 2 decks.	190	0	155	3	56	9	23	4	2589
	Third Rate.										
	Boscawen	70 on 2 decks.	180	0	146	8	54	0	22	4	2212
	Fourth Rate.										
	Vernon	50	176	0	144	6½	52	8½	17	1	2082
	Fifth Rate.										
	Pique	36	160	0	131	0	48	8	14	6	1622
	Sixth Rate.										
	Vestal	26	130	0	105	9	40	7½	10	6	913
	Carysfort	26	130	0	106	10	40	0	10	6	911
	Corvettes.										
	Rover	18	113	0	90	1¾	35	5	16	9	590
	Calypso	18	120	0	99	5½	37	6	18	0	731
	Brigs.										
	Columbine	16	105	0½	84	0	33	6¼	7	11	492
	Serpent	16	102	5	79	10	32	3	15	0	434
	Racer	16	100	8	78	9½	32	4¾	14	10	431
	Pantaloon	16	91	10	71	4	29	4	12	8	323
London	Sir Robert Seppings	92 on 2 decks.	205	6	170	4	54	4	23	2	2598
Castor		36	159	0	133	7	43	0	13	6	1283
Inconstant, Admiral Hayes		36	166	6	133	5¾	45	5	13	7	1422
Modeste, Admiral Hon. G. Elliot		18	120	0	98	7	32	9	7	11	562
Sapphire	Professor Inman	28	119	0	100	7½	33	8	8	0	605
Orestes		18	109	11	92	10½	30	6	7	6	459

Dimensions of French Ships of War, as built in 1837.

	Line-of-Battle.			Frigates.		Corvettes.	
Number of Guns	120	100	90	60	52	32	24
	Feet. Inch.	Feet. Inch.	Feet. Inch.	Feet. Inch.	Feet. Inch.	Feet. Inch.	Feet. Inch.
Length on gun-deck between rabbets	209 5	205 0½	198 6	178 1½	172 1	138 7½	125 4
Moulded breadth	55 3¾	54 11½	53 5¾	47 7	45 2½	36 0¼	32 7¼
Draught of water, forward	24 11¾	23 10¾	23 4	19 11½	...	14 9	13 6½
Draught of water, aft	26 8¾	26 0½	25 4	21 3½	...	16 3	14 10
Draught of water, mean	25 10¼	24 11½	24 4	20 7½	20 8	15 6	14 2¼
Load, displacement in tons	4940	4393	4013	2542	2267	999	738

The introduction of vessels propelled by steam for practical purposes dates its origin in the year 1812, when Henry Bell started the Comet steam-vessel on the Clyde, for the conveyance of passengers. In 1815 there were 10 steamers in existence, with an aggregate registered tonnage of 1633 tons. In 1825 this number had increased to 168, with an aggregate tonnage of 20,287 tons, and in 1835 the number was 538, with an aggregate tonnage of 80,520. Some interesting and valuable experiments were made about 1832, by Mr Scott Russell, on the Forth and Clyde Canal, with a view to introduce steam on canals. These were not successful in their object, but a class of very long and finely-formed boats for quick passenger traffic on canals were introduced at this time. These were drawn by two horses, and were expected to travel at the rate of 9 or 10 miles per hour, but it was found that if they were not at once put to this speed, but started sluggishly or gradually, a wave was formed in front of them, and continued to precede, washing over the banks of the canal and over the towing-path. Under these circumstances the horses were much distressed with the labour which they had to perform. If, on the other hand, they were urged into a speed of 9 or 10 miles an hour at once upon starting, no wave was formed, and the boat seemed to rise on the surface of the water and to be propelled with comparative ease so long as that speed was maintained; but if they flagged, and their rate of travelling fell to 6 or 7 miles an hour, the wave was formed, and it then became necessary to reduce their speed to a walk.

History. A.D. 1837.

till it disappeared, and then to start them again at once into the higher speed. This peculiar result was no doubt mainly caused by the confined space of the canal, but no scientific investigation to account for it has yet been given. The lines of these boats were called wave-lines by Mr Scott Russell, and for ease of propulsion in smooth water they are undoubtedly beneficial. Lines of a similar character were also used about the same time by Mr Fearnall in fast-passenger steamers on the Thames. Their advantage was made very apparent by the construction of the Vesper in 1837, a passenger-boat from London Bridge to Gravesend. This boat went through the water at a speed of about 12 miles an hour, with scarcely any wave or even a ripple at her bows, while her competitors were carrying a heavy wave and swell before them. Other vessels with lines of a similar character were built subsequently by Messrs Fletcher and Fearnall, by Mr Ditchburn, who had been in their employment, and also by others.

Up to 1836 the mercantile marine had laboured under the disadvantage of a tonnage law for the charging of dues, which, by the mode of measurement enacted, held out a premium for the construction of inferior ships. In this year a new act was passed, and a better system introduced. By this act the internal capacity of a ship became the measure of her tonnage, and the serious objections to the former law were obviated.

It was about this period that iron began to be used to any great extent as a material for ship-building. Its merits for this purpose will be discussed hereafter, when treating of the practical construction of ships. Mr Manby, Mr Laird of Liverpool, and Mr Fairbairn of Manchester, were the first constructors of vessels of any size of this material. Mr Fairbairn, in 1833 and 1834, built two passenger-steamers of iron to ply on the Humber, between Selby and Hull, and in 1836 he commenced the business of iron ship-building, in company with others, with the writer as the resident managing partner, at Millwall, on the Thames. In 1837 Mr Laird built an iron steam-vessel, the Rainbow, for the General Steam Navigation Company at Deptford, and from that time the use of iron has rapidly increased.

The next important step in the history of ship-building was the introduction of the screw-propeller. Many proposals had been made, and patents taken out, for propellers of this nature; but a small vessel fitted with a propeller, patented by Ericsson, was the first brought into practical use. A small experimental vessel called the F. B. Ogdon was built in 1837, and fitted by Ericsson with one of his propellers, and the Lords Commissioners of the Admiralty, attended by their surveyor, Sir William Symonds, took a trip in her in that year. They, however, failed to see the advantage of such an invention to men-of-war, and refused to entertain any proposal for its introduction into the navy. Mr F. P. Smith also built a small experimental vessel during this year, and fitted her with a screw propeller. Ericsson, on receiving no encouragement from the British government, took steps to bring his invention before the Americans, and a small vessel, the Robert F. Stockton, was built by him in 1838, in this country, with this view, and made the voyage safely to America. Mr Smith, in the meantime, induced a number of influential men to form a company to carry out his invention, and in 1839 the Archimedes was built by them, to test and demonstrate its value. The success of this vessel was such, and the advantages likely to accrue to men-of-war from the introduction of the screw were so apparent, that the Rattler was then ordered to be built in one of the government yards. This vessel was on the same lines as one of the Admiralty paddle-wheel steamers, but its stern was lengthened to fit it to receive the screw propeller. Her success was undeniable, but the progress of the screw in the navy was very slow for many years, owing to the opposition of Sir William Symonds, and to the frequent changes of the Board of Admiralty. Some progress, however, was made in the introduction of screw-ships into the navy, several small vessels being built to the designs of Mr Fincham, the master-shipwright of Portsmouth yard. This officer was in favour of its introduction, as were all the officers of the engineering department under the Board of Admiralty, and they were supported by the Right Hon. Mr Corry, the secretary of the Admiralty at that time. The Arrogant and Dauntless, two screw frigates, were afterwards built by Mr Fincham; and, at the same time, the Termagant, also a screw-frigate, was built by Mr White of Cowes.

History. A.D. 184

After this time, the growing dissatisfaction with the excessive rolling of Sir William Symonds' ships, his obstinate adherence to his own forms of construction, together with his unwillingness to co-operate in the introduction of screw-steam ships into the navy, led the Board of Admiralty, of that date, to order that a committee of reference should be constituted, to whom all designs for ships should be submitted before they were laid down. This led to Sir William Symonds resigning his office, and Sir Baldwin Walker, the present surveyor, was appointed as his successor.

Sir Baldwin Walker had not given his attention to the study of naval architecture theoretically, and the Board of Admiralty announced that they should not expect him to originate the lines of the vessels to be built, but that these should be designed by naval architects attached to his office. The construction of the ships of the royal navy was thus placed on a proper footing; and if this arrangement had been carried out, and the naval architects had had full power given to them, and been at the same time competent men, the country ought to have reaped the benefit of so judicious an arrangement.

With respect to the class of ships ordered to be built at this period in the dockyards, no change in accordance with the advancing state of screw propulsion took place. The naval members of the Board of Admiralty were men who had long looked upon the noble line of battle-ships of the navy as not to be surpassed, and they could not apparently make up their minds to desecrate them, as they seemed to consider it, by the introduction of steam-power. The result of this somewhat romantic feeling was, that early in Sir Baldwin Walker's administration a number of sailing three-deckers were laid down, in opposition to the expressed opinion of the leading civil professional officers attached to the Admiralty. Not one of these vessels has been launched, or will be launched, as a sailing vessel. They have all been converted, or are under conversion, into screw-ships, by being lengthened in midships, at the bows and also at the sterns. The greater proportion of the other sailing three-deckers are also being razéed and converted into two-decked screw-ships, their sterns only being altered. These important changes on the last-mentioned vessels are being carried out, while two of the members of the late School of Naval Architecture are the assistant surveyors; and a repetition of the errors committed at the end of the last century, on the occasion of a similar operation upon several ships, will no doubt be avoided. The errors committed at that time have been described by Mr Wilson, as previously quoted, and are ascribed by him to a want of sufficient scientific knowledge; but as this is not the case at the present time, the country may now expect a very fine class of vessels to be the result.

It may also be remarked, that the introduction of the system of distilling the necessary supply of fresh-water on board the ships, and thus obviating the necessity of carrying so great a weight of fresh-water, has materially facilitated the arrangements for these alterations.

Table of the British Navy, extracted from the Navy List, October 1859.

Class.	Propelling power.	Guns.	In commission.	In ordinary, and repairing for service.	Harbour vessels, hulks, &c.	Building.	Totals.
Three-decked ships,	Screw	110 to 131	2	4	...	2	8
Do. do.	Sails	110 to 120	9	1	1	...	11
Two-decked ships...	Screw	60 to 100	34	12	...	10	56
Do. do. ...	Sails	72 to 84	12	23	...	...	35
Frigates................	Screw	36 to 50	19	18	...	5	42
Do.	Sails	40 to 50	12	70	...	...	82
Corvettes and sloops	Screw	4 to 21	29	11	...	10	50
Do. do. ...	Sails	14 to 26	20	45	...	...	65
Frigates and sloops,	Paddle	3 to 22	46	18	...	...	64
Transports	Screw	...	7	3	...	...	10
Despatch vessels ...	Screw	2 to 4	16	4	...	2	22
Gun & other vessels	Screw	2 to 4	8	3	...	1	12
Yachts, tugs, &c.	Paddle	...	37	16	...	...	53
Do., and other vessels..........	Sails	...	12	17	...	...	29
Floating batteries...	Screw	16	...	8	...	...	8
Total	...	...	...	...	...	...	547
Gun-boats	Screw	2	...	...	...	...	160
Frigates, iron-cased, not yet in Navy-list—building............	...	...	...	...	...	...	4
Grand total ...	...	...	...	...	...	...	711

By a Parliamentary return published during 1859, it appears that the total number of ships of all classes belonging to the navies of other kingdoms was then as follows:—

France	448	Holland	139	Prussia	55
Russia	164	Belgium	7	Greece	26
Sweden—principally small vessels	311	Spain	82	Turkey	49
		The Two Sicilies	121	Brazil	27
Norway	143	Austria	135	Peru	15
Denmark	120	Portugal	37	Chili	5
United States	79	Sardinia	28	Mexico	9

The history of ship-building in the royal navy up to the present time (1860), cannot be closed without reference to the class of small gun-boats and of iron-cased floating batteries and vessels which are now being introduced into the service. The gun-boats are of three classes, varying slightly in size and horse-power. The greater proportion of them are 106 ft. long between the perpendiculars, 22 ft. beam and 8 ft. deep, and are fitted with high-pressure engines of sixty horse-power. They are of 233 tons burden, and their draught of water, when ready for sea, is about 6 ft. The importance of this class of vessels as a protection against invasion cannot be overrated. The introduction of steam as a mechanical agent for the propulsion of vessels, independent of wind and tide, brings back almost the same state of things as existed when hostile fleets were composed of rowing galleys. The supremacy on the ocean which this country has so long held by means of the experience of a large portion of her population as seamen, must now depend on other sources of strength besides this; and it behoves the nation to make preparations suitable to meet the altered circumstances. If our fleet were to suffer any reverse, and thus leave the sea free to an enemy; or if an enemy came to a determination to try and evade our fleet, and land an army on our shores, that army might be embarked at many different points, and, with steam as an agent, the different portions of it might, with almost perfect certainty, meet at any appointed time at any spot. When once upon our coasts, they could move along them with a rapidity far beyond that at which any troops on shore could follow them, if they were confined to the ordinary means of transport. If, however, our shores were iron-bound by coast lines of railroads, so that troops could be moved along them and concentrated rapidly at any spot, with the assistance of the electric telegraph our power of resisting the landing of any foreign force would be immeasurably increased. The art of war has been said by the highest authorities to lie mainly in the power of suddenly concentrating men on any one point; and if our railroads and telegraphic communications can be made available for this purpose, the importance of keeping up a large and effective force of steam gun-boats, lying, in the time of an expected invasion, in every bay and creek of our indented shores, is evident. For the construction of a fleet of such vessels, iron is fortunately the most valuable material, as the evils attending its use in large men-of-war will not militate against its use in these vessels. If they should be struck by shot, the men will be above the splinters; and by building them with their frames very far apart, and with a strong inner and outer sheathing, both water-tight on every frame, they may be made almost unsinkable. The chief advantage, however, of iron for such vessels is its durability, if they are constructed in such a manner, that all the parts may be kept painted, and care be then taken that they be periodically cleaned and painted. Iron vessels so constructed and hauled up on shore, and thus attended to, might be considered as almost free from decay.

The applicability for purposes of war of iron vessels constructed in the ordinary way early engaged the attention of the writer; and in 1845, in concert with the late Major-General, then Colonel Dundas, of the Royal Artillery, one of the officers of the arsenal at Woolwich, he arranged some experiments to test the effects of shot on such vessels. So little importance, however, was at that time attached to the subject by the authorities, that at first no official notice was taken by the Admiralty of these experiments, the targets, representing a portion of the side of an iron vessel, being constructed in the dockyard at Woolwich under merely verbal sanction from the Captain Superintendent of that yard. By these experiments it was at once shown that iron plates of half an inch or five-eighths of an inch thick were easily penetrated by solid 32-pounder shot; that the hole made was no greater than the size of the shot; and that the injury was merely local, and easily repairable. These experiments also proved that the shot, in striking plates of this thickness, was frequently, though not invariably, broken, and that the portion of plate taken out by the shot was broken into a number of small and most dangerous splinters. Targets made of plates of the best Low Moor iron were tried in comparison with targets made of common boiler plate; but the difference of the quality of these two kinds of iron made no difference whatever in the splintering or in the general effect.

To guard against the risk of a ship being sunk by the clean hole thus shown to be made through the iron by a shot, the parasol shot-plug was introduced at this time by the military officers. This plug is composed of thrummed sail-cloth, or of India-rubber cloth, in the form of an umbrella or parasol with a long handle, and is intended to be pushed out through the shot-hole, and then opened and drawn back on the hole, so as to cover it, and prevent the entrance of water.

Layers of timber, varying in thickness from 3 and 4 inches up to 15 and 18 inches, placed behind the iron, were then tried, with a view of collecting and stopping the splinters. It was found that this was not effected with less than about 14 inches of thickness. Wadding and packings of various kinds were tried, with an inner sheathing of plate on the ribs to sustain it, but no beneficial result was found to be obtained from any course of this kind. A layer of a mixture of saw-dust and Indian rubber was subsequently tried, and this was found to answer well, but it required to be of nearly as great thickness as the solid wood.

An experiment was also made with a target placed at an angle with the line of fire; but the thickness of plate of which these targets were composed was found not to be sufficient to make a 32-pounder shot glance when fired from a distance of 200 yards with the ordinary charge for short ranges. The shot struck between two ribs, and kept its course, making a long slot, or elongated hole.

To test the effects of a spent shot, a shot was merely pitched against the target from a gun brought within a short range, and fired with the smallest possible quantity of gunpowder. The shot was not broken, and it went through the target, making, as in other cases, a hole no larger than itself; but the edges of the plate round the periphery of the hole were bent backwards with ragged radiating points.

History.

A.D. 1860.

History.

A.D. 18

The inside of the target was also fired at, to represent the effect of a shot passing through a ship, and striking the off side; the effect was the same as before, except that the rivets within a circle of about 2 feet to 3 feet radius, which attached the plates to the ribs, were shaken, and the heads of some of them were broken off.

In 1845 and 1846, the Admiralty of the day, with a view of testing the efficiency of iron for men-of-war, after having had the Dover packet, built of iron, for some years in their service, and subsequently the Birkenhead iron paddle-wheel steamer, ordered the Minx, two guns and of 303 tons, and Sharpshooter, eight guns, and of 503 tons, and several frigates, to be built of iron. Of these latter, the Simoom, of 1980 tons, built by Mr Robert Napier of Glasgow, is always quoted as the type. The Ministry of the country, however, having changed, and with it the Board of Admiralty, before the completion of these frigates, they were ordered to be converted into troop-ships, and the views of their original proposers unfortunately were not carried out with them, nor, still more unfortunately, with the smaller class of vessels. If the foresight of Sir George Cockburn and Sir Charles Adam, and those associated with them at this time at the Admiralty, in attempting the construction of vessels of these small classes, had been followed up, the country would not have been without them at the beginning of the Russian war, when they were so much wanted, and when a fleet of them had to be constructed, without experience as to the best form and size, in great haste, and with much loss both of money and of credit to the country.

The experiments at Woolwich in 1845 having shown the necessity of guarding against splinters, the sides of the iron frigates, between the main and upper deck, opposite where the men fighting the guns would be chiefly collected in the time of action, were ordered to be lined with wood, whilst the other portions were intended to be left unprotected, as splinters from them would be of less importance. This, however, did not satisfy the new Board of Admiralty; and with the view of confirming the correctness of their decision in ordering these frigates to be converted into troop-ships, a further set of experiments were ordered to be made in 1848 from the Excellent at Portsmouth, by firing against targets made to represent portions of the Simoom. These experiments corroborated all the results previously obtained by those at Woolwich Arsenal, and seem to have further proved an important fact, which did not then suggest itself, and was not tested, that plates of 5-8ths inch thick prevented any shells then known from passing through and exploding inside the ship. This fact, however, was not made known to the House of Commons or to the public generally, and the tide of public opinion was thus strongly directed against the use of iron ships for purposes of war by the amount of information on the subject officially promulgated.

Some years previous to 1848, other experiments against iron had been tried, with a totally different object in view, but from which results of much importance to ships of war have followed. These experiments were made at Portsmouth against a target composed of fourteen thicknesses of half-inch boiler plates, bolted together so as to form a mass 7 inches thick. This was found practically to be sufficient to stop 32-pounder shot. A much more important and elaborate series of experiments on this subject were made about this time in America; and from these it was found that a thickness of 6-inch solid hammered iron was practically invulnerable against the power of any ordnance then in use.

After these experiments, Napoleon III., who has paid great attention to the subject of artillery, conceived the idea of encasing a ship in thick plates of iron, as in armour, to resist shot. In 1853, this idea seems to have been publicly broached by him; and in 1854, the governments of England and France both constructed vessels on this principle, to be brought into action against Russia. They were called floating batteries, as they are mere barges, built for the purpose of carrying their guns and their armour-plates, with a small amount of steam-power sufficient to give them the power of motion, so as to put themselves into position after having been towed to the field of action. They vary from 1535 to 1954 tons burthen, and carry 14 to 16 of the heaviest guns, and their draught of water does not exceed 9 feet, so as to enable them to approach the forts against which they were intended to act.

Those built in France having been completed at an earlier date than those built in England, one of the French batteries was brought into action against the Russian fort of Kinburn, and with the most complete success. After this, the French immediately set about carrying out the idea to a greater extent, and in more perfect ships. In England, also, the subject was pressed upon the consideration of the Admiralty; and in 1857, the late Captain Moorsom[1] published a pamphlet upon it, finding himself unable in any other way to obtain attention to the views which he held, and to rouse the Admiralty to the importance of the matter under discussion. In it he advocated and proved the feasibility of taking the two upper decks or tiers of guns off the three-decked ships of the fleet, and converting them into iron-cased frigates, by protecting the remaining lower deck with a covering of iron plates, 4 inches thick. He failed, however, in being able to influence the Board of Admiralty, or the Controller of the Navy; and it was not till the close of the year 1858, and the beginning of 1859, that four iron-cased vessels were ordered to be constructed in this country.

The French, in the meantime, had been more energetic, and the result was, that in 1860 of iron-cased vessels they had launched two first-rates, and had also on the stocks four second-rates, four third-rates, and five gun-boats, all to be cased with iron plates, and all well advanced. It has also been said, that orders have been given by the same Government to proceed with the construction of ten more first-rates, on the model of La Gloire, one of those already completed and tried, and found to be successful both in speed and in sea-going qualities.

In England, at the same date, the two first-rates of this class of vessel are both launched, the Warrior and the Black Prince; but they are not yet completed nor ready to be tried. The two second-rates are not yet launched, and no vessels of a lower class have as yet been designed or ordered to be built. A third first-rate is ordered to be built in the dockyard at Chatham, but has not yet been commenced.

La Gloire, the French iron-cased first-class frigate, is built of wood, and is said to have been designed upon the model of one of their most successful line-of-battle ships, acting upon the views advocated by the late Captain Moorsom, in his pamphlet of 1857. She is 252 feet 6 inches long between the perpendiculars, and 55 feet beam, draws upwards of 27 feet of water, and is said to have obtained a speed of 11½ knots under steam. She carries her ports about 6 feet 6 inches out of water, and her armament at present is said to consist of thirty-four rifled guns, 54-pounders, and two shell guns forward, all protected, as will be seen by the annexed sketch of her. She is built with an upright or rather receding stem, prepared for running down an opponent. Mr Cunningham, from whose

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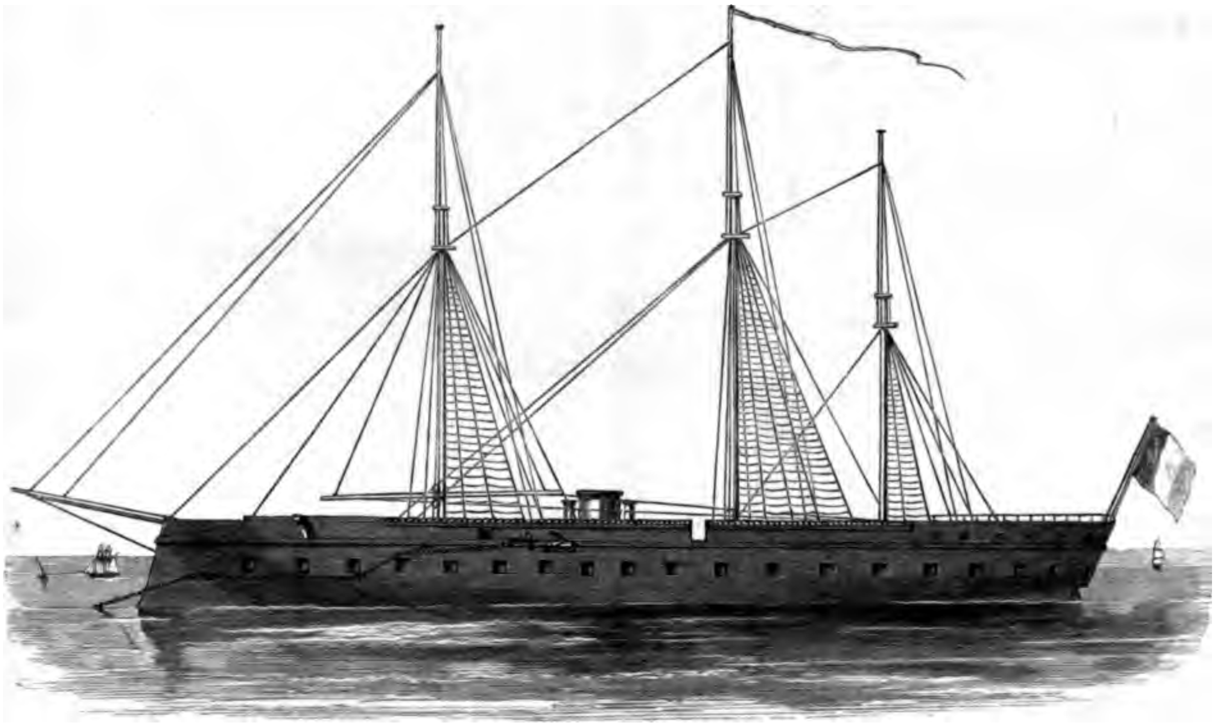
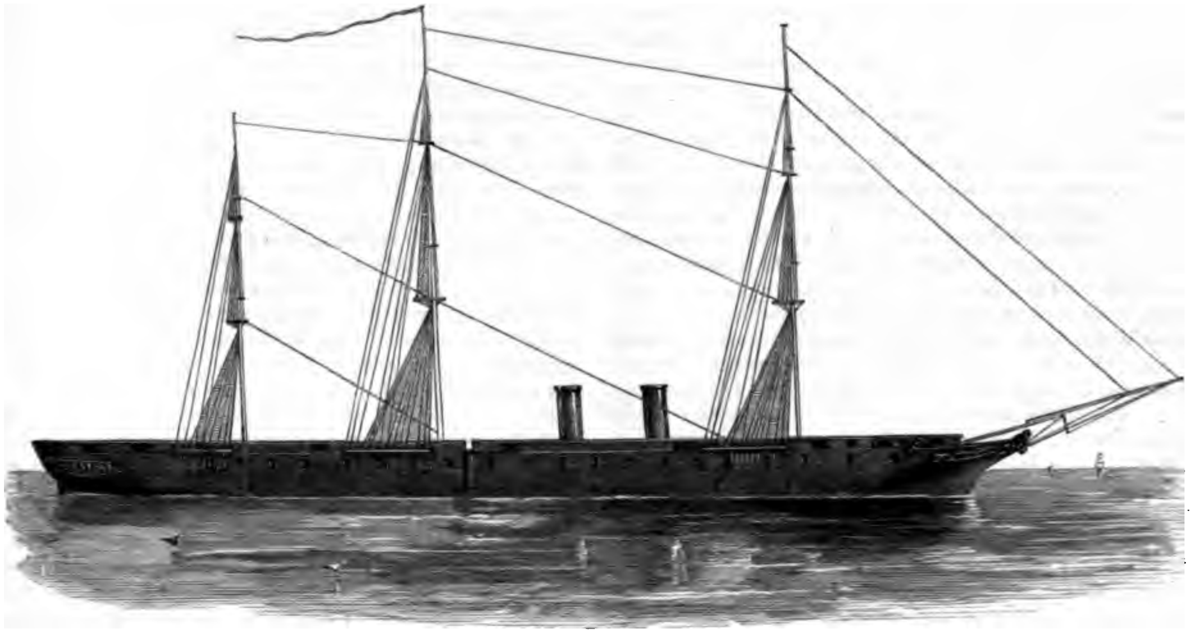
[1] Inventor of the percussion-shell now in use in H. M. service, and who served in command of the Naval Brigade at the siege of Sevastopol, and in whom the country lost a most valuable artillerist.

hand-sketch of her on the spot, the annexed wood-cut is made, states that he was informed that her upper deck is bomb-proof; and he was also led to believe that there is a battery on deck prepared to enfilade the deck in case of her being boarded, though how this is to be done, if the boarders are to be opposed by the crew in a hand to hand fight, without the destruction of defenders as well as assailants, is not apparent. From the sketch it will be observed that the foremast is very far aft, and that the mizenmast is very far forward. The position of these masts, therefore, will tend to ease the ship very much in pitching and scending; and the moderate height of the masts, and their simple rig, will tend to ease her rolling. The rigging is carried very far aft, probably for the purpose of supporting the masts, in the event of the ship running stem on against an opponent, and having her way stopped.

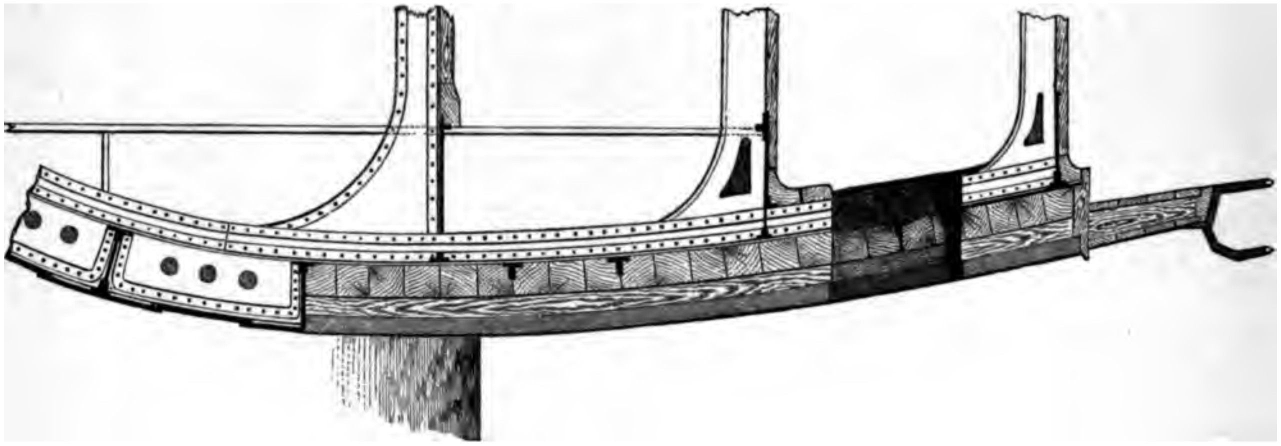


La Gloire.



The Warrior.

The Warrior and the Black Prince, the English iron-cased first-class frigates, are built of iron. They are 380 feet long between the perpendiculars, and about 420 feet long over all, 58 feet beam and 41½ feet deep from the spar deck, and of 6173 tons burden. The armour-plates with which they are sheathed are 4½ inches thick. They are not laid directly on the iron sheathing of the ship, but teak, 18 inches thick, is interposed between them and the sheathing, with a view of supporting the armour-plates by a little elasticity behind them, and also to prevent the joints of the sheathing from being started by the concussion when the plates are struck by shot. The construction will be understood by the annexed section of the Black Prince, and by the explanation of the mode of constructing iron ships, as given in the portion of this article devoted to practical shipbuilding. The engines of those frigates are of 1250 nominal horse-power, and they are expected to realise a speed of 13½ or 14 knots an hour.



Section of Black Prince.

Section of Black Prince.

It is not proposed here to enter upon the question of the relative value of the system of interposing a mass of timber between the armour-plates and the sheathing of the ship, compared with making the armour-plates themselves thicker; but it may be remarked, that the introduction of this element of decay is much to be deprecated, if it could possibly be avoided; and the fact, that the resistance of iron plates is increased in proportion to the squares of their depths, seems to indicate that increasing the thickness would be the better course to pursue. On a ship clothed as the Warrior, armour-plates of 6 inches thick could thus be used without any increase of weight, and their resistance, compared with that of a 4½-inch plate, would be nearly double; and it does not appear to have been yet proved that any evil effects would follow from the adoption of such a course.

The Warrior and Black Prince are constructed to carry 40 guns, 34 on the main deck, all 68-pounders, and on the upper deck 2 pivot guns, 68-pounders, and 4 Armstrong guns. The ports are intended to be about 9 feet above the water when the ship is ready for sea, with everything on board. The thick armour-plating of these ships does not extend for the whole length from stem to stern, but for a length of about 213 feet in the middle, and for a height of 22 feet vertically, 16 feet above the water-line, and 6 feet below it; 26 guns are protected by this extent of armour. Near where the armour-plating ceases, and a short distance within it, water-tight bulkheads, protected by similar armour-plates, are carried across the ship. The finely formed portions of the bow and the stern are constructed in the same manner as those of any strongly-built iron vessel, as explained hereafter, when treating of practical building. They are divided into a great number of water-tight compartments, the bulkheads or divisions running both fore and aft and athwartships. On a minute examination of all the details, it is believed that great credit will be found to be due to the designers for the way in which the safety of the ship, and all the varied requirements of a man-of-war, have been provided for, and also for the way in which the many contingencies to which such ships are subject have been provided against. It is quite evident that every one, conversant with the subject of naval architecture, and the various contending influences that have to be met, who will examine into the details of the Warrior or the Black Prince, must be satisfied that great thought and consideration have been given to the subject, and that, on the whole, the conclusions arrived at have been judicious. Though it is not apparent in the same way from the sketch, these vessels are equally able with La Gloire to run down an opponent, if a desirable opportunity to do so should present itself. It is argued by some, that the English ships are too long, and that they will therefore take too long a time, and too much room to turn, to be able to run down any vessel that sees their intention beforehand; but the difference between them and La Gloire in this respect is not so great; and any one who has ever been present at a boat regatta, and has seen a duck or punt hunt, will know well, that a sharp and fast man-of-war's gig, be it a little longer or a little shorter, is not the class of boat that will catch the duck; and no more would La Gloire, under similar circumstances, get a chance of running down our gun-boats, if we were to surround her with the number that might be built for the sum of money that such a vessel as she is must cost. Frigates, corvettes, and gun-boats, might be constructed at very moderate cost, of plates sufficiently thick to make them safe against all known shell, and therefore against fire; and with sufficient divisions to make them almost unsinkable by any number of solid shot likely to strike them; and they might be armed with guns, or rifled mortars, or carronades of extraordinary calibre, with both guns and crew safe under Captain Coles's shields, as hereafter explained. Gun-boats so constructed and so armed would be serious opponents to these huge mail-clad ships. They could also be supplied with buoys carrying pieces of rope or chain, prepared to foul the screw propeller of their great opponent, and which, if thus deprived of her speed, would be very much at their mercy.

The stems of the Warrior and Black Prince below water project forward beyond the line of the knee of the head, which forms an exterior or false stem beyond the real stem, which latter rises up perpendicularly in the interior, and is supported by a fore-and-aft bulkhead. It is thus that they are equally prepared with La Gloire to run stem on into an adversary. It is not to be supposed, that in the event of a general close action of two fleets, such vessels would "*run a muck*" into the enemy's fleet, armed, as of course every vessel would be, with at least one or more guns, capable of injuring them in their vulnerable points, which would no doubt be known; and if the fleets once came to close action, and the ships were without way, all chance of running each other down would for the time be at an end. It is not the legitimate purpose of this article to discuss naval tactics, but these few remarks will perhaps be pardoned, as bearing upon the question so important at this time, as to what class of vessel it is most judicious for this country to build, in addition to a sufficient number of mail-clad ships, to meet the extraordinary, and (as at least one high authority[1] thinks) perhaps the passing circumstance of the construction of a certain number of ships of this class by the present Emperor of the French.

The general importance of the whole subject of naval warfare is at present much felt throughout the country, and the improvement and efficiency of the navy, as its best defence, have in consequence been much discussed both by civilians and professional men. The opinions of the late Earl of Dundonald on this point must carry great weight; and in his memoirs, lately published, the following important passage will be found. "In short, immoveable stations of defence, as a protection against invasion, are not only costly and of doubtful utility, but a reliance on them is, in my mind, an indication of a declining state. It is little short of national imbecility to suppose that, because we erect imposing fortifications, an enemy will come to them, when he can operate elsewhere without the slightest regard to them, and the more so, as the common experience of warfare will tell him that numerous fortifications are in the highest degree national weakness, by splitting into detail the army which ought to be in the field against him, but who are compelled to remain and take care of their fortifications. Yet half the sum required for fortifications as defences in case of war would suffice to place the navy in a condition of affording far more effectual protection. There is no security equal to that which may be obtained by putting it out of the power of an enemy to execute hostile intentions. This can never be effected by forts, but may be accomplished by adoption of proper measures, which I shall at present refrain from commenting on."

In consequence, therefore, of the general interest felt upon this subject, proposals of various kinds have been made, with a view to make our ships less vulnerable than they now are, and thus to make them more formidable against any opponents. Amongst these the proposal of Captain Cowper Phipps Coles seems to deserve especial notice. He places two guns side by side, under a dome-shaped shield, constructed of wrought iron of such thickness as to be invulnerable. The muzzles only of the guns are visible on the outside, arrangements for their training and for their elevation or depression being made in the interior, and they are placed with their covering shield on a revolving platform, moved by machinery, so that they can be pointed in any direction. He has by models and explanations very clearly demonstrated the feasibility of his proposal, and the practicability of the mode he has invented for carrying it out, but at the same time it is necessary that the ship which carries his invulnerable shield should be herself as far invulnerable as possible.

An important proposal has also been made by Mr Jones of Liverpool, to build iron-cased frigates with their sides inclined inwards at an angle of about 52° from the vertical line, with a view to making the shot glance, by which a less thickness of iron plating might be sufficient. Though the target provided by him was perhaps more successful in resisting shot than any other experimented upon by the Excellent at Portsmouth, there yet appears to be many objections to the introduction of his system. The first and most obvious is the greater amount of surface on the incline required to protect the same amount of vertical space on a ship's side against the usual horizontal firing; and to such an extent is this the case, that a coating of iron on the angular or inclined system, of $3\frac{1}{2}$ inches thick, at an angle of 52°, will weigh as much as a vertical coating of $5\frac{3}{4}$ inches thick. Considerable inconvenience in the working of the guns will also arise from the angle of the side; and the rolling of the ship will tend, at certain periods of each oscillation, to lessen the angle of inclination, and therefore diminish its power to make the shot glance. Captain Coles has proposed to adopt this principle in the construction of the ships to carry his invulnerable shields. He places his shields on the upper deck, and carries up an upright side on his ship outside the angular plated side, and by this he obviates the objections to the form of the ship proposed by Mr Jones, as being likely to produce uneasy rolling.

On the whole, it is believed that an increased thickness of armour plates, with the ports for the guns protected, or their size diminished to the greatest possible amount, on a ship of the best known form for insuring steadiness and speed, will be found the simplest mode of increasing its invulnerability to any practicable degree.

It will now be necessary to return to the mercantile marine, and notice shortly the progress made therein within the last few years, leaving this part of the subject, however, to be more largely treated of under the head of Steam-Ships.

Extract from Return of British Merchant-Shipping by the Registrar-General of the Board of Trade.

Year.	Number and Tonnage of New Vessels Built and Registered in the British Empire in each Year.				Total Number of Registered Merchant-Vessels belonging to the British Empire in each Year.						Men.
	Sailing Vessels.		Steamers.		Sailing Vessels.		Steamers.		Total.		
	Number.	Tons.	Number.	Tons.	Number.	Tons.	Number.	Tons.	Number.	Tons.	
1840	1904	285,289	77	10,639	28,138	3,215,731	824	95,807	28,962	3,311,538	201,340
1845	1183	154,783	73	11,950	30,805	3,582,859	1012	131,202	31,817	3,714,061	224,900
1850	1381	229,603	81	15,527	32,938	4,045,331	1350	187,631	34,288	4,232,962	239,283
1855	1319	305,113	263	84,862	33,782	4,842,263	1910	408,290	35,692	5,250,553	261,194

In the merchant-service, the screw, for some time after the trials of the Archimedes and the Rattler, though they were generally looked upon as prognosticating success, made but little progress. A company trading to Rotterdam, Messrs Laming and Company, were amongst the first to adopt it; and the mercantile marine owes much to their enterprising spirit in this respect. Their vessels were very successful, and attracted much attention from the time of their first introduction; and doubtless much of their immediate success may be attributed to men of high stand-

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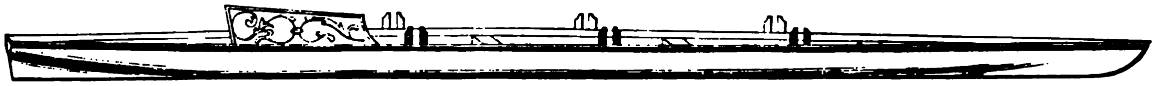
[1] Sir Howard Douglas has expressed this opinion in a letter addressed to the Institution of Naval Architects, and in which the writer is inclined to agree with him though differing from him in his opinion in favour of wooden ships.

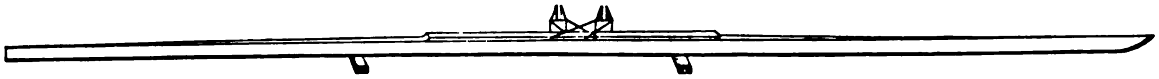
ing in their respective professions of ship-builders and engineers being employed in their construction, and being left unfettered to work out the end that was desired. From that time screw-vessels, constructed of iron, began rapidly to supersede paddle-wheel steamers and sailing vessels, especially for the conveyance of perishable merchandize, such as fruit and provisions; and the great capability of combining sailing and steaming which the screw affords, will no doubt tend to the continued increase of auxiliary steamers. The preceding table of the merchant-shipping of the country shows the extent to which the substitution of steamers for sailing vessels is taking place.

Reference has been previously made to the beneficial influence of the yacht clubs throughout the country. The English yachts were supposed to be unrivalled in speed; and in 1851 a challenge cup was given, open to the whole world for competition. A yacht from America, however, came over to this country, and carried off the prize. She soon showed such great superiority that the favourite English yachts at once gave up the contest, and it appeared likely that she would be allowed to walk over the course. To prevent this the late Mr Robert Stephenson entered his yacht, the Titania, built by Mr Scott Russell, to compete with her, and thus give her an opportunity of showing the extent of her superiority, and on what points that superiority was greatest. Representations of these two yachts are given in Plates V^{A}. & VI., and their relative performances and qualities will be examined hereafter. Though the introduction of steam has done much to lessen the interest taken in yachting, yet it is to be hoped that the valuable encouragement given to naval architects, and to the maritime predilections of the country by yachting clubs will be continued, and that many will follow the example already set by a few spirited men, of placing a small amount of auxiliary steam-power in their yachts with screw-propellers. This is done without impairing their beauty, and renders them certain in their movements when desired.

In connection with this subject, and as a means of forming a taste for it, the rowing and racing boats of the youths at public schools, and of the young men at the universities and elsewhere, may be mentioned. The following may be taken as the average performances of such boats at the present day. The drawings and the dimensions are from boats built by Messrs Searle and Sons of Lambeth, London:—



RANDAN GIG, 28 Feet Long.
A Pleasure Boat for three Pairs of Sculls; or for a Pair of Sculls in the middle, and with a single Oar or Scull forward and aft in addition when desired.



A SCULLING OUTRIGGER, 30 Feet Long.
New Style for Racing in Smooth Water.

EIGHT-OARED OUTRIGGER, 60 Feet Long.
New Style for Racing in Smooth Water.

EIGHT-OARED CUTTER, 60 Feet Long.
The Old Style of Racing Boat, or for Water for which the Outrigger is considered of too slight a Build.

Description of Boat.	Length.	Breadth.	Depth.	Weight.	Maximum speed per hour in still water.
OUTRIGGER RACING BOATS—	Feet.	Ft. In. Ft. In.		lb.	Miles.
Outrigger sculling boat	32	0 10 to 1 2	8½ in.	30 to 40	6
„ pair-oared	34	1 3 to 1 6	9 to 11 in.	45 to 55	6½ to 7
„ four-oared	42 to 45	1 10 to 2 3	1 foot.	100 to 112	8½ to 9
„ six-oared	50 to 54	2 0 to 2 4	1 „	150 to 190	9 to 9½
„ eight-oared	57 to 65	2 2 to 2 4	1 „	280 to 330	9½ to 10
RACING BOATS OF THE OLD STYLE—			Ft. In. Ft. In.		
Sculling boat	30	3 4 to 3 6	1 0 to 1 2	55 to 60	5½
Randan wherry	32	3 4 to 3 6	1 0 to 1 3	100 to 140	6
Four-oared cutter	40 to 42	3 6 to 3 8	1 1 to 1 3	224 to 280	7½ to 8
Six-oared cutter	45 to 50	3 6 to 3 8	1 1 to 1 3	336 to 376	8
Eight-oared cutter	54 to 58	3 6 to 3 8	1 1 to 1 3	520 to 600	8½ to 9
THE LIGHTER KIND OF PLEASURE BOATS—					
Pair-oared gig	23 to 25	3 6 to 3 8	1 foot 4 in.	180 to 200	4 to 4½
Randan gig	27 to 30	3 6 to 3 8	1 „ 4 „	200 to 224	5
Four-oared gig	40 to 42	3 4 to 3 6	1 „ 3 „	250 to 300	6½ to 7
Six-oared gig	55 to 48	3 4 to 3 6	1 „ 3 „	350 to 400	7
Eight-oared gig	54 to 58	3 2 to 3 4	1 „ 2 „	560 to 620	7½

To pass from these diminutive but beautiful specimens of naval architecture, the last great work which requires to be noticed in this brief outline of the history of the rise and progress of ship-building is the construction of the Great Eastern, Plate VIII. The dimensions of this vessel, as given on the plate, are so far beyond those of ordinary vessels, that it is necessary to draw particular attention to them. At the period of writing this article she has not been to sea except for one or two trial trips. Her performances will be discussed hereafter, but the results predicted by science as to her speed, with a given amount of steam-power, appear to have been realized. How far mercantile enterprise will be benefited by the construction of vessels of her magnitude remains to be proved.

Calculations incidental to designing a Ship.

DESCRIPTION OF THE MANNER OF PERFORMING THE CALCULATIONS INCIDENTAL TO DESIGNING A SHIP, WITH INVESTIGATIONS OF SOME OF THE PRINCIPAL ELEMENTS OF THE DESIGN.

Theory.

The labours of the numerous men of science who have devoted either the whole or a portion of their attention to the various problems embraced in the theory of ships, have left but few of its abstract principles uninvestigated; most of the proportions of a ship have been examined, and the laws on which they depend clearly defined, either by the aid of mathematical demonstration, or by experimental induction. There are, however, some questions which, though sound in theory, still depend on the results of physical experiments for perfecting their practical application.

Many of the elements of naval construction are dependent on the known laws of nature; and it may now be said that the principal difficulties of these are surmounted, and are familiar to the instructed naval architect. These are of themselves sufficient to insure the attainment of a certain and considerable degree of excellency in a ship, to give it a preponderance of any given quality, to discover the causes of any bad quality, and to point out the means of providing a remedy for the faults discovered.

The forces which act upon a ship in motion, in a fluid, even though the fluid be at rest, are as yet but imperfectly defined by mathematicians; and the elements of naval construction dependent on the laws regulating them are, therefore, less known and less certain in their application. The form of a ship's body need not, however, remain imperfect, because the curve of the solid of least resistance is uncertain, since enough has resulted from the consideration of the nature of that solid to prove its inapplicability to vessels in general; and theoretic perfection of the science in this particular would, therefore, be of no practical utility.

A very unphilosophic mode of reasoning is frequently applied to the question of the application of the exact sciences to naval architecture. It has been argued, that because men without any great amount of scientific knowledge have produced good ships, therefore the exact sciences are not necessary for the advancement of naval architecture. In such instances the success has resulted in some cases from chance, in others from induction after a succession of failures, but more frequently from the results of observations on other good ships; and in all these cases, wherever the changes from a foregoing example have been of any moment, the result has been a matter of doubt until tested by trial after completion. It is true that the scientific naval architect cannot effect, by any mathematical process, the synthetical composition of a perfect ship, but he may, by the application of the principles fully established and known to him, produce one with a full confidence of its possessing a preponderance of those qualities which he has considered it desirable that it should possess. The mistake is in the assumption that men of science consider that the theory of naval architecture is already perfected, and is a definite science, whereas this is far from being the case; and it can only be advanced gradually to a greater degree of perfection by an analysis of the actual performances of ships at sea, collected and registered, and the abstract sciences then brought to bear upon them. In every science a perfect theory is the result of the perfection of the science. The time is gone by, when a theory was first formed, and facts were then warped or twisted to suit the pre-conceived theory.

It is now proposed to proceed to show, in as concise a manner as possible, the method of performing the calculations necessary to determine the essential elements of the design of a ship's body, and which are required in the course of preparing the original draught or drawing. The rules to find the areas of plane figures, bounded by straight lines and curves, will first be given; and afterwards those for finding the volumes of solids, bounded by planes and curvilinear spaces.

Calculations incidental to designing a Ship.

To find the area of a plane area, bounded by straight lines and a curve.

Simpson's rules for finding the areas of plane surfaces.

Art. 1. If the area is symmetrical in regard to the line $A_1\,A_n$, that is, if a line $A_1\,A_n$ can be found to divide the area into two equal parts, as $A_1\,a_n$ and $A_1\,b_n$; –

Divide this line (or axis) into a convenient number of equal parts, taking care to have an *even* number of such parts, then draw the lines $A_1\,a_1$, $A_2\,a_2$, $A_3\,a_3$, &c., $A_n\,a_n$ at right angles to the line $A_1\,A_n$, through the points A_1, A_2, A_3, &c., A_n, and meeting the curve in the points a_1, a_2, a_3, &c., a_n, these lines being called ordinates;

The second, $A_2\,a_2$, fourth, $A_4\,a_4$, &c., are called the EVEN ordinates. The *third* $A_3\,a_3$, fifth $A_5\,a_5$, &c., are called the ODD ordinates (the first and last being omitted).

Then, if these ordinates be measured on the same scale as the equal distances $A_1\,A_2$, $A_2\,A_3$, &c., the following rules will give the area of the figure:—

Rule I.—*To the sum of the first and last ordinates add four times the sum of all the* EVEN *ordinates, and twice the sum of all the* ODD *ordinates (omitting the first and last); multiply this final sum by the common distance between the ordinates, divide by* 3, *and the result will be the area (nearly).*

Note 1.—The following is the usual demonstration given to this rule, which is due to Thomas Simpson, who was Professor of Mathematics at Woolwich, about the middle of the last century:—

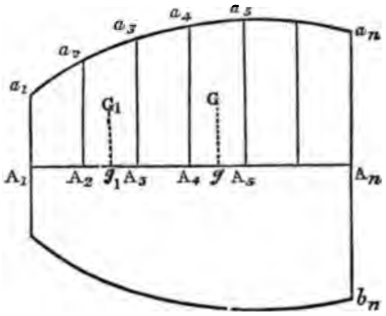


Fig. 3.

Referring to fig. 3,

$$\text{Put } A_1\,a_1 = \alpha_1,\ A_2\,a_2 = \alpha_2,\ A_3\,a_3 = \alpha_3, \text{\&c., } A_n\,a_n = \alpha_n,$$
$$A_1\,A_2 = A_2\,A_3 = A_3\,A_4, \text{\&c., } A_{n-1}\,A_n = h$$

We suppose a parabolic curve, the equation to which is

$$y = A + B\,x + C\,x^2 \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (1)$$

to pass through the *three* points a_1, a_2, a_3; for since (1) contains three arbitrary constants A, B, C, we can, as is well known, make the curve (1) pass through three given points. Now, since (1) passes through a_1, we know (if A_1 be taken as origin) that $y = \alpha_1$ when $x = o$; when $x = h$, $y = \alpha_2 = A_2\,a_2$, and $y = \alpha_3 = A_3\,a_3$ when $x = 2\,h$; hence we have the following equations:—

$\alpha_1 = A$ . . (2) $\alpha_2 = \alpha_1 + B\,h + C\,h^2$ . . (3) $\alpha_3 = \alpha_1 + 2\,B\,h + 4\,C\,h^2$ . . (4) between (3) and (4) we readily determine B and C, viz.:—

$$B = \frac{4\,\alpha_2 - \alpha_3 - 3\,\alpha_1}{2\,h} \quad . \ . \ . \ . \ . \ . \ . \quad (5)$$

$$C = \frac{\alpha_3 - 2\alpha_2 + \alpha_1}{2\,h^2} \quad . \ . \ . \ . \ . \ . \ . \quad (6)$$

Introducing these values into (1), we obtain

$$y = \alpha_1 + \frac{4\,\alpha_2 - \alpha_3 - 3\,\alpha_1}{2\,h}x + \frac{\alpha_3 - 2\,\alpha_2 + \alpha_1}{2\,h^2}x^2.$$

But by the Integral Calculus we know that the area of a curve is represented by

$\int y\,dx$, taken between proper limits. In the present case these limits are o and $2h$.

$$\therefore \text{ area of } A_1\,a_3, \text{ or} \int_0^{2h} y\,dx = 2\alpha_1\,h + \left(\frac{4\alpha_2 - \alpha_3 - 3\alpha}{4h}\right)h^2$$

Calculations incidental to designing a Ship.

$+\left(\frac{a_3-2a_2+a_1}{6h^2}\right)h^3$, or area of $A_1\,a_3=\frac{h}{3}\left(a_1+a_3+4a_2\right)$, after a little reduction.

Again, by making a parabola of the same form as (1) pass through the three points a_3, a_4, a_5, we obtain a result precisely similar to the above, that is,

$$\text{area } A_3\ a_5=\frac{h}{3}(a_3+a_5+4a_4),\text{ and}$$

$$\text{area } A_5\ a_7=\frac{h}{3}(a_5+a_7+4a_6),$$

$$\text{area } A_{n-2}\,a_n=\frac{h}{3}(a_{n-1}+a_n+4a_{n-2}).$$

Adding these areas we find

$$\text{(I.) Area } A_1\,a_n=\frac{h}{3}\Big\{a_1+a_n+4\,(a_2+a_4+a_6+\&c.,\ a_{n-2})$$
$$+2\,(a_3+a_5,\&c.,\,a_{n-1})\Big\}$$

It ought to be observed that in the application of this, and the following rules, an *odd* number of ordinates are always to be taken, and the nearer the ordinates are taken, that is, the less the common interval, the more nearly will the final result approach the *true* area of the figure.

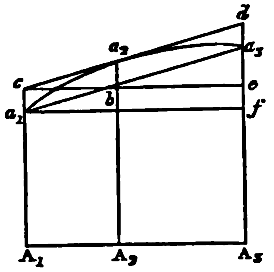


Fig. 4.

For those who are not familiar with the Integral Calculus, another demonstration may be obtained, as follows:—

Through the point a_2, draw a tangent to the parabola which passes through a_1, a_2, a_3, and produce $A_1\,a_1$, $A_3\,a_3$, to meet this tangent in the points c and d; join $a_1\,a_3$; intersecting $A_2\,a_2$ in b; through a_1 and c draw $c\ e$ and $a_1\ f$ parallel to $A_1\,A_3$, then it is shown in all works on Conic Sections that $a_1\,a_3$ is parallel to $c\,d$. Hence by Euc. I. 35—

Paral.^{m} $a_1\,d$ = paral.^{m} $c\,f$, because they are on the same base and between the same parallels $A_1\,c_1$, $A_3\,d$.

$$\text{Now, } A_2\,b=\frac{A_1\,a_1+A_3\,a_3}{2}\text{ and } A_2\,a_2=a_2$$

$$\therefore \text{area of parabola } a_1\,ba_3\,a_2\,a_1=\frac{2}{3}\text{paral.}^m\,a_1\,d=\frac{2}{3}\text{paral.}^m\,c\,f\,^{1}$$

$$=\frac{2}{3}\left(a_2-\frac{a_1+a_3}{2}\right)\times 2h,\text{ since } A_1\,A_3=a\,f=2h.$$

$$\text{Also area of trapezoid } A_1\,a_1\,a_3\,A_3=\left(\frac{Aa_1+A_3\,a_3}{2}\right)A_1\,A_3$$
$$=\quad h\,(a_1+a_3).$$

Adding these two areas, we obtain that of the whole figure

$$A_1\,a_1\,a_2\,a_3\,A_3=\frac{h}{3}\Big\{3a_1+3a_3+4a_2-2a_1-2a_3\Big\}$$
$$=\frac{h}{3}\Big\{a_1+4a_2+a_3.\Big\}$$

By repeating this process for the area of the figures $A_3\,a_3\,a_4\,a_5\,A_5$, &c., &c., and adding the results, we obtain for the whole area $A_1\,a_n$ the same result as before.

If a_2 were less than a_1, the parabola would be convex towards $A_1\,A_3$; but the same rule would still apply, for A_2b would then be equal to $\frac{a_1+a_3}{2}-a_2$, and this introduced into the form for finding the area of the parabola, leads to the same result as that already obtained.

Another demonstration, on different principles, will be given in Note (3.)

RULE II.—*To the sum of the first and last ordinates, add* THREE TIMES *the sum of the second, third, fifth, sixth, eighth, ninth, &c., ordinates, and* TWICE *the sum of the fourth, seventh, tenth, thirteenth, &c., ordinates (omitting the last ordinate); multiply this final sum by three times the common distance between the ordinates, divide the product by* 8, *and the result will give the area (nearly).*

Calculations incidental to designing a Ship.

Note 2.—To obtain what naval architects call the "Second Rule," we suppose a parabola, the equation to which is

$$y=A+Bx+Cx^2+Dx^3\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ (1)$$

to pass through the four points a_1, a_2, a_3 a_4 (fig. 3), the four constants being determined by these conditions; that is, when x takes the successive values o, h, $2h$, $3h$; y becomes a_1, a_2, a_3, and a_4; hence the following equations:

$$a_1=A\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ (2)\because\text{ when } x=o\quad y=a_1$$
$$a_2-a_1=Bh+Ch^2+Dh^3\ .\ .\ .\ .\ .\ (3)\because\text{ when } x=h,\ y=a_2$$
$$a_3-a_1=2Bh+4Ch^2+8Dh^3\ .\ .\ .\ (4)\because\text{ when } x=2h,\ y=a_3$$
$$a_4-a_1=3Bh+9Ch^2+27Dh^3\ .\ .\ (5)\because\text{ when } x=3h,\ y=a_4\,.$$

$$(4)-(3)\times 2\text{ gives } a_3-2a_2+a_1=2Ch^2+6Dh^3\ .\ .\ .\ .\ .\ .\ .\ .\ (6)$$
$$(5)+(3)-(4)\times 2\text{ gives } a_4-2a_3+a_2=2Ch^2+12Dh^3\ .\ .\ .\ .\ .\ (7)$$
$$(7)-(6)\text{ gives } 6Dh^3=a_4-3a_3+3a_2-a_1\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ (8)$$
$$\text{From (6) and (8) } 2Ch^2=a_4+4a_3-5a_2+2a_1\ .\ .\ .\ .\ .\ .\ .\ (9)$$
$$\text{From (3), (8) and (9) } 6Bh=2a_4-9a_3+18a_2-11a_1\ .\ .\ .\ (10)$$

$$\text{But area, or}\int_{o}^{3h}y\,dx=\int_{o}^{3h}\Big\{A+Bx+Cx^2+Dx^3\Big\}\,dx$$

(we write the limits of x, o and $3h$, because at A_1, x is o, and at A_4, x is $3h$).

$$\therefore\ \text{Area } A_1\,a_4=\frac{3h}{8}\Big\{8\,A+12\,Bh+24\,Ch^2+54\,Dh^3.\Big\}$$

Introducing the values of A, B, C, and D, given by the above equations, we find, after some obvious reductions,

$$\text{Area } A_1\,a_4=\frac{3h}{8}\Big\{a_1+a_4+3\,a_2+3\,a_3\Big\}\ .\ .\ .\ .\ .\ (11.)$$

In like manner, by making a curve similar to (1) pass through the points a_4, a_5, a_6, a_7, we have

$$\text{Area } A_4\,a_7=\frac{3h}{8}\Big\{a_4+a_7+3\,a_5+3\,a_6\Big\}\ .\ .\ .\ .\ .\ (12.)$$

$$\text{Area } A_7\,a_{10}=\frac{3h}{8}\Big\{a_7+a_{10}+3\,a_8+3\,a_9\Big\}\ .\ .\ .\ .\ .\ (13.)$$
$$\vdots\qquad\vdots$$
$$\text{Area } A_{n-3}a_n=\frac{3h}{8}\Big\{a_{n-3}+a_n+3\,a_{n-2}+3\,a_{n-1}\Big\}\ .\ .\ (N.)$$

Adding equations (11), (12), (13), &c., (N), we get

$$\text{(II.) Area } A_1\,a_n=\frac{3h}{8}\Big\{a_1+a_n+3\,(a_2+a_3+a_5+a_6+\&c.,\ a_{n-2}$$
$$+a_{n-1})+2\,(a_4+a_7+a_{10}+\&c.,\ a_{n-3})\Big\}$$

It will be seen from the foregoing method that we may make a curve of the form

$$y=A+Bx+Cx^2+Dx^3+Ex^4+\&c.,\ Nx_{n-1}$$

pass through n points, taking care that the equation shall contain n arbitrary constants, to be determined by the conditions that the curve may pass through a_1, a_2, a_3, a_4, &c., a_n (fig. 3, page 140), when x and y are respectively $x=o$, $x=h$, $x=2\,h$, &c., $x=(n-1)\,h$,

$$y=a_1,\ y=a_2,\ y=a_3,\ \&c.,\ y=a_n,$$

a_1, a_2, a_3, &c., and h, having the same interpretation as before; the ordinates being taken at equal distances apart, as on this hypothesis the calculation of the area is much simplified.

Rules obtained after this manner for any given number of ordinates will, in general, give us the area of the figure more correctly than if we employed the preceding rules, because in the latter case we suppose a continuous curve to pass through the given points, whereas, in the former cases, we have a *series of curves* passing through the given points, and the curvilinear boundary is itself supposed to be a continuous curve. Such rules (for many ordinates) give rise to a great deal of labour in obtaining them, and entail almost as much labour in their application. In the latter case, moreover, logarithms will assist us to some extent, and in the former,

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[1] The equation to a parabola being $y^2=4\,m\,x$, or $y=2\,m^{\frac{1}{2}}\,x^{\frac{1}{2}}$ . . . . . (1)

$$\text{Area, or}\int_{o}^{x}y\,dx=2m^{\frac{1}{2}}\int_{o}^{x}x^{\frac{1}{2}}\,dx=\frac{4a^{\frac{1}{2}}\,x^{\frac{3}{2}}}{3}=\frac{2\,xy}{3}\text{ by (1)}$$

$$\therefore\ \text{area}=\frac{4xy}{3}=\frac{2}{3}\text{ circumscribed parallelogram.}$$

Calculations incidental to designing a Ship.

there are some remarkable properties of the natural numbers connected with the determination of the arbitrary constants, and on which perhaps more light may hereafter be thrown. We have remarked some curious properties of the squares, cubes, &c., of numbers connected with the eliminations. There can be no doubt that many other rules of a very simple kind may be obtained on the condition that any number of the constants may disappear from the general equation, which is equivalent to as many conditions.

Emerson, in his *Arithmetic of Infinites*, published by Nourse in the year 1767, gives the following formulæ, obtained by the foregoing processes—from one up to nine ordinates.

Area $= h\alpha_1$ . . . . for one ordinate.

$= \frac{h}{2}(\alpha_1+\alpha_2)$ . . . . for two ordinates.

(1) $= \frac{h}{3}(\alpha_1+\alpha_3+4\alpha_2)$ . . . . for three ordinates.

(2) $= \frac{3h}{8}\left\{\alpha_1+\alpha_4+3(\alpha_2+\alpha_3)\right\}$ . . . . for four ordinates.

(3) $= \frac{h}{25}\left\{7(\alpha_1+\alpha_5)+32(\alpha_2+\alpha_4)+12\alpha_3\right\}$ for five ordinates.

(4) $= \frac{5h}{288}\left\{19(\alpha_1+\alpha_6)+75(\alpha_2+\alpha_5)+50(\alpha_3+\alpha_4)\right\}$ six do.

(5) $= \frac{h}{140}\left\{41(\alpha_1+\alpha_7)+216(\alpha_2+\alpha_6)+27(\alpha_3+\alpha_5)+272\alpha_4\right\}$ for seven ordinates.

(6) $= \frac{7h}{17280}\left\{751(\alpha_1+\alpha_8)+3577(\alpha_2+\alpha_7)+1323(\alpha_3+\alpha_6)+2989(\alpha_3+\alpha_4)\right\}$ for eight ordinates.

(7) $= \frac{4h}{14175}\left\{989(\alpha_1+\alpha_9)+5888(\alpha_2+\alpha_8)-928(\alpha_3+\alpha_7)+10496(\alpha_4+\alpha_6)-4540\alpha_5,\right\}$ for nine ordinates.

Where extreme accuracy is required, these may be combined in such a way as to give the area. For instance, if there were fifteen ordinates in a figure, (5) and (7) may be combined, remembering that the last ordinate of (5) becomes the first in (7), &c., &c.

When seven ordinates are considered sufficient, the following elegant rule, due to the late Mr Thomas Weddle, of the Military College, Sandhurst, may be employed:—

RULE III.—*When* SEVEN *ordinates are employed.*[1] *To five times the sum of the* EVEN *ordinates, add the fourth, or middle ordinate, and all the odd ordinates; multiply this sum by* THREE TIMES *the common distance between the ordinates, divide by* 10, *and the result will give the area* (nearly).[2]

Note 3.—The Calculus of Finite Differences may be advantageously employed to approximate to the areas of surfaces, lengths of curves, volumes of solids, centres of gravity, moments of inertia, &c. For triple integrals may generally be reduced to integrals of the form

$$\int_{x_1}^{x_2} u\,dx$$

where u represents a function of x, or $f(x)$, as it is usually written, and x_1, x_2 represent the limits of the integral.

Now, if we suppose x to vary by the constant difference Δx, we may suppose $z = \frac{x}{\Delta x}$, and if α_1, α_2, α_3, &c., α_n be the values of u when $z = o, 1, 2, 3$, &c., n, we have, by Taylor's theorem,

$$u = \alpha_1 + z\Delta\alpha_1 + z(z-1)\frac{\Delta^2\alpha_1}{1\cdot2}, + z(z-1)(z-2)\frac{\Delta^3\alpha}{1\cdot2\cdot3} + \text{\&c.}, \;.\;.\; (1.)$$

But by hypothesis Δx is constant, and according to the notation we have previously employed, we may suppose it $= h \therefore \frac{x}{h} = z$, and $\frac{dx}{h} = dz$. Multiplying each side of (1) by these differentials, and integrating, we have

$$\frac{1}{h}\int u\,dx = z\alpha_1 + \frac{z^2}{2}\Delta\alpha_1 + \left(\frac{z^3}{3}-\frac{z^2}{2}\right)\frac{\Delta^2\alpha_1}{1\cdot2} + \left(\frac{z^4}{4}-\frac{3z^3}{3}+\frac{2z^2}{2}\right)\frac{\Delta^3\alpha}{1\cdot2\cdot3}$$

$$+\left(\frac{z^5}{5}-\frac{6z^4}{4}+\frac{11z^3}{3}-\frac{6z^2}{2}\right)\frac{\Delta^4\alpha_1}{1\cdot2\cdot3\cdot4} + \left(\frac{z^6}{6}-\frac{10z^5}{5}+\frac{35z^4}{4}-\frac{50z^3}{3}+\frac{24z^2}{2}\right)\frac{\Delta^5\alpha_1}{\underline{|5}}$$

$$+\left(\frac{z^7}{7}-\frac{15z^6}{6}+\frac{85z^5}{5}-\frac{225z^4}{4}+\frac{274z^3}{3}-\frac{120z^2}{2}\right)\frac{\Delta^6\alpha_1}{\underline{|6}}$$

$$+\left(\frac{z^8}{8}-\frac{21z^7}{7}+\frac{175z^6}{6}-\frac{735z^5}{5}+\frac{1624z^4}{4}-\frac{1764z^3}{3}+\frac{720z^2}{2}\right)\frac{\Delta^7\alpha_1}{\underline{|7}}$$

$$+\left(\frac{z^9}{9}-\frac{28z^8}{8}+\frac{322z^7}{7}-\frac{1960z^6}{6}+\frac{6769z^5}{5}-\frac{13132z^4}{4}+\frac{13068z^3}{3}-\frac{5040z^2}{2}\right)\frac{\Delta^8\alpha_1}{\underline{|8}}$$

$$+\left(\frac{z^{10}}{10}-\frac{36z^9}{9}+\frac{546z^8}{8}-\frac{4536z^7}{7}+\frac{22449z^6}{6}-\frac{67284z^5}{5}+\frac{118124z^4}{4}-\frac{109584z^3}{3}+\frac{40320z^2}{2}\right)\frac{\Delta^9\alpha_1}{\underline{|9}}$$

$$+\left(\frac{z^{11}}{11}-\frac{45z^{10}}{10}+\frac{870z^9}{9}-\frac{9450z^8}{8}+\frac{63273z^7}{7}-\frac{269325z^6}{6}+\frac{723680z^5}{5}-\frac{1172700z^4}{4}+\frac{1026576z^3}{3}-\frac{362880z^2}{2}\right)\frac{\Delta^{10}\alpha_1}{\underline{|10}}$$

$$+\left(\frac{z^{12}}{12}-\frac{55z^{11}}{11}+\frac{1320z^{10}}{10}-\frac{18150z^9}{9}+\frac{157773z^8}{8}-\frac{902055z^7}{7}+\frac{3416930z^6}{6}-\frac{8409500z^5}{5}+\frac{12753576z^4}{4}-\frac{10628640z^3}{3}+\frac{3628800z^2}{2}\right)\frac{\Delta^{11}\alpha_1}{\underline{|11}}$$

$$+\left(\frac{z^{13}}{13}-\frac{66z^{12}}{12}+\frac{1925z^{11}}{11}-\frac{32670z^{10}}{10}+\frac{357423z^9}{9}-\frac{2637558z^8}{8}+\frac{13339545z^7}{7}-\frac{45995730z^6}{6}+\frac{105258876z^5}{5}-\frac{150917976z^4}{4}+\frac{120543840z^3}{3}-\frac{35916800z^2}{2}\right)\frac{\Delta^{12}\alpha_1}{\underline{|12}}$$

$$+ \text{\&c.}, \;+\; \text{\&c.}, \;.\;.\;.\;.\;.\;.\;.\;.\; (2.)$$

The coefficients in each of these terms are readily obtained by multiplying $(p-1)(p-2)(p-3)(p-4)(p-5)$, &c. $(p-n)$ together.

If we take this integral between the limits $z = 0$ and $z = 2$, which correspond to $x = 0$ and $x = 2h$, after multiplying by h.

$$\int_0^{2h} u\,dx = h\left\{2\alpha_1 + 2\Delta\alpha_1 + \frac{1}{3}\Delta^2\alpha_1 - \frac{1}{90}\Delta^4\alpha_1 + \frac{1}{90}\Delta^5\alpha_1 - \frac{37}{3780}\Delta^6\alpha_1 + \text{\&c.}\right\}$$

But by the principles of the Calculus of Finite Differences:

$$\Delta\alpha_1 = \alpha_2 - \alpha_1$$
$$\Delta^2\alpha_1 = \alpha_3 - 2\alpha_2 + \alpha_1$$

$$\therefore \int_0^{2h} u\,dx = \frac{h}{3}\left\{\alpha_1 + 4\alpha_2 + 2\alpha_3 - \frac{1}{30}\Delta^4\alpha_1 + \frac{1}{30}\Delta^5\alpha_1 - \frac{37}{1260}\Delta^6\alpha_1 + \text{\&c.}\right\}$$

Now, if we add similar expressions for the area included between $x = 2h$ and $x = 4h$; $x = 4h$ and $x = 6h$, &c. $x = (n-2)h$ and $x = nh$ (n being an even number).

Calculations incidental to designing a Ship.

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[1] Seven, thirteen, nineteen, &c., ordinates, may be employed on the same hypothesis, as is mentioned hereafter.

[2] The fourth ordinate is considered among the *even* ordinates.

Calculations incidental to designing a Ship.

$$\int_0^{nh} u dx = \frac{h}{3}\Big\{ \alpha_1 + \alpha_n + 4(\alpha_2 + \alpha_4 + \alpha_6 + \&c. + \alpha_{n-2})$$

$$+ 2(\alpha_3 + \alpha_5 + \alpha_7 + \&c. + \alpha_{n-1}\Big\}.$$

$$- \frac{1}{30}(\Delta^4\alpha_1 + \Delta^4\alpha_2 + \Delta^4\alpha_4 + \&c. \quad \Delta^4\alpha_{n-1}).$$

$$+ \frac{1}{30}(\Delta^5\alpha_1 + \Delta^5\alpha_2 + \Delta^5\alpha_4 + \&c. \quad \Delta^5\alpha_{n-1}).$$

$$- \frac{37}{1260}(\Delta^6\alpha_1 + \Delta^6\alpha_2 + \&c. \quad \&c. \qquad).$$

$$+ \quad \&c. \quad \&c. \quad \&c. \qquad \Big\} \quad \ldots\ldots \quad (3.)$$

The first line corresponds to the Rule we have already obtained (I.) by supposing a parabola to pass through the extremities of the ordinates $\alpha_1, \alpha_2, \alpha_3$; and another through $\alpha_3, \alpha_4, \alpha_5$, &c.

The following terms are the correction of the first line; hence, when great accuracy is required, the following results may be taken into account.

To obtain Rule (III.), we only have to suppose the integral (1) taken between the limits $z = 0$ and $z = 6$, or $x = 0$ and $x = 6h$, as was done by Mr Weddle in his demonstration, given in the *Dublin and Cambridge Mathematical Journal* for February 1856, which is similar to this:

$$\therefore \int_0^{6h} u dx = h\Big\{6\alpha_1 + 18\,\Delta\alpha_1 + 27\,\Delta^2\alpha_1 + 24\,\Delta^3\alpha_1 + \frac{123}{10}\Delta^4\alpha_1$$

$$+ \frac{33}{10}\Delta^5\alpha_1 + \frac{41}{140}\Delta^6\alpha_1 + \&c.\Big\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.)$$

And we may suppose *sixth* differences *constant*, and then all the terms after $\Delta^6\alpha_1$ in (4) will vanish; but $\frac{41}{140}$ differs from $\frac{42}{140}$ by the small fraction $\frac{1}{140}$; hence, instead of $\frac{41}{140}$ we may write $\frac{42}{140}$ or $\frac{3}{10}$ without material error. Replacing $\Delta\alpha_1$ by $\alpha_2 - \alpha_1$, $\Delta^2\alpha_1$ by $\alpha_3 - 2\alpha_2 + \alpha_1$, $\Delta^3\alpha_1$ by $\alpha_4 - 3\alpha_3 + 3\alpha_2 - \alpha_1$ &c., after some obvious reductions (4) becomes

$$\int_0^{6h} u dx = \frac{3h}{10}\Big\{\alpha_1 + \alpha_3 + \alpha_5 + \alpha_7 + 5(\alpha_2 + \alpha_6) + 6\alpha_4\Big\}$$

$$= \frac{3h}{10}\Big\{\alpha_1 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_7 + 5(\alpha_2 + \alpha_4 + \alpha_6)\Big\} \quad \ldots\ldots\ldots\ldots \quad (5.)$$

'From the foregoing investigation, it is clear, that formula (5.) gives the *exact* area, when fifth differences are constant, while it differs (in excess) from the true value by $\frac{1}{140}\Delta^6\alpha_1$ when *sixth*, or even *seventh*, differences are constant. In other cases it will give the area very nearly, providing the differences, beginning at the sixth, are small."[1]

As many rules as we please may be obtained by integrating (1.) from $z = 0$ to $z = 1$, $z = 0$ to $z = 2$, $z = 0$ to $z = 3$, $z = 0$ to $z = 4$, &c.: from $z = 0$ to $z = n$, and, neglecting small quantities, as has been done by Mr Weddle, and by supposing the $(n-1)^{th}$ order of differences constant.[2]

Rule (II.) may be obtained by integrating equations (1.) from $z = 0$ to $z = 3$, which will be the same as supposing a series of parabolas to pass through the extremities of $\alpha_1, \alpha_2, \alpha_3, \alpha_4$; $\alpha_4, \alpha_5, \alpha_6, \alpha_7$, &c., as was the case in formula (3).

In these rules, if the curve passes through A_1 or A_n, the first or last ordinate must be considered 0.

Some examples will now be given on the application of the preceding rules.

(1.) Find the area of a figure, bounded by right lines and a curve, the ordinates of which are taken at 3 feet apart, and measure 1, 2, 3, 4, 5, 4, 3, 2, and 1 feet respectively.

Calculations incidental to designing a Ship.

By Rule (I.)

Ordinates.	Even Ordinates.	Odd Ordinates.
1 1st ord.	2	3
1 last do.	4	5
–	4	3
2 sum of 1st and last ord.	2	—
48 four times sum of even do.	—	11 sum of odd ord.
22 twice sum of odd do.	12 sum of even ord.	2
—	4	—
72	—	22 twice sum of do.
1 = ⅓ common distance.	48 – four times do.	
—		
72 = area.		

By Rule (II.)

Ordinates.	Ordinates.	Ordinates.
1 first ord.	2 second ord.	4 fourth ord.
1 last do.	3 third do.	3 seventh do.
–	5 fifth do.	–
2 sum of 1st and last ord.	4 sixth do.	7 sum of do.
48 { – thrice sum of 2d, 3d, 5th, 6th, &c.	2 eight do.	2
	—	—
14 twice sum of 4th, 7th.	16 sum of do.	14 twice sum of do.
—	3	
64	—	
9 = 3 times com. dist.	48 three times sum of do.	
8)576		

72 = area, which agrees exactly with the area obtained by Rule (I.)

(2.) Find the area of a figure where the ordinates are 10, 12, 13, 14, 13, 12, and 10 feet, respectively, and the common distance 2 feet.

By Rule (I.) $\quad \text{Area} = \frac{2}{3}\Big\{10 + 10 + 4(12 + 14 + 12) + 2(13 + 13)\Big\} = 149\tfrac{1}{3}$ feet.

By Rule (II.) $\quad \text{Area} = \frac{3 \times 2}{8}\Big\{10 + 10 + 3(12 + 13 + 13 + 12) + 2 \times 14\Big\} = 148\tfrac{1}{2}$ feet.

By Rule (III.) $\quad \text{Area} = \frac{3 \times 2}{10}\Big\{10 + 13 + 14 + 13 + 10 + 5(12 + 14 + 12)\Big\} = 150$ feet.

(3.) Find the area where the ordinates are 20·75, 21·78, 22·56, 23·79, 22·64, 21·51; and 21·51, the common distance being 6 feet.

By Rule (I.) $\quad \text{Area} = \frac{6}{3}\Big\{20{\cdot}75 + 21{\cdot}51 + 4(21{\cdot}78 + 23{\cdot}79 + 21{\cdot}51) + 2(22{\cdot}56 + 22{\cdot}64)\Big\} = 801{\cdot}96$ feet.

By Rule (II.) $\quad \text{Area} = \frac{6 \times 3}{8}\Big\{20{\cdot}75 + 21{\cdot}51 + 3(21{\cdot}78 + 22{\cdot}56 + 22{\cdot}64 + 21{\cdot}51) + 2 \times 23{\cdot}79\Big\} = 799{\cdot}4475.$

By Rule (III.) $\quad \text{Area} = \frac{6 \times 3}{10}\Big\{20{\cdot}75 + 22{\cdot}56 + 23{\cdot}79 + 22{\cdot}64 + 21{\cdot}51 + 5(21{\cdot}78 + 23{\cdot}79 + 21{\cdot}51)\Big\} = 803{\cdot}97.$

As is stated in Note (3.), Rule (III.) can only be applied to obtain a very near approximation to the true area when the sixth and seventh ordinates are alike, or differ by a very small quantity.

By applying these rules to find the area of the quadrant $A_1\,a_7$, the radius of which is 6 feet, it will be seen how much the results differ from the true area.

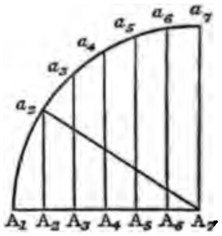

Fig. 5.

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[1] The *Dub. and C. Math. Journal*, Feb. 1854.

[2] The coefficients of the various orders of differences have been extended, in order that the reader may obtain some of these rules for himself.

Calculations incidental to designing a Ship.

Divide the radius $A_1 A_7$ into six equal parts (Fig. 5), and erect the ordinates $A_2 a_2$, $A_3 a_3$, &c. observing that $A_1 a_1 = 0$.

$$A_2 a_2 = \sqrt{(A_7 a_2)^2 - (A_7 A_2)^2} = \sqrt{6^2 - 5^2} = \sqrt{11} = 3{\cdot}3163$$
$$A_3 a_3 = \sqrt{(A_7 a_3)^2 - (A_7 A_3)^2} = \sqrt{6^2 - 4^2} = \sqrt{20} = 4{\cdot}4721$$
$$A_4 a_4 = \sqrt{6^2 - 3^2} = \sqrt{27} = 5{\cdot}1961$$
$$A_5 a_5 = \sqrt{6^2 - 2^2} = \sqrt{32} = 5{\cdot}6568$$
$$A_6 a_6 = \sqrt{6^2 - 1^2} = \sqrt{35} = 5{\cdot}9160$$
$$A_7 a_7 = 6$$

The area found by Rule (I.) = 27·9901 feet.
" (II.) = 27·9285 "
" (III.) = 28·0401 "

Apply formula (5.) given at the end of Note (1.)

$$\text{Area} = \frac{h}{140}\left\{41(a_1 + a_7) + 216(a_2 + a_6) + 27(a_3 + a_5) + 272\,a_4\right\}.$$

Where $h = 6$, $a_1 = 0$, $a_2 = 3{\cdot}3163$, $a_3 = 4{\cdot}4721$, &c.
And area = 28·05 feet.

But true area of quadrant $= \dfrac{6^2 \times 3{\cdot}1416}{4} = 28{\cdot}2744$, so that Rule (III.) and formula (5.), in the present case, give the area almost accurately.

(4.) The ordinates of a curve taken 6 feet apart are, 20, 22, 24, 25 ; 24, 23, and 21 feet, respectively : find the area of the figure.

By Rule (I.) $\text{Area} = \frac{6}{3}\left\{20 + 21 + 4(22 + 25 + 23) + 2(24 + 24)\right\} = 834$ feet.

By Rule (II.) $\text{Area} = \frac{3 \times 6}{8}\left\{20 + 21 + 3(22 + 24 + 24 + 23) + 2 \times 25\right\} = 832{\cdot}5$ feet.

By Rule (III.) $\text{Area} = \frac{3 \times 6}{10}\left\{20 + 24 + 25 + 21 + 5(22 + 25 + 23\right\} = 835{\cdot}2$ feet.

By formula (5.) $\text{Area} = \frac{6}{140}\left\{20 + 21 + 216(22 + 23) + 27(24 + 24) + 272 \times 25\right\} = 835{\cdot}5$ feet.

(5.) Find the area, when the ordinates, taken 4 feet apart measure 0, 2·275, 3·476, 4·567, 5·673, 6·451, 5·341, 4·236, 3·254, 3·065, 2·784, 1·876, and 0, respectively.

By Rule (I.) Area = 174·629$\dot{3}$.

(6.) Find the area by Rules (II.) and (III.) when the ordinates, taken 1 foot apart, measure, 0, 1·7684, 2·3457, 3·4567, 3·214, 2·97654, and 2·8543 feet, respectively.

By Rule (II.) Area = 15·2556, &c.
By Rule (III.) Area = 15·86367

Displacement.

Art. 2. Def.—By the ***Displacement*** of a ship is meant the volume of water which the ship displaces when floating on its surface.

Now, by the principles of Hydrostatics, it is well known that the *weight* of a body floating in water, or any other fluid, is equal to the weight of the water or fluid displaced. Hence, after obtaining the displacement of a body, it is only necessary to multiply the volume (say in cubic feet) of the displaced fluid, by the weight of a cubic foot of the fluid, in order to obtain the weight of the floating body.

Def.—*By a plane of flotation is meant that section of the vessel, in any position, made by the surface of the water.*

Several general rules have been given to determine the displacement of ships, which can be but approximations to the true results, since the outlines of ships differ so widely, and it is therefore not considered necessary to give them.

In order to find the displacement, the ship is supposed to be divided by any number of equi-distant horizontal planes, that is, planes taken parallel to the load-water line, and also by any convenient number of equi-distant vertical planes, intersecting, of course, the former series of horizontal planes at right angles. These planes are generally projected by the draughtsman on the three plans of the vessel, viz., the body plan, the sheer plan, and half-breadth plan. (See Plate I.)

Calculations incidental to designing a Ship.

As is seen in the half-breadth plan, the ship is divided into two equal portions by a vertical plane, running from stem to stern; and the perpendicular distances measured on each horizontal plane, from their intersection with this plane to the ship's side, are considered as ordinates.

Thus, in the half-breadth plan (Plate I.), F 7 is the projection of the vertical plane which divides the ship into two equal parts, and F*f* E*s* are the ordinates in the horizontal plane, F, 7_m, any number of these horizontal planes may be taken, and for the purposes of calculation they may be numbered 1, 2, 3, 4, &c.; and A . B . C . &c.

The small portions, fore and aft, are usually calculated separately, the horizontal and vertical planes being taken much nearer to each other in consequence of the greater curvature of the vessel at these parts.

The calculation of the displacement may be proceeded with in two ways:—

1st, By finding the *areas* of all the horizontal sections, and employing these as ordinates in Rule (I.) or (II.)

2d, By finding the areas of all the vertical sections, and using these as ordinates in the same rules.

These two results ought to agree.

Or, the rule may be enunciated as follows, ordinates on the half-breadth plan being understood :—

Rule IV. *To the sum of the* FIRST *and* LAST *horizontal sectional areas, add* FOUR *times the sum of all the* EVEN *horizontal areas, and* TWICE *the sum of all the* ODD *horizontal areas; multiply this final sum by* ONE-THIRD *the common distance between these horizontal planes, and this result gives one-half the displacement.*

We could not, from what has already been done, *à priori*, conclude that "Simpson's Rule" would enable us to find the volume of a solid, bounded by planes and a curvilinear surface. The following demonstration, however, proves that it holds true.

Note 4.—Let $A_1\, c_3$ represent a portion of such a body, bounded by the planes $A_1\, C_3$, $C_3\, a_3$, $A_1\, a_3$, $C_1\, a_1$, $C_1\, c_3$, and by the surface $a_1\, c_3$, we take the planes $A_1\, a_3$, $A_1\, c_1$, and $A_1\, a_3$, as the three planes of reference, viz., $(x\, y)$, $(y\, z)$, and $(x\, z)$, respectively.

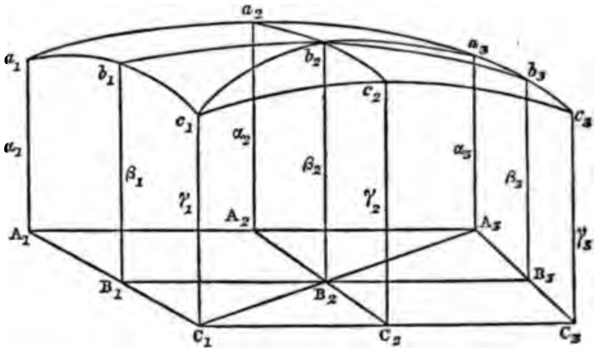

Fig. 6.

Bisect $A_1 A_3$, $A_1 C_1$, $C_1 C_3$, $A_3 C_3$, in the points A_2, B_1, C_2, and B_3, respectively; join $A_2\, C_2$, and $B_1\, B_3$; through these right lines let planes $A_2\, c_2$, $B_1\, b_3$, be drawn at right angles to the plane $A_1\, C_3$, then

Assume $A_1 A_2 = A_2 A_3 = B_1 B_2 = B_2 B_3 = C_1 C_2 = C_2 C_3 = h$
$A_1 B_1 = B_1 C_1 = A_2 B_2 = B_2 C_2 = A_3 B_3 = B_3 C_3 = h$
$A_1 a_1 = \alpha_1$, $B_1 b_1 = \beta_1$, $C_1 c_1 = \gamma_1$
$A_2 a_2 = \alpha_2$, $B_2 b_2 = \beta_2$, $C_2 c_2 = \gamma_2$
$A_3 a_3 = \alpha_3$, $B_3 b_3 = \beta_3$, $C_3 c_3 = \gamma_3$

We may then imagine a surface of the form (1.) to pass through the nine points, a_1, a_2, a_3, b_1, b_2, b_3, c_1, c_2, c_3.

$$z = A + Bx + Cx^2 + B_1 y + C_1 y^2 + Dxy + Ex^2 y + Exy^2 + Cx^2 y^2 \;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;. \quad (I.)$$

Calculations incidental to designing a Ship.

Since it contains *nine* arbitrary constants, A, B, C, B_1, C_1, &c., observing that the *x*s are measured along A_1 A_3, the *y*s along A_1 C_1, and the *z*s are A_1 a_1, A_2 a_2, A_3 a_3, B_1 b_1, &c. Hence we have the following equations:—

(1.) $\alpha_1 = A$ ....when $x = 0,\ y = 0,\ z = \alpha_1$...by (I.)

(2.) $\alpha_2 - \alpha_1 = Bh + Ch^2$ .... $x = h,\ y = 0,\ z = A_2\,a_2 = \alpha_2$

(3.) $\alpha_3 - \alpha_1 = 2Bh + 4Ch^2$ .... $x = 2h,\ y = 0,\ z = A_3\,a_3 = \alpha_3$

(4.) $\beta_1 - \alpha_1 = B_1k + C_1k^2$ .... $x = 0,\ y = k,\ z = B_1\,b_1 = \beta_1$

(5.) $\gamma_1 - \alpha_1 = 2B_1k + 4C_1k^2$ ...... $x = 0,\ y = 2k,\ z = C_1\,c_1 = \gamma_1$

(6.) $\beta_2 - \alpha_2 - \beta_1 + \alpha_1 = Dhk + Eh^2k + Ehk^2 + Gh^2k^2$...by (2.) and (4.)............................... $x = h,\ y = k,\ z = B_2b_2 = \beta_2$

(7.) $\beta_3 - \alpha_3 - \beta_1 + \alpha_1 = 2Dhk + 4Eh^2k + 2Ehk^2 + 4Gh^2k^2$...by (3.) and (4.).............................$x = 2h,\ y = k,\ z = B_3\,b_3 = \beta_3$

(8.) $\gamma_2 - \alpha_2 - \gamma_1 + \alpha_1 = 2Dhk + 2Eh^2k + 4Ehk^2 + 4Gh^2k^2$...by (2.) and (5.)..........................$x = h,\ y = 2k,\ z = C_2\,c_2 = \gamma_2$

(9.) $\gamma_3 - \alpha_3 - \gamma_1 + \alpha_1 = 4Dhk + 8Eh^2k + 8Ehk^2 + 16Gh^2k^2$...by (3.) and (5.).........................$x = 2h,\ y = 2k,\ z = C_3c_3 = \gamma_3$

Now, B, C, B_1 and C_1 are readily determined from equations (2), (3), (4), and (5), and D, E, F, and G, from equations (6), (7), (8), and (9); their values are—

$$A = \alpha_1$$

$$B = \frac{4\alpha_2 - 3\alpha_1 - \alpha_3}{2h}.$$

$$C = \frac{\alpha_1 - 2\alpha_2 + \alpha_3}{2h^2}.$$

$$B_1 = \frac{4\beta_1 - 3\alpha_1 - \gamma_1}{2k}.$$

$$C_1 = \frac{\alpha_1 - 2\beta_1 + \gamma_1}{2k^2}.$$

$$D = \frac{16\beta_2 + 9\alpha_1 + 3\alpha_3 + 3\gamma_1 + \gamma_3 - 12\alpha_2 - 12\beta_1 - 4\beta_3 - 4\gamma_2}{4hk}.$$

$$E = \frac{6\alpha_2 + 4\beta_1 + 4\beta_3 + 2\gamma_2 - 3\alpha_1 - 3\alpha_3 - 8\beta_2 - \gamma_1 - \gamma_3}{4h^2k}.$$

$$F = \frac{4\alpha_2 + 6\beta_1 + 2\beta_3 + 4\gamma_2 - 3\alpha_1 - \alpha_3 - 8\beta_2 - 3\gamma_1 - \gamma_3}{4hk^2}.$$

$$G = \frac{\alpha_1 + \alpha_3 + 4\beta_2 + \gamma_1 + \gamma_3 - 2\alpha_2 - 2\beta_1 - 2\gamma_2 - 2\beta_3}{4h^2k^2}.$$

In order to find the volume of a solid, we must integrate the equation $\iiint dx\,dy\,dz$, as shown in most works on the Differential and Integral Calculus, or, what amounts to the same thing, $\iint z\,dx\,dy$, where z is given by the equation to the surface, and the integrations in regard to x and y are to be determined by the conditions of the question. It is evident that, in the present case, the limiting values of x are 0 and $2h$, those of y being 0 and $2k$. Hence

$$\int_0^{2h}\!\!\int_0^{2k} z\,dxdy = \int_0^{2h}\!\!\int_0^{2k} dx\,dy\,(A + Bx + Cx^2 + B_1y + C_1y^2 + Dxy + Ex^2y + Exy^2 + Gx^2y^2) = \frac{hk}{9}\Big\{36\,A + 36\,Bh + 48\,Ch^2 + 36\,B_1h + 48\,C_1k^2 + 36\,Dhk + 48\,Eh^2k + 48\,Ehk^2 + 64\,Gh^2k^2\Big\}.$$

Introducing the values of A, B, C, &c. already found, we get, after obvious reductions, volume

$$A_1c_3 = \frac{hk}{9}\Big\{\alpha_1 + 4\alpha_2 + \alpha_3 + 4\,(\beta_1 + 4\,\beta_2 + \beta_3) + \gamma_1 + 4\,\gamma_2 + \gamma_3\Big\} \quad . \quad . \quad . \quad . \quad . \quad \text{(II.)}$$

On examining the equations, we perceive that $\frac{h}{3}\,(\alpha_1 + 4\,\beta_2 + z_3)$ represents the area of the section $A_1\,a_3$ (*Vide* Equation I., p. 141), and $\frac{h}{3}\,(\beta_1 + 4\,\beta_2 + \beta_3)$ represents the area $B_1\,b_3$; also, $\frac{h}{3}\,(\gamma_1 + 4\,\gamma_2 + \gamma_3)$ that of $C_1\,c_3$. Writing for the area of $A_1\,a_3$, A_1; for that of $B_1\,b_3$, A_2; for $C_2\,c_3$, A_3 (Equation II.) becomes

$$\text{Volume } A_1\,c_3 = \frac{k}{3}\,(A_1 + 4\,A_2 + A_3) \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(III.)}$$

Calculations incidental to designing a Ship.

By making similar paraboloidal surfaces pass through c_1, c_2, c_3, and six other points, &c. we have

$$\text{Volume } A_3\,c_5 \text{ next portion} = \frac{k}{3}\,(A_3 + 4\,A_4 + A_5).$$

$$\text{,, } \qquad \text{,, } \qquad = \frac{k}{3}\,(A_5 + 4\,A_6 + A_7).$$

$$\text{,, } \quad \text{last portion} = \frac{k}{3}\,(A_{n-2} + 4\,A_{n-1} + A_n).$$

Adding these—

$$\text{Total volume} = \frac{k}{3}\Big\{A_1 + A_n + 4\,(A_2 + A_4 + A_6 + \&c. + A_{n-1} + 2\,(A_3 + A_5 + \&c. + A_{n-2})\Big\} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(IV.)}$$

We might have regarded $\frac{k}{3}\,(\alpha_1 + 4\,\beta_1 + \gamma_1)$ as the area of the section $A_1\,c_1$, or B_1, as we shall denote it, $\frac{k}{3}\,(\alpha_2 + 4\,\beta_2 + \gamma_2)$ that of $A_2\,c_2$, &c., or B_2, &c., and then

$$\text{Volume} = \frac{h}{3}\Big\{B_1 + B_n + 4\,(B_2 + B_4 + \&c. + B_{n-1}) + 2\,(B_3 + B_5 + \&c.\ B_{n-2})\Big\}.$$

Multiplying these volumes by 2, we get the total displacement of the ship.

A Rule similar to that of (II.) Note (2) may be found by making a surface, the equation to which is of the form $z = A + Bx + Cx^2 + Dx^3 + B_1y + C_1y^2 + D_1y^3 + Exy + Ex^2y + Gxy^2 + Hx^2y^2 + Ix^3y + Kxy^3 + Lx^3y^2 + Mx^2y^3 + Nx^3y^3$ pass through sixteen points, since the equation contains this number of arbitrary constants, which are determined as before, and the integrations are taken from $x = 0$ to $x = 3h$, and $y = 0$ to $y = 3k$. We shall leave this work for the student, and proceed at once to

Observe that *vertical* areas may be employed in the place of *horizontal* areas, and care must be taken to omit the first and last areas from the *odd* ones in each case.

Rule (II.) might have been employed; but the following is the neatest, most concise, and at the same time sufficiently accurate, that has yet been given. It is by the Rev. Joseph Woolley, M.A., LL.D., Her Majesty's Inspector of Schools, to whom naval architects are under great obligations for the attention he has given to this branch of science:—

RULE V. (1.) *Add together all the* EVEN *ordinates in the* FIRST *and* LAST *horizontal planes.*

(2.) *Add together all the* EVEN *ordinates in the 3d, 5th, 7th, &c., sections, omitting the* FIRST *and* LAST, *and multiply the sum by* 2.

(3.) *Add together all the* FIRST *and* LAST *ordinates of all the* EVEN *horizontal planes.*

(4.). *Take* TWICE *the sum of all the ordinates, omitting the* FIRST *and* LAST *of all the* EVEN *horizontal planes.*

Then, *add together the results of* (1), (2), (3), (4), *and multiply this final sum by* TWO-THIRDS *of the product of the common distances between the horizontal and vertical planes, and this result gives the displacement.*

Note 5.—Not having seen the demonstration by Dr Woolley to this rule, the editors beg to offer the following, which must be somewhat similar in principle.

Dr Woolley supposes fig. 6 to be divided into two portions by a plane passing through $C_1\,B_2\,A_3\,a_3\,b_2\,c_1$, and the equation to the surface passing through $a_1\,b_1\,c_1\,b_2\,a_2\,a_3$ may be assumed as

$$z = A + Bx + Cx^2 + B_1y + C_1y^2 + Dxy \quad . \quad . \quad . \quad . \quad \text{(I.)}$$

And the limits are $x = 0$ and $x = 2h$, and since, $A_1\,C_1 = 2k$, at any point y, we must have $y = \left(\frac{2h - x}{h}\right)k$.

$$\therefore \int_0^{2h}\!\!\int_0^{(2h-x)\frac{k}{h}} z\,dxdy = \int_0^{2h}\!\!\int_0^{(2h-x)\frac{k}{h}} dxdy(A + Bx + Cx^2 + B_1y + C_1y^2 + Dxy).$$

Calculations incidental to designing a Ship.

$$= \int_0^{2h} dx \left\{ A\left(\frac{2h-x}{h}\right)k + Bkx\left(\frac{2h-x}{h}\right) + Ckx^2\left(\frac{2h-x}{h}\right) \right.$$

$$+ \frac{B_1k^2}{2}\left(\frac{4h^2-4hx+x^2}{h^2}\right) + \frac{C_1k^3}{3}\left(\frac{8h^3-12h^2x+6hx^2-x^3}{h^3}\right)$$

$$\left. + \frac{Dk^2x}{2}\left(\frac{4h^2-4hx+x^2}{h^2}\right) \right\}$$

$$= 2Ahk + \frac{4Bh^2k}{3} + \frac{4Ch^3k}{3} + \frac{4B_1hk^2}{3} + \frac{4C_1hk^3}{3} + \frac{2Dh^2k^2}{3} \quad \text{(II.)}$$

Now, since the surface (I.) passes through the six points already mentioned, we readily determine A, B, C_1, &c., as in the last note Their values are

$$A = \alpha_1$$
$$2Bh = 4\alpha_2 - \alpha_3 - 3\alpha_1$$
$$2Ch^2 = \alpha_1 - 2\alpha_2 + \alpha_3$$
$$2B_1k = 4\beta_1 - \gamma_1 - 3\alpha_1$$
$$2C_1k^2 = \alpha_1 - 2\beta_1 + \gamma_1$$
$$Dhk = \alpha_1 + \beta_1 - \alpha_2 - \beta_1$$

Writing these values in (II.) it reduces to

$$\text{Volume} = \frac{2hk}{3}\left\{ \alpha_2 + \beta_1 + \beta_2 \right\}$$

In the same way, we find the volume of the figure $C_1\, c_1\, b_2\, a_3\, C_3$

$$= \frac{2hk}{3}\left\{ \gamma_2 + \beta_3 + \beta_2 \right\}$$

Adding these results, we find for the whole volume $A_1\, c_3$

$$\frac{2hk}{3}\left\{ \alpha_2 + \beta_1 + 2\beta_2 + \beta_3 + \gamma_2 \right\}$$

With similar expressions for the other portions of the ship.

$$\therefore \text{ Whole volume} = \frac{2hk}{3}\left\{ \beta_1 + \beta_n + 2(\beta_3 + \beta_5 + \beta_7 + \text{\&c.}) \right.$$
$$\left. + (\alpha_2 + \gamma_2 + \alpha_4 + \gamma_4 + \text{\&c.}) + 2(\beta_2 + \beta_4 + \beta_6 + \beta_8 + \text{\&c.} \right\}$$

To find the Centres of Gravity of Bodies.

ART. 3. As a knowledge of the centres of gravity of bodies is of so much importance in the calculation of stability, it has been thought advisable to introduce the subject here at some length.

Various definitions have been given of the centre of gravity of a body. It is shown in almost every work on Statics, that *there is a point in* (sometimes *without*) *every body such, that if the particles of the body be acted on by parallel forces, and the point already mentioned be fixed or supported, the body will remain in equilibrium, no matter in what position it is placed;*[1] and when the *forces* herein mentioned are replaced by the *weights* of the elementary portions of the body, or bodies, this point is known as the *centre of gravity* of the body or bodies.[2]

Gravity, or the force which attracts all bodies towards the earth's centre, is supposed to act on every particle of the body in parallel and vertical directions. This force is supposed to be constant at the earth's surface, and therefore attracts all bodies with an equal intensity. The reader will readily perceive that this hypothesis cannot differ materially from the truth when he compares the earth's radius with the dimensions of all bodies at its surface, and remembers that this attractive force varies inversely as the square of the distance. Under these circumstances, then, the centres of gravity of bodies are calculated. This point cannot be obtained, however, without the aid of the Integral Calculus, except in the case of a few plane surfaces and solids. We shall premise that when bodies are *homogeneous*, or of the same density throughout their parts,—that is, having equal weights, comprised under equal volumes,—we may then replace *weights* by *masses*, and conversely. Thus, if M represent the mass of a body, d the density of a unit of the body, V the volume, W the weight, then

Calculations incidental to designing a Ship.

$$M = d \times V \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1.)$$
$$W = g \times d \times V = gM \quad . \; . \; . \; . \; . \; . \quad (2.)^3$$

When a body is not homogeneous throughout its parts, the determination of the centre of gravity becomes somewhat more difficult.

To find the Centre of Gravity of an Area similar to fig. 8.

Centre of gravity.

ART. 4.—RULE VI. *Multiply the ordinates, beginning at the first by* 0, 1, 2, 3, 4, *&c., respectively, and employ these as ordinates in Rule (I.); multiply the result thus obtained by one-third of the common interval squared, divide by the area of the curve, and the result gives the distance we are to measure along* $A_1\,A_n$*—i.e.,* $A_1\,g$.[4]

Having obtained the distance A_1g, we may obtain the length of the perpendicular Gg (G being the centre of gravity of the figure, and g the point where the perpendicular drawn from G intersects A_1A^n.) by

RULE VII. *To the sum of the* SQUARES *of the* FIRST *and* LAST *ordinates, add* FOUR *times the sum of the squares of all the* EVEN *ordinates, twice the sum of the squares of all the* ODD *ordinates; multiply by one-third the common interval, and divide this result by twice the area, the quotient gives the perpendicular height of the centre of gravity above the axis* $A_1\,A_n$.[5]

Similar rules apply for finding the centres of gravity of the displacement of a ship.

ART. 5. *To find the centre of gravity of the displacement of a ship floating in the water, and in a state of equilibrium*—

The horizontal sections are taken at equal distances apart and parallel to the plane of flotation. The vertical sections are also taken at equal distances apart and parallel to the midship section. The ship is then cut into two equal portions by a plane running fore and aft, and at right angles to the two planes just mentioned. In the following rules, *half areas* and *half volumes* are to be understood.

RULE VIII. *Find the areas of all the horizontal sections (such as those shown in the half-breadth plan) and multiply these, beginning from the first, or plane of flotation, by the consecutive numbers* 0, 1, 2, 3, 4, *&c., respectively; introduce these products as ordinates into "Simpson's Rule;" multiply this result by one-third of the square of common distance between the sections, divide by the volume, and the quotient gives the distance of the centre of gravity below the plane of flotation.*[4]

RULE IX. *Find the areas of all the vertical sections, multiply these, beginning from the first*[6] *by the consecutive numbers* 0, 1, 2, 3, 4, *&c., respectively, and work as in the last rule; the result thus obtained gives the distance of the centre of gravity from the first vertical plane.*

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[1] Pratt's *Mechanical Philosophy*, 2d edit., pp. 18 and 19.

[2] *The centre of gravity* has also been defined as that point within or without the body, from which, if the body be conceived to be suspended, it will remain in equilibrium in any position.

[3] "g, or 'the accelerating force of gravity,' is uniform, and is the same for all substances, and in the latitude of London = 32·18 feet." (Earnshaw's *Dynamics*, 3d edit., p. 42.)

[4] Care must be taken *not* to multiply by one-third of the common distance, as is mentioned in Rule I.

[5] The *last* ordinate must not be reckoned among the *odd* ordinates in these and the following rules.

[6] Either the first vertical section of the main body nearest the bow or stern may be taken as the first.

Calculations incidental to designing a Ship.

Centre of gravity.

These two distances fix the position of the centre of gravity of the main body. Since a ship is symmetrical in regard to the plane which divides it, fore and aft, into two equal parts, we know that the centre of gravity must lie in this plane.

No account is here taken of the small portions at the stem, stern, and that between the keel and last horizontal section. These are usually calculated separately, and in the same way as the main body. Having obtained the centres of gravity of all these portions, we readily obtain the centre of gravity of the total displacement by the rule which follows, observing, that if we consider the *first vertical plane* to be that nearest the bow, the volume of the small portion forward multiplied by the distance of its centre of gravity from the plane just mentioned must be *subtracted*. Or, in other words, if we consider all horizontal distances, measured in the *opposite* direction (from the first vertical plane) to the centre of gravity of the main body as *negative*, and all distances measured in the *same direction* as *positive*, we have then only to add the products *algebraically*, and this is to be understood in the following rule (one product being always *negative* in Rule XI.) All *results will be positive* in finding the distance of the centre of gravity *below the plane of flotation*.

RULE X. *Multiply each of the volumes by the perpendicular distance of its centre of gravity from the plane of flotation, and add the products; divide this result by the sum of all the volumes, and the quotient is the distance of the centre of gravity of the total displacement below the plane of flotation.* Also,

RULE XI. *Multiply each of the volumes by the perpendicular distance of its centre of gravity from the first vertical plane, and add algebraically (observing that one result will be negative), divide this result by the sum of all the volumes, and the quotient is the distance of the centre of gravity of the total displacement from the first vertical plane.*

One of the properties of Guldinus is also of great use in finding centres of gravity when the necessary data are supplied.

RULE XII. *Any solid of revolution is equal to the area of the surface which generates this solid, multiplied by the circumference, which is described by the centre of gravity of the latter.*

Without attempting to demonstrate formulæ (1.) of this article, since a demonstration may be found in almost every work on Statics, we proceed to lay before the mathematical reader the principles on which the centres of gravity are calculated.

Note 6.—If we consider, in the first place, a system of material points having weight, and connected in an invariable manner, the weights of these points may be considered as so many vertical forces acting in parallel directions. If, moreover, we take three fixed planes, mutually at right angles to each other, their point of intersection being the origin (as is done in Geometry of three dimensions) let ω_1 be the weight of the first material point, and its co-ordinates x_1, y_1, z_1, measured along the three co-ordinate axes: ω_2, x_2, y_2, z_2, the weight and co-ordinates of the second point, &c. &c.; also, let $\bar{x}$, $\bar{y}$, $\bar{z}$ represent the co-ordinates of the centre of gravity of the system of weights measured along the same axes, then we have

$$\left.\begin{aligned} \bar{x} &= \frac{\Sigma(\omega_1 x_1 + \omega_2 x_2 + \omega_3 x_3 + \&c.)}{\Sigma(\omega_1 + \omega_2 + \omega_3 + \&c.\ \&c.)} \\ \bar{y} &= \frac{\Sigma(\omega_1 y_1 + \omega_2 y_2 + \omega_3 y_3 + \&c.)}{\Sigma(\omega_1 + \omega_2 + \omega_3 + \&c.)} \\ \bar{z} &= \frac{\Sigma(\omega_1 z_1 + \omega_2 z_2 + \omega_3 z_3 + \&c.)}{\Sigma(\omega_1 + \omega_2 + \omega_3 + \&c.)} \end{aligned}\right\} \quad \ldots\ldots \quad (1.)$$

Remark.—These formulæ would be equally true if we suppose ω_1, ω_2, ω_3, &c. to represent the weights of any bodies whatever, and connected in an invariable manner, *providing we suppose these weights to act at their respective centres of gravity, and* x_1, y_1, z_1, *&c., to be the co-ordinates of these centres of gravity.* Next, if we suppose the density of the weights to be uniform throughout, we can replace the weights by their respective volumes v_1, v_2, v_3, &c. since $g \times d$ appears both in numerator and denominator. The proposition is also true for areas. Therefore, if A_1, A_2, A_3, &c. represent areas

$$\left.\begin{aligned} \bar{x} &= \frac{\Sigma(v_1 x_1 + v_2 x_2 + v_3 x_3 + \&c.)}{\Sigma(v_1 + v_2 + v_3 + \&c.)}, \\ \text{or } \bar{x} &= \frac{\Sigma(A_1 x_1 + A_2 x_2 + A_3 x_3 + \&c.)}{\Sigma(A_1 + A_2 + A_3 + \&c.)} \\ \bar{y} &= \frac{\Sigma(v_1 y_1 + v_2 y_2 + v_3 y_3 + \&c.)}{\Sigma(v_1 + v_2 + v_3 + \&c.)}, \\ \text{or } \bar{y} &= \frac{\Sigma(A_1 y_1 + A_2 y_2 + A_3 y_3 + \&c.)}{\Sigma(A_1 + A_2 + A_3 + \&c.)} \\ \bar{z} &= \frac{\Sigma(v_1 z_1 + v_2 z_2 + v_3 z_3 + \&c.)}{\Sigma(v_1 + v_2 + v_3 + \&c.)} \\ \text{or } \bar{z} &= \frac{\Sigma(A_1 z_1 + A_2 z_2 + A_3 z_3 + \&c.)}{\Sigma(A_1 + A_2 + A_3 + \&c.)} \end{aligned}\right\} \quad \ldots\ldots \quad (2.)$$

Calculations incidental to designing a Ship.

If the centres of gravity of the weights, volumes, or areas, as the case may be, range in a right line, the first equation gives the distance of their common centre of gravity from the origin. If the weights, or areas, &c., are in the same plane, the four former equations are all that are necessary to determine the centre of gravity.

Premising that the centre of gravity of a ball, or sphere, is at the centre of the body, we shall proceed to give two or three examples on these formulæ.

(1.) Four cannon-balls have their centres in the same right line at 2, 3, and 4 feet, respectively, apart, and weigh 68, 32, 12, and 8 lbs. respectively; that is, the "32" is 2 feet from the "68," the "12" is 3 feet from the "32," &c. Find the distance of the common centre of gravity from the centre of the "68" (supposing their centres to be in the same horizontal line).

Taking the origin at the centre of the "68," we have $x_1 = 0$, $x_2 = 2$, $x_3 = 2 + 3 = 5$, $x_4 = 2 + 3 + 4 = 9$ feet.

$$\therefore (1.)\ \bar{x} = \frac{68 \times 0 + 32 \times 2 + 12 \times 5 + 8 \times 9}{68 + 32 + 12 + 8} = 1{\cdot}6\dot{3} \text{ feet.}$$

That is, if the balls were connected by an indefinitely fine rigid rod, without weight, passing through the centres of the balls, the whole might be suspended, and remain in equilibrium, at a point distant 1·63 feet from the centre of the "68."

(2.) Five cannon-balls, whose weights are 2, 8, 12, 32, and 68 lbs., lie on the floor of a room, at the respective perpendicular distances 3, 4, 5, 6, and 7 feet from the side, and 1, 2, 3, 4, and 5 feet from one end of the room; find their common centre of gravity from that corner of the room where the side and end (from which these distances are measured) intersect, supposing the centres of the balls to lie in the plane of the floor.

$$\text{Here } \bar{x} = \frac{2 \times 3 + 8 \times 4 + 12 \times 5 + 32 \times 6 + 68 \times 7}{2 + 8 + 12 + 32 + 68} =$$

6·28 feet nearly.

$$\bar{y} = \frac{2 \times 1 + 8 \times 2 + 12 \times 3 + 32 \times 4 \times 68 \times 5}{2 + 8 + 12 + 32 + 68} =$$

4·28 feet nearly.

$$\text{But distance from corner} = \sqrt{\bar{x}^2 + \bar{y}^2}$$

$$= \sqrt{(6{\cdot}28)^2 + (4{\cdot}28)^2} =$$

7·6 feet nearly.

(3.) Four cannon-balls, whose weights are 1, 8, 32, and 68 lbs., are suspended in a room (of the form of a parallelopipedon), their vertical heights from the floor being 2, 4, 6, and 5 feet, respectively, and their perpendicular distances, from an end and side of the room, are 2, 4, 5, 6 feet, and 3, 5, 6, 7 feet, respectively; find the distance of the centre of gravity of the balls, from that corner of the room where the side and end, herein mentioned, intersect.

Calculations incidental to designing a Ship.

Here the side, end, and floor of the room are the planes of reference, and the origin at the corner, mentioned in the question, the line where the *side* intersects the floor may be taken as the axis of x, and the intersection of the *end* and floor as the axis of y, or, *vice versâ*, the intersections of the end and side being the axis of z.

$$\therefore \bar{x} = \frac{1 \times 2 + 8 \times 4 + 5 \times 32 + 6 \times 68}{1 + 8 + 32 + 68} = 5{\cdot}523 \text{ ft. nearly.}$$

$$\bar{y} = \frac{1 \times 3 + 8 \times 5 + 32 \times 6 + 68 \times 7}{1 + 8 + 32 + 68} = 6{\cdot}523 \quad \text{,,}$$

$$\bar{z} = \frac{1 \times 2 + 8 \times 4 + 32 \times 6 + 68 \times 5}{1 + 8 + 32 + 68} = 5{\cdot}192 \quad \text{,,}$$

Again, it is easily shown that the distance of a point $\bar{x}, \bar{y}, \bar{z}$, from the origin is—

$$d = \sqrt{\bar{x}^2 + \bar{y}^2 + \bar{z}^2} = \sqrt{(5{\cdot}523)^2 + (6{\cdot}523)^2 + (5{\cdot}192)^2} =$$ 10 feet nearly.

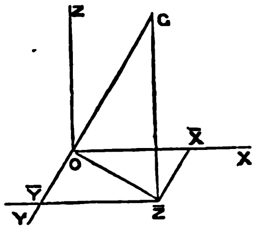

Fig. 5.

For if XOY be the plane of the floor, XOZ the side, and YOZ the end of the room, G the centre of gravity. Draw $G\bar{Z} \perp$ to the plane XOY; and from $\bar{Z}$ draw $\bar{Z}\bar{X}$ and $\bar{Z}\bar{Y}$ respectively, $\perp$ to OX and OY; then $O\bar{X} = \bar{x}$, $O\bar{Y} = \bar{y}$, $G\bar{Z} = \bar{z}$ in the above equations, and since the triangles $O\bar{X}\bar{Z}$, $O\bar{Z}G$ are right-angled,

$$OG^2 = O\bar{Z}^2 + G\bar{Z}^2 = O\bar{X}^2 + \bar{X}\bar{Z}^2 + G\bar{Z}^2, \text{ and } \bar{X}\bar{Z}^2 = O\bar{Y}^2.$$

$$\therefore OG = \sqrt{O\bar{X}^2 + O\bar{Y}^2 + G\bar{Z}^2}$$

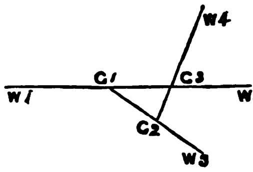

Fig. 6.

We might have determined the centre of gravity of any system of material points, or balls, not situated in the same line, or plane, and rigidly connected in the following manner: W_1, W_2, W_3, &c. representing these material points and their positions, join $W_1 W_2$, and let G_1 be their common centre of gravity, then these two points will act in the same manner as if their weights were collected at the point G_1. Join $G_1 W_3$, and let G_2 be the centre of gravity of W_1, W_2, acting at G_1, and of W_3; then W_1, W_2, W_3, may be conceived to act at G_2. Join $G_2 W_4$, &c. &c.

Note 7.—The principles made use of in equations (1.) may readily be extended to any body, or system of bodies; for, suppose the body referred to three co-ordinate planes mutually at right angles to each other, their common point of intersection being the origin, and x_1, y_1, z_1, the co-ordinates of any point in the body; then it is shown, in most works on the "Calculus," that the *volume* of an infinitesimal parallelopipedon, at that point, is represented by $\Delta x_1 \times \Delta y_1 \times \Delta z_1$.[1] Also, if δ_1 represents the density of a unit of volume at that point, the mass of the particle is $\delta_1 . \Delta x_1 . \Delta y_1 . \Delta z_1$, and its weight is $g\delta_1 \, \Delta x_1 \, \Delta y_1 \, \Delta z_1$. But as g is constant, it follows that we may either employ the weights or masses of the body in finding its centre of gravity, and

$$M = \Sigma\,(\delta_1 \, \Delta x_1 . \Delta y_1 . \Delta z_2 + \delta_2 \, \Delta x_2 \, \Delta y_2 \, \Delta z_2 + \text{\&c. \&c.})$$

$$\bar{x} = \frac{\Sigma\,(x_1 \, \delta_1 \, \Delta x_1 \, \Delta y_1 \, \Delta z_2 + x_2 \, \delta_2 \, \Delta_2 x_2 \, \Delta y_2 \, \Delta z_2 + \text{\&c.})}{M}$$

$$\bar{y} = \frac{\Sigma\,(y_1 \, \delta_1 \, \Delta x_1 \, \Delta y_1 \, \Delta z_1 + y_2 \, \delta_2 \, \Delta x_2 \, \Delta y_2 \, \Delta z_2 + \text{\&c.})}{M}$$

$$\bar{z} = \frac{\Sigma\,(z_1 \, \delta_1 \, \Delta x_1 \, \Delta y_1 \, \Delta z_1 + z_2 \, \delta_2 \, \Delta x_2 \, \Delta y_2 \, \Delta z_2 + \text{\&c.})}{M}$$

But at the limit $\Delta x_1, \Delta y_1, \Delta z_1$ become dx_1, dy_1, dz_1, and dropping the suffixes, and extending the summation, or rather integration, to all the elements of the body, we obtain

$$(1.) \qquad M = \int\!\!\int\!\!\int dx \, dy \, dz \, . \, \delta.$$

Where δ is given by an equation of the form $\delta = f(x, y, z)$.

Hence $\bar{x} = \dfrac{\int\!\int\!\int x \, dx \, dy \, dz \, . \, \delta}{M}$, $\bar{y} = \dfrac{\int\!\int\!\int y \, dx \, dy \, dz \, \delta}{M}$, $\bar{z} = \dfrac{\int\!\int\!\int z \, dx \, dy \, dz \, \delta}{M}$.

Calculations incidental to designing a Ship.

These equations are to be taken between proper limits, and if the body is homogeneous, δ will appear in both numerators and denominators, and the equations may then be written:

$$(2.) \begin{cases} V = \int\!\!\int\!\!\int dx \, dy \, dz. \\ \bar{x} = \dfrac{\int\!\int\!\int x \, dx \, dy \, dz}{V}, \; \bar{y} = \dfrac{\int\!\int\!\int y \, dx \, dy \, dz}{V}, \; \bar{z} = \dfrac{\int\!\int\!\int z \, dx \, dy \, dz}{V}. \end{cases}$$

We may obtain a clearer idea of these integrals from the following considerations. Let us take the first of the latter set of equations, and integrate, first, in regard to z, and next in regard to y, observing that in these integrations x is constant, we may then write

$$\bar{x} = \int \left\{ \frac{x \int\!\int dy \, dz}{V} \right\} dx.$$

Where the quantity within the brackets represents the product of x by the *area*, A, of a plane section of the figure, perpendicular to the axis of x, and at a distance x from the plane of zy.

$\therefore \bar{x} = \dfrac{\int A \, x dx}{V}$, and similar expressions may be obtained for $\bar{y}$

If it be required to find the centre of gravity of *any* area, &c. we have only to suppose it to lie in the plane of xy and formulæ (2) reduce to

$$(3.) \begin{cases} A = \int\!\!\int dx \, dy = \int y \, dx \text{ (if we integrate in regard to } y) \\ \bar{x} = \dfrac{\int\!\int x \, dx \, dy}{A} = \dfrac{\int xy \, dx}{A}, \; \bar{y} = \dfrac{\int\!\int y \, dx \, dy}{A} = \dfrac{1}{2} \dfrac{\int y^2 \, dx}{A}. \end{cases}$$

Remark.—In many cases it is convenient to employ *polar co-ordinates* to find centres of gravity, and we have for the transformation

$$x = r \sin \theta \cos \phi, \; y = r \sin \theta \sin \phi, \; z = r \cos \theta,$$

Formulæ (2.) become

$$(4.) \begin{cases} \bar{x} = \dfrac{\int\!\int\!\int r^3 \sin{}^2\theta \cos \phi \, dr . d\theta . d\phi}{\int\!\int\!\int r^2 \sin \theta \, dr . d\theta . d\phi}, \\ \bar{y} = \dfrac{\int\!\int\!\int r^3 \sin{}^2\theta \sin \phi \, dr \, d\theta \, d\phi}{\int\!\int\!\int r^2 \sin \theta \, dr \, d\theta \, d\phi}, \\ \bar{z} = \dfrac{\int\!\int\!\int r^3 \sin \theta \cos \theta \, dr \, d\theta \, d\phi}{\int\!\int\!\int r^2 \sin \theta \, dr \, d\theta \, d\phi}, \end{cases}$$

where $\int\!\int\!\int r^2 \sin \theta \, dr \, d\theta \, d\phi$ between proper limits gives the volume.

We shall at once proceed to show by formulæ (3.) how to find the centre of gravity of an area, similar to the horizontal or vertical sections of a ship, premising that the notation is the same as that employed above (p. 29).

Note 8.—To find the centre of gravity of the portion $A_1 a_3$, the equation to the parabola passing through a_1, a_2, a_3, being (h the common interval).

$$y = A + Bx + Cx^2, \; \bar{x}_1 \text{ denoting } A_1 g_1 \text{ and } \bar{y}_1, G_1 g_1.$$

$$\bar{x}_1 = \frac{\int xy \, dx}{\int y \, dx} = \frac{\int_0^{2h} x (A + Bx + Cx^2) \, dx}{\int_0^{2h} (A + Bx + Cx^2) \, dx}$$

$$= \frac{\frac{h^2}{3} \left\{ 6A + 8Bh + 12Ch^2 \right\}}{\frac{h}{3} \left\{ 6A + 6Bh + 8Ch^2 \right\}} = h \left\{ \frac{6A + 8Bh + 12Ch^2}{6A + 6Bh + 8Ch^2} \right\}.$$

But by Note (1), formulæ (2, 5, and 6) $A = y_1$, $B = \dfrac{4y_2 - y_3 - 3y_1}{2h}$, and $C = \dfrac{y_3 - 2y_2 + y_1}{2h^2}$. Writing these in the above, we get

$$\bar{x}_1 = \frac{2h\,(2y_2 + y_3)}{y_1 + y_3 + 4y_2}.$$

In the same way, the centre of gravity of $A_3 A_5$, along the line $A_1 A_n$ is found to be

$$A_3 g_2 = \frac{2h\,(2y_4 + y_5)}{y_3 + y_5 + 4y_4}. \quad \therefore A_1 g_2 = A_1 A_3 + A_3 g_2 = 2h +$$

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[1] Δx_1, Δy_1, Δz_1, represent the respective increments of x_1, y_1, z_1.

Calculations incidental to designing a Ship.

$$\frac{2h\,(\alpha_4 + \alpha_5)}{\alpha_3 + \alpha_5 + 4\alpha_4}, \text{ or if } \bar{x}_2 = A_1\,g_2,\ \bar{x}_3 = A_2\,g_3, \text{ \&c.}$$

$$\bar{x}_2 = 2h + \frac{2h\,(2\alpha_4 + \alpha_5)}{\alpha_3 + \alpha_5 + 4\alpha_4} = \frac{2h\,(\alpha_3 + 6\alpha_4 + 2\alpha_5)}{\alpha_3 + \alpha_5 + 4\alpha_4}.$$

$$\bar{x}_3 = 4h + \frac{2h\,(2\alpha_6 + \alpha_7)}{\alpha_5 + \alpha_7 + 4\alpha_6} = \frac{2h\,(2\alpha_5 + 10\alpha_6 + 3\alpha_7)}{\alpha_5 + \alpha_7 + 4\alpha_6}.$$

And if g be the distance along the line $A_1\ A_n$ of the centre of gravity of the whole figure, we have by formula (2), since the areas may be supposed to be collected at their respective centres of gravity, G_1, G_2, G_3, &c.

$$Ag \text{ or } \bar{x} = \frac{\text{Area } A_1 a_3 \times Ag_1 + \text{area } A_3 a_5 \times A_1 g_2 + \text{area } A_5 a_7 \times A_1 g_3 +}{\text{Area } A_1\,a_3 + \text{area } A_3\,a_5 + \text{area } A_5\,a_7 + \text{\&c. \&c.}}$$

$$= \frac{A_1\bar{x}_1 + A_2\bar{x}_2 + A_3\bar{x}_3 + \text{\&c.} + A_n\,\bar{x}_n}{A_1 + A_2 + A_3 + \text{\&c.} + A_n}.$$

Introducing the values of A_1, A_2, A_3, &c. $\bar{x}_1$, $\bar{x}_2$, $\bar{x}_3$, &c. already found, this reduces to

$$\text{(I.)}\ \bar{x} = h\,\frac{\{0 + (n-1)\,\alpha_n + 4\,(\alpha_2 + 3\alpha_4 + 5\alpha_6 + 7\alpha_8 + \text{\&c.}}{\alpha_1 + \alpha_n + 4\,(\alpha_2 + \alpha_4 + \alpha_5 + \alpha_6 + \text{\&c.})}$$

$$\frac{+ 2(2\alpha_3 + 4\alpha_5 + 6\alpha_7 + \text{\&c.})\}}{+ 2(\alpha_3 + \alpha_5 + \alpha_7 + \text{\&c.})}.$$

Next, to find Gg, or $\bar{y}$, we have

$$\bar{y}_1 = \tfrac{1}{2}\frac{\int_0^{2h} y^2\,dx}{\int_0^{2h} y\,dx},\ \bar{y}_2 = \tfrac{1}{2}\frac{\int_0^{2h} y^2\,dx}{\int_0^{2h} y\,dx}, \text{ \&c. \&c.}$$

But $y^2 = (A + Bx + Cx^2)^2$; and this integration, added to the work connected with the substitution into the form

$$\bar{y} = \frac{A_1\bar{y}_1 + A_2\bar{y}_2 + \text{\&c.}}{A_1 + A_2 + \text{\&c.}}.$$

would lead to an immense amount of labour, which may be avoided by observing that the integral $\int y^2\,dx$ may be taken to represent the *area* of a curve, the ordinates of which are the squares of those at given points of the curve, as α_1, α_2, α_3, &c. With this understanding, we readily find, by employing "Simpson's Rule,"

$$\text{(II.)}\ \bar{y} = \tfrac{1}{2} \text{ of } \frac{\alpha_1^2 + \alpha_n^2 + 4\,(\alpha_2^2 + \alpha_4^2 + \alpha_6^2 + \text{\&c.}) +}{\alpha_1 + \alpha_2 + 4\,(\alpha_2 + \alpha_4 + \alpha_6 + \text{\&c.}) +}$$

$$\frac{2\,(\alpha_3^2 + \alpha_5^2 + \alpha_7^2 + \text{\&c.})}{2\,(\alpha_3 + \alpha_5 + \alpha_7 + \text{\&c.})};$$ whence the centre of gravity of the curve is completely determined.

Note 9.—We next proceed to show how the centre of gravity of the volume of a figure similar to fig. 6, page 33, may be found, its equation being

$$z = A + Bx + Cx^2 + B_1\,y + C_1\,y^2 + Dxy + Ex^2\,y + Exy^2 + G_1\,x^2\,y^2.$$

By formulæ 2 if we integrate in regard to z,

$$\bar{x} = \frac{\int\int xz\,dxdy}{\int z\,dx\,dy} =$$

$$\frac{\int_0^{2h}\int_0^{2k} xdxdy\ (A + Bx + Cx^2 + B_1y + C_1y^2 + Dxy +}{\int_0^{2h}\int_0^{2k} dxdy\ (A + Bx + Cx^2 + B_1y + C_1y^2 + Dxy +}$$

$$\frac{Ex^2y + Exy^2 + Gx^2y^2)}{Ex^2y + Exy^2 + Gx^2y^2)}$$

$$= \frac{\frac{hk}{9}\left\{\ 36\,Ah + 48\,Bh^2 + 72\,Ch^3 + 36\,B_1\,hk + 48\,C_1\,hk^2 +\right.}{\frac{hk}{9}\left\{\ 36\,A + 36\,Bh + 48\,Ch^2 + 36\,B_1k + 48\,C_1\,k^2 +\right.}$$

$$\frac{\left.48\,Dh^2k + 72\,Eh^3k + 64\,Fh^2k^2 + 96\,Gh^3k^2\right\}}{\left.36\,Dhk + 48\,Eh^2k + 48\,Fhk^2 + 64\,Gh^2k^2\right\}}.$$

But $A = \alpha_1$, $B = \frac{4\alpha_2 - 3\alpha_1 - \alpha_3}{2h}$, $C = \frac{\alpha_1 - 2\alpha_2 + \alpha_3}{2h^2}$, &c.

Calculations incidental to designing a Ship.

as was shown on page 29. Introducing these values, we find—

$$\bar{x} = h\,.\,\frac{2\,(2\alpha_2 + \alpha_3) + 8\,(2\beta_2 + \beta_3) + 2\,(2\gamma_2 + \gamma_3)}{\alpha_1 + 4\alpha_2 + \alpha_3 + 4\,(\beta_1 + 4\,\beta_2 + \beta_3) + \gamma_1 + 4\,\gamma_2 + \gamma_3}$$

$$\bar{y} = \frac{\int\int yz\,dxdy}{\int\int z\,dxdy} = \frac{\int_0^{2h}\int_0^{2k} dxdy\ y(A + Bx + Cx^2 + B_1y}{\int_0^{2h}\int_0^{2k} dxdy\ (A + Bx + Cx^2 + B_1y}$$

$$\frac{+ C_1\,y^2 + Dxy + Ex^2y + Exy^2 + Gx^2\,y^2)}{+ C_1\,y^2 + Dxy + Ex^2\,y + Fxy^2 + Gx^2\,y^2)}.$$

$$= \frac{\frac{hk}{9}\left\{\ 36\,Ak + 36\,Bhk + 48\,Ch^2\,k + 48\,B_1\,k^2 + 72\,C_1\,k^3\right.}{\frac{hk}{9}\left\{\ 36\,A + 36\,Bh + 48\,Ch^2 + 36\,B_1\,k + 48\,C_1\,k^2\right.}$$

$$\frac{\left.+ 48\,Dhk^2 + 64\,Eh^2k^2 + 72\,Fhk^3 + 96\,Gh^2\,k\right\}}{\left.+ 36\,Dhk + 48\,Eh^2\,k + 48\,Fhk^2 + 64\,Gh^2\,k\right\}};$$ which, after introducing the values of the constant, and reducing, becomes

$$\bar{y} = k\,.\left\{\frac{2\,(2\beta_1 + \gamma_1) + 8\,(2\beta_2 + \gamma_2) + 2\,(2\beta_3 + \gamma_3)}{\alpha_1 + 4\alpha_2 + \alpha_3 + 4(\beta_1 + 4\beta_2 + \beta_3) + \gamma_1 + 4\gamma_2 + \gamma_3}\right\}.$$

Also,

$$\bar{z} = \frac{\int\int z^2\,dxdy}{\int\int z\,dxdy}.$$

But, as before, we avoid the labour of integrations, &c., if we consider the expression $\int\int z^2\,dxdy$ as the volume of a figure, *the squares of the areas* of which may be introduced into "Simpson's Rule."

We should obtain similar expressions for the centres of gravity of the volumes of the other solids, and by introducing the results into the formulæ—

$$\bar{x} = \frac{V_1\,\bar{x}_1 + V_2\,\bar{x}_2 + V_3\,\bar{x}_3 + \text{\&c.}}{V_1 + V_2 + V_3 + \text{\&c.}}$$

$$\bar{y} = \frac{V_1\,\bar{y}_1 + V_2\,\bar{y}_2 + V_3\,\bar{y}_3 + \text{\&c.}}{V_1 + V_2 + V_3 + \text{\&c.}}$$

we obtain the rule, in common use among naval architects, namely:—

If A_1, A_2, A_3, &c., represent the areas of half the horizontal sections, or the sections shown by the half-breadth plan, and h the common interval between those sections, we know that the centres of gravity of the whole horizontal sections in question lie in the planes of these areas at distances $0, h, 2h, 3h$, &c., respectively, from the origin.

$$\text{(III.)} \therefore \bar{x} = \frac{A_1 \times 0 + (n-1)\,hA_n + 4h\,(A_2 + 3A_4 + 5A_6 +}{A_1 + A_n + 4\,(A_2 + A_4 +}$$

$$\frac{6A_8 + \text{\&c.}) + 2h\,(2A_3 + 4A_5 + 6A_7 + \text{\&c.})}{A_6 + \text{\&c.}) + 2\,(A_3 + A_5 + A_7 + \text{\&c.})};$$

$$\text{or } \bar{x} = h\ .\ \left\{\frac{(n-1)\ A_n + 4\,(A_2 + 3A_4 + 5A_6 + \text{\&c.}) +}{A_1 + A_n + 4\,(A_2 + A_4 + A_6 + \text{\&c.}) +}\right.$$

$$\left.\frac{2\,(2A_3 + 4A_5 + \text{\&c.})}{2\,(A_3 + A_5 + A_7 + \text{\&c.}}\right\}.$$

In like manner, if A_1', A_2', A_3', &c. represent the half areas of the vertical section, and k the common interval between them.

$$\text{(IV.) Then } \bar{y} = k\ \left\{\frac{(n-1)\,A_n' + 4(A_2' + 3A_4' + 5A_6' + \text{\&c.})}{A_1' + A_n' + 4(A_2' + A_4' + A_6' + \text{\&c.})}\right.$$

$$\left.\frac{+ 2\,(2A_3' + 4A_5' + \text{\&c.})}{+ 2\,(A_3' + A_5' + \text{\&c.})}\right\}.$$

Hence the centre of gravity of the displacement is determined; for we know that it will lie somewhere in the plane which cuts the vessel into two equal parts, and the value of $\bar{x}$ gives its distance below the load-water plane, $\bar{y}$ gives its distance from the origin,

Calculations incidental to designing a Ship.

which may be taken for convenience at the point of intersection of the load-water plane, the plane just mentioned, and the first vertical plane next the bow, or stern (as the calculator pleases). We will suppose the former, and that the centres of gravity of the small portions, fore and aft, and below the last horizontal plane, are not taken into account. Let V_f, V_a, V_k, be their volumes, $\bar{x}_f$, $\bar{x}_a$, $\bar{x}_k$, $\bar{y}_f$, $\bar{y}_a$, $\bar{y}_k$, the distances of their centres of gravity from the origin. Therefore, for the whole ship, V representing the volume between the first and last vertical sections,

$$\bar{X} = \frac{V\bar{x} + V_k \bar{x}_k + V_a \bar{x}_a - V_f \bar{x}_f}{V + V_k + V_a + V_f}$$

$$\bar{Y} = \frac{V\bar{y} + V_k \bar{y}_k + V_a \bar{y}_a + V_f \bar{y}_f}{V + V_k + V_a + V_f}.$$

Observe that $V_f \bar{x}_f$ has a negative sign because it is in the opposite side of the origin to the other quantities, that is, x_f is negative.

Note 10.—The mathematical reader will at once perceive that these are not the only rules which might be obtained to calculate the centre of gravity of a vessel. As has been remarked before, the Calculus of Finite Difference again comes to our aid; and, by neglecting small orders of differences, we may obtain any number of rules we please. As an instance, let us take the case given by Mr Weddle for a curve passing through seven points, and suppose sixth differences constant. We have for $\bar{x}$, using the same notation as in Note 3,

$\bar{x} = \int xy\,dx$ taken between proper limits; and $y = \alpha + z\,\Delta\alpha + z(z-1)\frac{\Delta^2\alpha}{1\cdot2} + \&c.$; where $z = \frac{x}{h}$. Multiplying this by $zdz = \frac{xdx}{h^2}$, we have $\bar{x}$ or $\frac{1}{h^2}\int xy\,dx = \int \Big\{\alpha\, zdz + (z^2dz)\,\Delta\alpha + (z-1)\,dz\,.\,\frac{\Delta^2\alpha}{1\cdot2} + \&c.\Big\} = \frac{\alpha z^2}{2} + \frac{z^3}{3}\,\Delta\alpha + \left(\frac{z^4}{4} - \frac{z^3}{3}\right)\frac{\Delta^2\alpha}{1\cdot2} + \left(\frac{z^5}{5} - \frac{3z^4}{4} + \frac{2z^3}{3}\right)\frac{\Delta^3\alpha}{2\cdot3} + \left(\frac{z^6}{6} - \frac{6z^5}{5} + \frac{11z^4}{4} - \frac{6z^3}{3}\right)\frac{\Delta^4\alpha}{2\cdot3\cdot4} + \left(\frac{z^7}{7} - \frac{10z^6}{6} + \frac{35z^5}{5} - \frac{50z^4}{4} + \frac{24z^3}{3}\right)\frac{\Delta^5\alpha}{2\cdot3\cdot4\cdot5} + \left(\frac{z^8}{8} - \frac{15z^7}{7} + \frac{85z^6}{6} - \frac{225z^5}{5} + \frac{274z^4}{4} - \frac{120z^3}{3}\right) \times \frac{\Delta^6\alpha}{1\cdot2\cdot3\cdot4\cdot5\cdot6} + \&c.\ \&c.$

Taking this integral from $z = 0$ to $z = 6$, or $x = 0$ to $x = 6h$, and multiplying by h^2, we find, after considerable reductions,

$$\bar{x} = h^2\left\{18\alpha + 72\,\Delta\alpha + 126\,\Delta^2\alpha + \frac{606}{5}\,\Delta^3\alpha + \frac{657}{10}\,\Delta^4\alpha + \frac{639}{35}\,\Delta^5\alpha + \frac{123}{70}\,\Delta^6\alpha\right\}.$$

We might obtain a tenth rule by neglecting small quantities; but we shall simply write down the total result, leaving the reader to obtain any other rules he may think proper.

$$\begin{aligned} \alpha &= \alpha_1 \\ \Delta\alpha &= \alpha_2 - \alpha_1 \\ \Delta^2\alpha &= \alpha_3 - 2\alpha_2 + \alpha_1 \\ &\&c.\ \&c. \end{aligned}$$

Introducing these values, and reducing

Calculations incidental to designing a Ship.

$$\bar{x} = \frac{h^2}{70}\left\{36\,\alpha_2 + 9\alpha_3 + 136\,\alpha_4 + 18\,\alpha_5 + 180\,\alpha_6 + 61\alpha_7)\right\}$$

$= \frac{9h^2}{70}\left\{\frac{28\,\alpha_4 + 5\alpha_7}{9} + 4\,(\alpha_2 + 3\alpha_4 + 5\alpha_6) + (\alpha_3 + 2\alpha_5 + 4\alpha_9)\right\}$; which will give a result much more accurate than that obtained by "Simpson's Rule." The result for $\bar{y}$ may be obtained by "Simpson's Rule," or by squaring the value of y, given above, and neglecting the squares and products of higher order of differences.

Property of Guldinus.

Note 11.—The reader will have no difficulty in obtaining for any plane surface [1]

$$\bar{y} = \frac{\int\int y\,dx\,dy}{\int y\,dx};$$

or $\bar{y} \times A = \frac{1}{2}\int(Y_1^2 - Y_0^2)\,dx$; if A represent the area of the surface, and Y_1 Y_0 denote the limits of y. Multiply both sides by 2π.

$$\therefore\ A \times 2\pi\bar{y} = \pi\int Y_1^2\,dx - \pi\int Y_0^2\,dx.$$

The left hand side is the area of the surface multiplied by the circumference described by its centre of gravity, and the right hand side denotes the difference of the volumes of revolution described by the plane surfaces comprised between the axis of x, the extreme ordinates, and the curve which terminates the generating surface.[2]

Examples.

(1.) Find the centre of gravity of an area, similar to fig. (3.) page 29. the equidistant ordinates measuring 2·5, 3, 3·5, 4, 5, 6, 5·5, 5, 4, 3, 2, 1·5 and 1 feet, respectively, the common interval being 2 feet.

1st, To find the Area by "Simpson's Rule."

Ordinates.	Ordinates.	Ordinates.
2·5 first ordinate.	3 second ord.	3·5 third ordinate.
1·0 last „	4 fourth „	5·0 fifth „
——	6 sixth „	5·5 seventh „
3·5 sum of first and last ord.	5 eighth „	4·0 ninth „
	3 tenth „	2·0 eleventh „
	1·5 twelfth „	——
	——	20 sum of odd ord.
	22·5 sum of „	2
	4	——
	——	40 twice sum of ord.

90·0 four times sum of ordinate.
40·0 twice sum of odd „
3·5 sum of first and last „
——
133·5
2 common interval.
——
3)267
——
89 = area.

2d, To find the Distance of the Centre of Gravity from A_1.

$$\left.\begin{array}{rrcrcr} \text{1st,} & 2\cdot5 & \times & 0 & = & 0 \\ \text{2d,} & 3 & \times & 1 & = & 3 \\ \text{3d,} & 3\cdot5 & \times & 2 & = & 7 \\ \text{4th,} & 4 & \times & 3 & = & 12 \\ \text{5th,} & 5 & \times & 4 & = & 20 \\ \text{6th,} & 6 & \times & 5 & = & 30 \\ \text{7th,} & 5\cdot5 & \times & 6 & = & 33 \\ \text{8th,} & 5 & \times & 7 & = & 35 \\ \text{9th,} & 4 & \times & 8 & = & 32 \\ \text{10th,} & 3 & \times & 9 & = & 27 \\ \text{11th,} & 2 & \times & 10 & = & 20 \\ \text{12th,} & 1\cdot5 & \times & 11 & = & 16\cdot5 \\ \text{13th,} & 1 & \times & 12 & = & 12 \end{array}\right\} \text{ordinates multiplied by 0, 1, 2, 3, \&c.}$$

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[1] This and other properties are due to Pappus, and were published by Guldinus, a Jesuit, who was Professor of Mathematics at Rome, in the middle of the seventeenth century.

[2] See any work on the Calculus for the interpretation of the expressions on the right hand side.

Calculations incidental to designing a Ship.

By "Simpson's Rule."

Results.	Results.	Results.
0 first result.	3 second result.	7 third result.
12 last "	12 fourth "	20 fifth "
—	30 sixth "	33 seventh "
12 sum of "	35 eighth "	32 ninth "
	27 tenth "	20 eleventh "
	16·5 twelfth "	—
		112 sum of odd results.

123·5 sum of even results,
4
—
494 four times "
224 two times "
12 first and last "
—
730
2 common interval.
—
3)1460
—
486·66
2 common interval.
—
973· 3

112 sum of odd results.
2
—
224

∴ Distance of centre of gravity from $A_1 = \frac{973 \cdot 3}{89} = 12 \cdot 4344$.

$(2 \cdot 5)^2 = 6 \cdot 25$
$3^2 = 9 \cdot 00$
$(3 \cdot 5)^2 = 12 \cdot 25$
$4^2 = 16 \cdot 00$
$5^2 = 25 \cdot 00$
$6^2 = 36 \cdot 00$
$(5 \cdot 5)^2 = 30 \cdot 25$
$5^2 = 25 \cdot 00$
$4^2 = 16 \cdot 00$
$3^2 = 9 \cdot 00$
$2^2 = 4 \cdot 00$
$(1 \cdot 5)^2 = 2 \cdot 25$
$1^2 = 1$

6·00
16·00
36·00
25·00
9·00
2·25
—
97·25
4
—
389 four times sum of even ord. squared.

12·25
25·00
30·25
16·00
4·00
—
87· 5
2
—
175 twice sum of odd ord. sqd.

6·25
1
—
7·25 sum of first and last ordinates squared.
389·00
175·00
—
571·25

By last process, we have

$$\therefore \text{Perpendicular } Gg = \frac{571 \cdot 25 \times \frac{2}{3}}{267 \times \frac{2}{3}} = 2 \cdot 139, \text{ \&c.}^1$$

Exercises for practice.

(2.) Find the centre of gravity of a figure similar to the above, when the ordinates are taken 3 feet apart and measure 1·25, 2·35, 4·56, 7·87, 8·97, 9·65, 10·54, 9·97, 8·65, 7·54, 6·34, 7·43, 5·42, 4·53, 4·23 feet respectively.

Distance along the axis from A_1 = 20·82.
Distance above the axis at the above point = 3·945.

(3.) Find the same, as in the last example, when the equidistant ordinates measure 20, 20·5, 21, 22, 22·5, 23, 24·5, 25, 26; 25, 24, 23; 23, 22·5, 21, 20; 19, 18, and 17 feet, respectively, and are taken at 6 feet apart.

Distance along the axis from $A_1 A_n$ from A_1 = 52·82.
Perpendicular distance above ditto at the above point = 11·18.

(4.) Find the same, as in the former examples, when the ordinates are 0, 2, 3, 3·5, 4·5, 5, 6, 7·5, 8, 8·5, 9, 8, 7, 6, 5·5, 4·5, 4, 3·5, 3, 2·5, and 2 feet, and their distance apart is 2 feet.

Distance along $A_1 A_n$ from A_1 = 20 feet nearly.
Distance above $A_1 A_n$ at the above point = 3·0506.

(5.) Find the same when the equidistant ordinates measure 17, 18, 18·5, 19, 19·5, 20, 20·5, 21, 22, 23, 22, 21·5, 20, 19, and 18 feet, their distance apart being 4 feet.

Distance along $A_1 A_n$ from A_1 = 28·605.
Distance above $A_1 A_n$ at the above point = 10·134.

Examples on the Calculation of the Centre of Gravity of Displacement.

Calculations incidental to designing a Ship.

Common interval, 1 foot.

Half Horizontal Areas in square feet, found by Simpson's Rule.				Half-Areas multiplied by 0, 1, 2, 3, &c.
289·25	×	0	=	000·00
300·05	×	1	=	300·05
325·00	×	2	=	650·00
400·25	×	3	=	1200·75
405·25	×	4	=	1621·00
450·65	×	5	=	2253·25
470·75	×	6	=	2824·50
490·00	×	7	=	3430·00
495·25	×	8	=	3962·00
500·00	×	9	=	4500·00
487·65	×	10	=	4876·50
470·55	×	11	=	5176·05
460·65	×	12	=	5527·80
450·75	×	13	=	5859·75
435·25	×	14	=	6093·50
400·15	×	15	=	6002·25
390·00	×	16	=	6240·00
375·25	×	17	=	6379·25
350·00	×	18	=	6300·00

7643·23 = volume by Simpson's Rule.

Common interval, 10·56 feet.

Half-vertical Areas in square feet.				Half-Areas multiplied by 0, 1, 2, &c. respectively.
49·75	×	0	=	000·00
49·95	×	1	=	49·95
52·00	×	2	=	104·00
54·25	×	3	=	162·75
56·45	×	4	=	225·80
78·43	×	5	=	392·15
60·00	×	6	=	360·00
55·25	×	7	=	386·75
48·65	×	8	=	389·20
47·00	×	9	=	423·00
45·75	×	10	=	457·50
43·50	×	11	=	478·50
42·23	×	12	=	506·76
40·22	×	13	=	522·86
38·21	×	14	=	534·94

Volume by Simpson's Rule = 7643·23 nearly.

1st, Beginning with the results in the right-hand column of the horizontal section :—

Results.	Results.	Results.
0000·000	300·05	650·00
6300·000	1200·75	1621·00
—	2253·25	2824·50
6300·000 sum of 1st and last	3430·00	3962·00
	4500·00	4876·50
	5176·05	5527·80
	5859·75	6093·50
	6002·25	6240·00
	6379·25	— [results.
	— [results.	31795·30 sum of *odd*
	35101·35 sum of *even*	2
	4	—
	—	63590·6 twice do.

140405·4 four times do.
63590·6 twice sum of odd do.
6300·0 sum of first and last do.
—
210296
1 common interval.
—
3)210296
—
70098·6 result obtained by "Simpson's Rule."

Therefore, distance of centre of gravity of main body *below* the plane of flotation $= \frac{70098 \cdot \dot{6}}{\text{volume}} = \frac{70098 \cdot \dot{6}}{7643 \cdot 23} = 9 \cdot 17$ feet.

2d, Taking the results in the right-hand column of the vertical section :—

Results.	Results.	Results.
000·00 first result.	49·95	104·00
534·94 last do.	162·75	225·80
—	392·15	360·00
534·94 sum of do.	386·75	389·20
	423·00	457·50
	478·50	506·76
	522·86	— [results.
	— [results.	2043·26 sum of *odd*
	2415·96 sum of *even*	2
	4	—
	—	4086·52 twice do.

9663·84 four times do.
4086·52 twice sum of odd do.
534·94 sum of first and last.
—
14285·30
10·56 common distance.
—
857118
714265
1428530
—
3)150852·768

---

[1] The calculator will always have a check on his work by observing the length of the axis $A_1 A_n$, and observing also whether or not the ordinates near the beginning differ widely from those at the end. If the ordinates do not differ widely in this sense, the centre of gravity will be determined by a line perpendicular to the axis *near* its middle point. If the ordinates are greater near the beginning than at the end, the centre of gravity determined along $A_1 A_n$ will be nearer the *first* ordinate than the *last*, and *vice versâ*.

Calculations incidental to designing a Ship.

50284·256 result obtained by "Simpson's Rule."
10·56 common distance.

301705536
251421280
502842560

531001·74336

$\therefore$ distance of centre of gravity from first vertical section $= \dfrac{53100174}{7643 \cdot 23}$

$= 69 \cdot 47$ feet.

We shall *suppose* the *first* vertical section 49·75 to be that nearest the *bow*, and

234·25 cubic feet, to be the volume of the portion below the last horizontal section, or the portion just above the keel.

22·5 feet, the distance of its centre of gravity below the plane of flotation.

70· „ from the first vertical plane.

324·75 cubic feet, the volume of the portion *before* the first vertical plane, or between this plane and the bow.

10 and 7 feet, the respective distances of the centre of gravity from the same planes as above.

576·00 cubic feet, the volume of the portion *aft* of the last vertical plane, or lying between this plane and the stern.

8 and 160 feet, the respective distances of the centre of gravity from the planes already mentioned.

Then, if d_f, d_v, be the distances of the centre of gravity of the total displacement from the planes of flotation and first vertical, we have

$$d_f = \frac{7643 \cdot 23 \times 9 \cdot 17 + 234 \cdot 25 \times 22 \cdot 5 + 324 \cdot 75 \times 10 + 576 \times 8}{7643 \cdot 23 + 234 \cdot 25 + 324 \cdot 75 + 576}$$

$= 9 \cdot 48$ feet below the plane of flotation.

$$d_v = \frac{7643 \cdot 23 \times 69 \cdot 47 + 234 \cdot 25 \times 70 + 576 \times 160 - 324 \cdot 75 \times 7}{7643 \cdot 23 + 234 \cdot 25 + 576 + 324 \cdot 75}$$

$= 71 \cdot 8$ nearly.

The reader will perceive that all the quantities are *added* in obtaining the former result, and that the last one is *subtracted* in the latter case. The reason for this is, that in the latter case, the portion forward lies on the *opposite* side of the first vertical plane to all the rest, or is measured, what we have called *backwards*. Now, if we had considered the first vertical section, 49·75, as being taken at the stern, then 324·75 × 7 would have been *added*, and 576 × 160 *subtracted*, in consequence of the portion aft lying, in this case, on the opposite side of the first vertical plane to the other portions. In the first result, all the portions lie *below* the plane of flotation. We also perceive that the centre of gravity lies between the sixth and seventh vertical sections inasmuch as their common distance is 10·56, and 10·56 × 6 = 63·36; also, 10·56 × 7 = 73·92; therefore 71·8 − 63·36 = 8·44 feet abaft the sixth section.

MOMENTS OF INERTIA, &c.

ART. 6.—As the calculation of *Moments of Inertia* are of the greatest importance in the determination of the stability of a vessel, we proceed to furnish the reader with a short sketch of the subject.

DEF. (I.)—*The sum of the products of the mass of each particle of any system into the square of its distance from any straight line is named the* MOMENT OF INERTIA *of that System about the given line.*

DEF. (II.)—*If k be a quantity such that the moment of inertia* $= Mk^2$, *then k, the distance at which we may suppose the whole mass,* M *of the body, collected so as not to alter the moment of inertia, receives the name of the* RADIUS OF GYRATION.

Thus, if m_1, m_2, m_3, &c., be the masses of the particles, and r_1, r_2, r_3, &c., their respective distances from a line about which the body or system revolves,

Moments of Inertia.

$$\text{Then } k^2 = \frac{m_1 r^2 + m_2 r_2^2 + m_3 r_3^2 + \text{\&c.}}{m_1 + m_2 + m_3 + \text{\&c.}} = \frac{\Sigma(m r^2)}{\Sigma(m)}$$

$$= \frac{\iiint \varrho\, r^2\, dx\, dy\, dz}{\iiint \varrho\, dx\, dy\, dz}$$

ϱ representing the density, and x, y, z, the co-ordinates of any point of the body or system.

In the calculation of the motion of a rigid body, or system of bodies invariably connected, we meet with the following expressions:—

$$\Sigma mx,\quad \Sigma my,\quad \Sigma mz$$
$$\Sigma mxy,\quad \Sigma mxz,\quad \Sigma myz$$
$$\Sigma mx^2,\quad \Sigma my^2,\quad \Sigma mz^2$$

Now if M represent the total mass of the body, or system, of which m represents a particle, $\bar{x}$, $\bar{y}$, $\bar{z}$, the co-ordinates of the centre of gravity, then

$$M\bar{x} = \Sigma mx,\ M\bar{y} = \Sigma my,\ M\bar{z} = \Sigma mz$$

Note 6, p. 36.

If we select a plane passing through the centre of gravity for one of the planes of reference, that of xy for instance,

then $M\bar{z} = o \therefore \Sigma mz = o$.

If we select for the axis of x, a line through the centre of gravity, and take the origin of co-ordinates at that centre, then we have simultaneously

$\bar{x} = o$, $\bar{y} = o$, $\bar{z} = o$, and therefore
$\Sigma mx = o$, $\Sigma my = o$, $\Sigma mz = o$.

In general for any body, or system of bodies, the *axes* of co-ordinates may be so selected that

Σmxy, Σmxz, and Σmyz become separately $= o$.

DEF. (III.)—Axes so chosen are called the *Principal Axes* of the body at the point which is taken as origin.

PROP. (I.)—*The moment of inertia of any system about any axis is equal to the moment of inertia about an axis through the centre of gravity parallel to the former;* PLUS *the product of the mass of the system into the square of the distance between the two axes.*

For, let p be a particle whose mass is m, and A and G be the traces of two lines (passing through p at right angles to each other) on a plane, the latter one being drawn through the centre of gravity G of the body. Draw pp' $\perp$ to A G, or A G produced and join pA, pG.

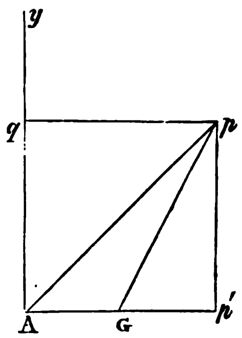

Fig. (A).

Then $pA^2 = pG^2 + AG^2 + 2AG \cdot Gp'$ (Euclid, II. 13),
And $\Sigma(m \cdot pA^2) = \Sigma(m \cdot pG^2) + \Sigma(m \cdot AG^2) + \Sigma(2m \cdot AG \cdot Gp')$.
But as above, $\Sigma mGp' = o \therefore \Sigma(2mAG \cdot Gp') = o$,

$$\text{And } \Sigma(m \cdot pA^2) = \Sigma(m \cdot pG^2) + \Sigma(m \cdot AG^2).$$

If h be the distance between the two axes here mentioned, and k the radius of gyration about an axis through G, the moment of inertia about the axis in question $= M(h^2 + k^2)$ and $\sqrt{h^2 + k^2}$ is generally named the radius of gyration about the given axis.

PROP. (II.)—*The moment of inertia of any plane area about a perpendicular axis is equal to the sum of the moments of inertia about any two lines at right angles to each other in the plane of the area passing through the point in which the axis meets the area.*

Referring to the figure in the last article where Ay is at right angles to Ap', and pq perpendicular to Ay.

$$Ap^2 = pq^2 + pp'^2$$
$$\therefore \Sigma(m \cdot Ap^2) = \Sigma(m \cdot pq^2) + \Sigma(m \cdot pp'^2)$$

Which establishes the proposition.

DEF. (IV.)—*The moments of inertia of a body about its principal axes at any point are called its principal moments at that point.*

If we take the principal axes for the co-ordinate axes and represent the principal moments by A, B, C, then if P be the moment of inertia about an axis whose direction cosines are α, β, γ, then

$$P = A\alpha^2 + B\beta^2 + C\gamma^2$$
$$\text{where } \alpha^2 + \beta^2 + \gamma^2 = 1$$
$$\therefore (A - P)\alpha^2 + (B - P)\beta^2 + (C - P)\gamma^2 = o$$

Moments of Inertia.

then one of the quantities $A-P$, $B-P$, or $C-P$ must have a negative sign, and therefore P must lie between the greatest and least of the quantities A, B, and C. Hence, of all moments of inertia about axes through a given point, the moment of inertia about one of the principal axes is greatest, and about another the least.[1]

Examples.

(1.) Find the moment of inertia of an indefinitely thin rod about an axis in its own plane at right angles to its length and passing through an extremity.

Let x be the distance of any point p from the axis, τ the indefinitely small thickness of the rod, and ϱ its density, supposed uniform, then

$$Mk^2=\varrho\tau\int_0^a x^2\,dx=\frac{\varrho\tau a^3}{3} \text{ where } a \text{ is the length}$$

But $M=\varrho\tau a$

$$\therefore\ k^2=\frac{a^2}{3}$$

(2.) Find the moment of inertia of a circle about an axis in its own plane passing through its centre.

A B the diameter or axis about which we wish to find the moment of inertia.

Take a lamina pq parallel to the given axis $Cr=x$, $pr=y$. Then,

$$x^2+y^2=a^2 \quad . \quad . \quad . \quad . \quad (I)$$

where $a=$ radius is the equation to the circle.

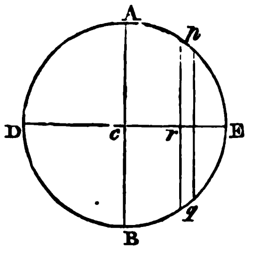

Fig. (B).

If τ be the very small thickness of the circle, ϱ its density, we have for the mass of the lamina $2\varrho\tau y dx$.

$$\therefore\ k^2=\frac{2\varrho\tau\int y dx\times x^2}{2\varrho\tau\int y dx}=\frac{\int x^2 y dx}{\int y dx}=\frac{\int x^2 dx\sqrt{a^2-x^2}}{\int dx\sqrt{a^2-x^2}}$$

$$=\frac{\frac{x^3(a^2-x^2)^{\frac12}}{4}-\frac{a^2x}{8}\sqrt{a^2-x^2}+\frac{a^4}{8}\sin.^{-1}\frac{x}{a}}{\frac{x}{2}\sqrt{a^2-x^2}+\frac{a^2}{2}\sin.^{-1}\frac{x}{a}}+C$$

Take this between the limits $x=a$ and $x=-a$ and $k^2=\frac{a^2}{4}$.

(3.) Find the radius of gyration of a circular area about a straight line parallel to its plane at a distance c from its centre.

$$k^2=\frac{a^2}{4}+c^2 \quad . \quad . \quad . \quad . \quad . \quad (\text{Prop. I.})$$

(4.) Show that the radius of gyration of an ellipse about its major and minor axes are $\frac{a^2}{4}$ and $\frac{b^2}{4}$ respectively.

(5). The radius of gyration of a circle perpendicular to its own plane and passing through its centre $=\frac{a^2}{4}$, and about a similar axis for the ellipse $=\frac{1}{4}(a^2+b^2)$. . . (Prop. II.)

(6.) The radius of gyration of a triangle about an axis perpendicular to its plane and passing through its centre of gravity $=\frac{1}{36}(a^2+b^2+c^2)$, and about an axis at right angles to its plane and passing through one of its angular points $=\frac{1}{12}(3a^2+3b^2-c^2)$ where c is the side opposite the angle through which the axis passes.

(7.) Find the radius of gyration of a parabolic area, 1st, about a line and its plane passing through the vertex at right angles to the axis; 2d, about the axis; 3d, about a line through its vertex at right angles to its plane.

Stability of Floating Bodies.

Then $y^2=4mx$.

1st, $\therefore$ rad. of gyration about line through vertex at right angles to axis and in the plane of parabola

$$=\frac{2\varrho\tau\int x^2 y dx}{2\varrho\tau\int y dx}=\frac{2m^{\frac12}\int x^{\frac52}dx}{2m^{\frac12}\int x^{\frac12}dx}=\frac{\frac{2}{7}x^{\frac72}}{\frac{2}{3}x^{\frac32}}+C$$

Take this from $x=o$ to $x=a$ and the result is $\frac{3}{7}a^2$.

2d, If $2b$ be the double ordinate, a the abscissa,

$$\text{Rad. of gyration about axis}=\frac{2\varrho\tau\int(a-x)\,y^2dy}{\varrho\tau\int(a-x)\,dy}=\frac{\int\left(a-\frac{y^2}{4m}\right)y^2dy}{\int\left(a-\frac{y^2}{4m}\right)dy}$$

$$=\frac{20\,amy^3-3y^5}{60\,amy-10\,y^3}+C.$$

But $m=\frac{b^2}{4a}$ and if we take the integral between the limits $y=b$ and $y=-b$ we obtain

$$\text{rad. of gyration about the axis}=\frac{1}{5}b^2$$

3d, rad. of gyration about an axis through vertex, at right angles to the plane of parabola $=\frac{3}{7}a^2+\frac{1}{5}b^2$ . . . . (Prop. II.)

(8.) Find the radius of gyration of the parabolic area $y=A+Bx+Cx^2$, bounded by the double ordinates $2a$, $2a_3$.

Note 1, p. 29.—About the axis $A_1\,x_1$ also about an axis parallel to the former at a distance c; hence, deduce the moment of inertia of the plane of flotation about its longitudinal and transverse axes through its centre of gravity.

STABILITY OF FLOATING BODIES.

Theory. General principles.

ART. 7.—Various definitions have been given of the *stability* of floating bodies. The reader will probably comprehend the term from the explanation and definitions which follow.

Euler, in his *Theory of the Construction of Vessels*, &c., as translated by Colonel Watson, observes, that, "As soon as a vessel becomes ever so little inclined, or displaced from its state of equilibrium, three consequences may happen:— 1*st*, Either the vessel remains in the inclined state; or, 2*dly*, It re-establishes itself in its preceding situation, when its equilibrium will be permanent, or rather, it will be endowed with a stability which may be great or little according to circumstances; or, 3*dly*, The vessel, after this inclination, will be completely overturned. This equilibrium is called unstable, or ready to fall. We can see, evidently, that neither this last case nor the first can have place in vessels; and with respect to the second case, a sufficient stability is absolutely necessary."[2]

The last remarks here made are not altogether true when a vessel is inclined through considerable angles by impulsive forces. We shall therefore proceed to investigate the different kinds of stability.

Statical Stability.

DEF. (I.)—STATICAL STABILITY *is defined to be the moment of* FORCE (*or effort*), *by which a floating body endeavours to regain its upright or vertical position, after having been deflected from that position.*

DEF. (II.)—DYNAMICAL STABILITY *is defined to be the amount of work*[3] *done on any body, in order to deflect it through any angle from its upright position.*

As has already been stated, it is shown in books on Hydrostatics, that when a body floats *in equilibrium*, the following conditions must be fulfilled:

---

[1] Griffin's *Dynamics of a Rigid Body*, p. 9.

[2] *Vide* chap. iv., sect. 22, of the work here mentioned.

[3] By the amount of work here alluded to, is meant the weight of the body, in pounds avoirdupois, multiplied by the vertical height, in feet, of the sum or difference of displacements of the centres of gravity of the body and of the water which it displaces.

Stability of Floating Bodies.

1*st*, . . $g\varrho V_d = gM$, or simply $\varrho V_d = M$,

where M represents the mass of the floating body, V_d the volume of water displaced, ϱ the density of a cubic unit (say a cubic foot) of water, and g the accelerating force of gravity.

2*d*, The centres of gravity of the body, and of the water which it displaces, must lie in the same vertical line—that is, in a line at right angles to the plane of flotation.

From the first condition, namely $V_d = \frac{M}{\varrho}$, it is at once manifest, that in many bodies, such as some of the solids of revolution, this will furnish us with an infinite number of positions of equilibrium, for all of which the second condition will be fulfilled.

When a body is inclined through any angle from its upright position, the plane of flotation will differ in position from the plane of flotation in the former case; and for every plane of floatation the centres of gravity of the vessel and its displacement will in general have different positions. If we suppose the vessel to *roll* and *pitch*[1] uniformly through any finite angles, the centre of gravity of displacement G_d, or centre of buoyancy, as this point is sometimes called, will describe a portion of a surface in the interior of the vessel.

It will be readily comprehended by the reader, that a vessel may possess a great amount of both kinds of *stability* specified in the definitions up to a certain point, that is, through a given angle from its upright position, and then instantaneously become unstable. Sufficient attention has not been paid to this fact, inasmuch as writers on stability, as applied to ships, generally neglect to discuss the case of unstable equilibrium. It is a well-known fact, that ships have been capsized through unforeseen impulsive forces, as in the case of the Royal George.[2] When the vessel has been inclined through any angle, it has been always customary to assume that the volume of the portion which is *emerged* is equal to that which is *immersed*. This is not accurately true, on account of the inertia of the vessel and the water, as well as on account of the effect of the wind in the sails, which may tend to increase the total displacement.

ART. 8. THEOREM I.—*The line joining the centres of gravity of the displacement of the body in any two positions is parallel to the line joining the centres of gravity of the immersed and emerged portions due to these positions.*

For, let FKL′ represent a transverse section of the body, made by the plane of the paper, and G_d, G'_d the projections of the centre of gravity of displacement in the two positions, g_e, g_i the projections of the centres of gravity of the *emerged* and *immersed* volumes due to the two positions.

Then the immersed portion of the body in the two positions will have the common part

$$V_d - v$$

(the section of which is shown by F′PLK), where v represents the volume of the part emerged or immersed.

Let O′ be the projection of the centre of gravity of the volume $V_d - v$ on the plane of the paper, then by the principles which have been already enunciated (Art. 4, p. 36, &c.), the centre of gravity G_d is determined from

$$G_d\, g_e \times v = G_d\, O' \times (V_d - v) \quad . \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

and the centre of gravity G'_d, in like manner from

$$g_i\, G'_d \times v = G'_d\, O' \times (V_d - v) \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

By (1.) and (2.) $g_e\, G_d \times G'_d\, O' = g_i\, G'_d \times G_d\, O'$;

or, $g_e\, G_d : G_d\, O' :: g_i\, G'_d : G'_d\, O$;

hence $G_d\, G'_d$ is parallel to $g_e\, g_i$. (*Euclid*. vi. 2.)

Next, if we consider the volumes immersed and emerged to be infinitely small, or, in other words, the two planes of flotation, of which FL, F′L′, are the projections, to be indefinitely near, the centres of gravity of these two volumes may be considered as situated in the plane of flotation (FL). In this case $G_d\, G'_d$ becomes parallel to FL, that is, $G_d\, G'_d$ becomes a *tangent* at G_d, to the *curve* traced out by the latter point in the plane of the paper. This is rigorously true at the limit, no matter in which direction we suppose the body to revolve (through an infinitely small angle); it follows, therefore, that all the tangents drawn through G_d are parallel to the plane of flotation; hence

THEOREM II.—*The* TANGENT PLANE,[3] *drawn through the centre of gravity of displacement in position to the surface traced out by this point during the rolling and pitching of the vessel, is parallel to the plane of flotation corresponding to that position.*

ART. 9.—If G (fig. 7) denote the centre of gravity of the floating body, and G_d that of the water displaced, then in positions of equilibrium $G_d\, G$ is a *normal*[4] to the surface described by the latter points. For, by the second condition of equilibrium, given in Art. 7, $G_d\, G$, is necessarily perpendicular to the plane of flotation, and is therefore perpendicular to the tangent-plane at the point G_d, since the latter plane is parallel to the former. Let us suppose the surface traced out by G_d to be actually described, then if from G, the centre of gravity of the body, we draw all the normals which it is possible to do from this point to the surface, we shall determine as many portions of G_d as there are normals, and consequently as many planes of flotation, for all of which there will be equilibrium of one kind or the other—that is, *stable* or *unstable*.

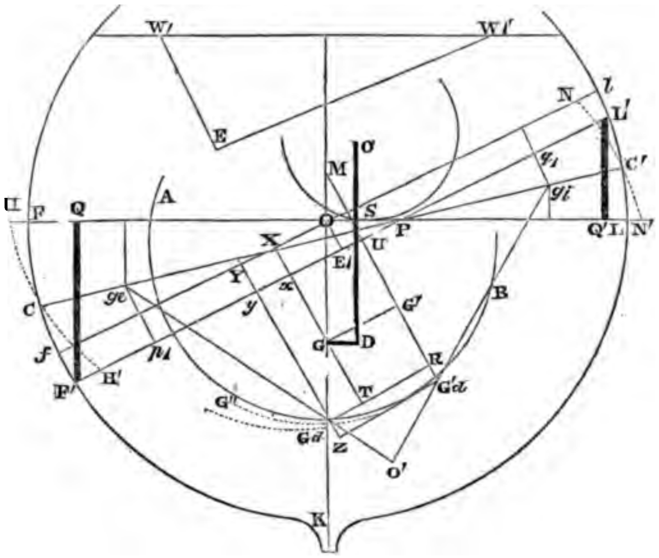

Fig. 7.

A rolling motion will be sufficient to establish the following principles:—

Let us suppose the plane of the paper to be that transverse vertical section of the vessel which contains the centres of gravity of the vessel and its displacement when floating *at rest*. Next let the body be made to roll through any angle, and the point G_d will describe a curve in the same plane, which is represented by AG^dB.

Let G_d, G'_d (fig. 7) be two consecutive positions of the centre of gravity of displacement (that is, two positions indefinitely near to each other); draw normals through these two points to the curve AG^dB, and let them intersect in M, the latter point in geometry and analysis receives the name of the *centre of curvature*; but in regard to the floating body it was named by Bouguer the *metacentre*, and the circle described through G_d with radius MG_d is called the *circle of curvature*, or sometimes the *osculating circle*.

The curve described by the centre of gravity of displacement (centre of buoyancy) has been named the *metacentric curve*. Mr Read, late master-shipwright of H. M. Dockyard, Sheerness, pro-

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[1] By a *rolling* motion is understood a motion about a longitudinal axis, or from stem to stern. By a *pitching* motion is to be understood the motion of the vessel about an axis at right angles to the former axis, or about an axis which lies in a transverse vertical section. During a *rolling* motion only, the centre of gravity of the vessel will remain in the same transverse section; and during a *pitching* motion only, the centre of gravity will remain in a vertical section at right angles to the former. When the motion is due to rolling and pitching combined, the vessel will revolve about an *instantaneous axis*, which may be determined.

[2] And in all probability many other vessels.

By a *tangent-plane* is here meant a plane which *touches* the surface described by G^d at a given point, and which, if produced, does not intersect this surface. For the general definition of a tangent-plane and its properties, see Hymer's and Gregory, and Walton's *Geometry of Three Dimensions*.

By a *normal* to a surface at a given point is meant the line drawn at right angles to the tangent-plane at that point.

posed to call it the *metacentric involute*, and the curve described by M the *metacentric evolute*,[1] which terms are strictly in accordance with mathematical theory.

It will be seen hereafter that the position of the metacentre is of the greatest importance in the determination of the stability and times of oscillation of vessels. Its height above the centre of gravity of displacement may be determined as follows—

ART. 10.—The notation and figure remaining the same as in the previous article; the ordinates measured on *the half-breadth plan* at the load-water line being employed.

RULE XIV.—*Cube the ordinates measured on the half-breadth plan, introduce these* CUBES *as ordinates in Rule I., p.* 140, *and proceed as therein stated; divide the result thus obtained by the volume of water displaced, and* TWO-THIRDS *of the quotient gives the distance of the metacentre from the centre of gravity of displacement.*

Let the vessel be slightly inclined from its upright position, we may consider the areas FPF′ and LPL′ to be two equal sectors of the same circle;[2] then $g_e\, g_i$, the line joining their centres of gravity, will bisect this angle. Draw $g_e\, p_1$, $g_i q_1$ perpendicular to F′L′, and G_dR perpendicular to MG'_d.

Let $r = FP = F'P = LP = L'P$, and it is well known that the centres of gravity are determined by

$$Pg_e = Pg_i = \frac{2\,r\,.\,\text{chord FF}'}{3\text{ arc FF}'} = \frac{2\,r\,.\,\text{chord LL}'}{3\text{ arc LL}'}$$

$$= \frac{4\,r\sin\frac{\phi}{2}}{3\,\phi},\ \phi\text{ being} = \angle\,\text{FPF}'$$

But area of sector FPF′ or PLL′ $= \frac{r^2\phi}{2}$. And

$$P\,p_1 = P\,q_1 = P\,g_e\,.\cos\frac{\phi}{2} = P\,g_i\,.\cos\frac{\phi}{2} = \frac{4\,r\sin\frac{\phi}{2}\cos\frac{\phi}{2}}{3\,\phi} = \frac{2\,r\sin\phi}{3\,\phi}.^{3}$$

Also moment of sector FPF′, or sector LPL′, = area FPF′ × $P\,p_1$

$$= \text{area LPL}' \times P\,q_1 = \frac{r^2\phi}{2} \times \frac{2\,r\sin\phi}{3\,\phi}.$$

$$= \frac{r^3\sin\phi}{3}.\ .\ .\ .\ .\ .\ .\ .\ .\ \text{(I.)}$$

Now, since the solids emerged and immersed are supposed to be equal, and that these solids may be conceived to be collected at their respective centres of gravity, it is clear that the centre of gravity of the volume of water emerged has been moved from p_1 to q_1 in the direction F′L′, while the total volume of water displaced by the vessel has been transferred from G_d to R in a parallel direction. Hence taking moments, we have, by elementary mechanical principles,

$$G_dR \times \varrho \times V_d = p_1 q_1 \times \varrho \times v.\ .\ .\ \ .\ .\ .\ \text{(II.)}$$

Or, $G_dR\,.\,V_d = p_1 q_1\,.\,v$.

But the angle FPF′ = angle $G_dMG'_d$ between two consecutive normals

$$\therefore\ MG_d\sin\phi = G_dR$$

$$\text{From (II.) } MG_d = \frac{p_1 q_1\,.\,v}{V_d\sin\phi}.\ .\ .\ .\ .\ .\ \text{(III.)}$$

Now, if we imagine a plane drawn parallel to the plane of the paper, or to the section shown in the figure, and at the infinitesimal distance Δx, the moments of the volumes of the solids emerged and immersed will be represented by

$$\frac{\sin\phi}{3}\,\Sigma\, r^3\,\Delta x,\ \text{from (I.), or } \frac{\sin\phi}{3}\int r^3 dx;$$

by employing the notation of the Integral Calculus, observing that the integral here given must be taken from stem to stern.

$$\therefore\ MG_d = \frac{2\sin\phi}{3}\,.\,\frac{1}{V_d\sin\phi}\int r^3\,dx.\ .\ .\ .\ \text{from (III.)}$$

$$= \frac{2}{3\,V_d}\int r^3\,dx.\ .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ \text{(IV.)}$$

The integral, $\int r^3\,dx$ is sometimes named the *moment of inertia* of the load-water section FL, about a horizontal axis through the centre of gravity.

It ought to be observed that, though we have here obtained the position of the metacentre of the vessel when in a vertical position, this point may in like manner be obtained, by employing the same rule, when the vessel is inclined through any angle, providing we substitute the ordinates of the *inclined load-water section* for those of the load-water section of the vessel when in an upright position.

ART. 11.—Having obtained the position of the metacentre, we are now in a position to determine the *nature* of the equilibrium when a vessel is in any position; for, if we call the lengths of the lines drawn from G, perpendicular to the curve described by G_d, NORMALS, then

THEOREM III.—*Positions of* STABLE *equilibrium correspond to* MINIMUM *normals, and positions of* UNSTABLE *equilibrium correspond to* MAXIMUM *normals: also these normals will have alternately maximum and minimum values.*[4]

Various demonstrations of this theorem have been given in books on Hydrostatics, and the reader will find the subject discussed in the *Mechanic's Magazine*, a periodical which contains many valuable papers on shipbuilding. The following exposition of the principle may be found sufficient for the mathematical reader.

If (fig. 7) M be the *centre of curvature* corresponding to G_d, and situated at first above G, the osculating circle at G_d will lie both within and without the curve AG_dB in the immediate neighbourhood of G_d, and the circle described from G as a centre, with radius GG_d, will lie entirely within the curve in the vicinity of G_d, and the normal GG_d will be a *minimum* among all those drawn from G to the points of the curve in the neighbourhood of G_d; that is, GG_d will be less than GG'_d and GG''_d. If M lie below G, we learn by the same reasoning that GG_d is greater than GG'_d and GG''_d, since the circle described from G with radius GG_d lies entirely without the curve AG_dB; that is, the contact is of the third order.[5]

These normals are alternately maxima and minima, since between two maximum values there is a minimum, and a maximum between two minima. There are as many maximum as minimum values; hence the number of positions of equilibrium, neglecting the *kind*, is *even*. Moreover,

THEOREM IV.—*When the metacentre lies* ABOVE *the centre of gravity of the vessel, the equilibrium is* STABLE.

For, if we incline the vessel in such a manner that G_d shall be at G'_d, indefinitely near to G_d, the normal at G'_d will pass through M (since the latter point is the intersection of two consecutive normals); then the weight of the water displaced applied at G'_d will be parallel to MG_d and will act upwards, whilst the weight of the body at G′ will act downwards in the direction parallel to MG_d and it is evident that the effect of these two forces will be to bring the points M and G'_d into their original position.[6]

THEOREM V.—*When the metacentre lies* BELOW *the centre of gravity of the vessel, the equilibrium is* UNSTABLE.

For, inclining the vessel as before, through an indefinitely small angle, the effect of the two forces just mentioned will be to bring G′ and M into a vertical position; and since G is above M, the vessel will be capsized.[6]

THEOREM VI.—*When the metacentre coincides with the centre of gravity, the equilibrium is said to be indifferent or neutral; that is, the vessel will rest in the position in which it is then placed.*

ART. 12.—Having obtained the *kind* of stability, we may

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[1] The *metacentric curve* is that made by any plane (a transverse vertical one in the present case) with the metacentric surface.

[2] It is not necessary to consider the sectors as equal, providing we bisect the angle FPF′; and with centre P and radii PC, PC′, we describe arcs of circles intersecting the two planes of flotation (the projections of which are FL and F′L′), the same result as is obtained below may be shown to hold true.

[3] Because $2\sin\frac{\phi}{2}\cos\frac{\phi}{2} = \sin\phi$.

[4] *Maximum* and *minimum* mean *greatest* and *least* values.

[5] See Hall's *Calculus*, p. 200.

[6] The axis about which the vessel rolls is here not supposed to pass through the centre of gravity.

Stability of Floating Bodies.

at once obtain the analytical condition for the NATURAL STABILITY of a body after having proved the following:—

THEOREM VII.—*The centre of gravity of a plane of flotation lies on the line of its intersection, with a plane of flotation indefinitely near to the former plane.*

Let PQ represent the intersection of the two planes here mentioned, g, g', the centres of gravity of the areas EPQ and LPQ, the areas being denoted by A and A′. Now, the centre of gravity of FPLQ is obtained by dividing $g g'$ into two parts reciprocally proportional to those areas. Let, then, ϕ be the infinitely small angle between the two planes of flotation, l and l' the perpendicular distances of g, g', from PQ. As the wedge-like portions emerged and immersed are exceedingly small, we may apply the principle of Guldinus, given at page 36, viz.:—[1]

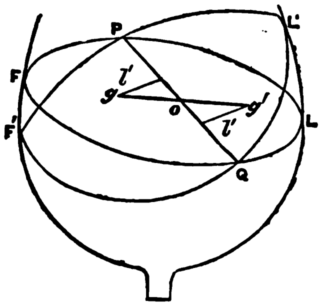

Fig. 8.

Volume F′FPQ $= Al\phi$, and volume LL′PQ $= A'l'\phi$; and since these volumes are equal

$$\therefore Al\phi = Al'\phi \text{ or } Al = A'l';$$

$$\text{that is, } l : l' :: A' : A \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (1)$$

From the similar triangles ghO, $g'h'O$, we have,

$$l : l' :: gO : g'O \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2)$$

hence by (1) and (2),

$$gO : g'O :: A' : A;$$

that is, O is the centre of gravity of the plane of flotation.

It is clear that the point O will trace out a curve in the plane of the paper, provided the body be made to revolve through a finite angle in this direction, and F′L′ is a tangent at O to this curve. Moreover, the vessel might be made to revolve in any direction, and the point O would then trace out what is called the *surface of flotation*. From the manner in which we have obtained the result just given, we arrive at Euler's theorem, viz.,—

The point of contact of the plane of flotation with the surface of flotation is the centre of gravity of that plane.

Moreover, if we conceive (ΔA_1) to represent an elemental portion of the plane FPQF, and r_1 the distance of this element from PQ, then $\phi(\Delta A_1) r_1$ will represent the corresponding volume of the portion FPQF′, assuming it to be a solid of revolution, and the total volume is got from

$$v = \phi\left\{(\Delta A_1) r_1 + (\Delta A_2) r_2 + (\Delta A_3) r_3 + \&c.\right\} = \phi \Sigma (\Delta A) r.$$

We know from the formula for determining the centre of gravity of bodies (p. 35), that

$$gO = \frac{\phi\left\{(\Delta A_1) r_1^2 + (\Delta A_2) r_2^2 + (\Delta A_3) r_3^2 + \&c.\right\}}{\phi\left\{(\Delta A_1) r_1 + (\Delta A_2) r_2 + (\Delta A_3) r_3 + \&c.\right\}}$$

$$= \frac{\phi \Sigma (\Delta A) r^2}{\phi \Sigma (\Delta A) r} = \frac{\phi \int dA \, . \, r^2}{\phi \int dA \, . \, r}.$$

By employing the notation of the Integral Calculus, and bearing in mind that these integrals are to be taken between proper limits:—

Now, $\int dA \, . \, r^2$ is called the *moment of inertia* of the plane PQF in regard to the axis PQ, the density being unity. (See Art 6.)

$\therefore gO = \frac{\phi k_1}{v}$, . k_1 representing this moment of inertia; also,

$g'O = \frac{\phi k_2}{v}$, where k_2 represents the moment of inertia of the plane LPQ, in regard to the same axis.

But $gg' = gO + g'O = \frac{\phi(k_1 + k_2)}{v} = \frac{\phi k}{v}$, k being the moment of inertia of the plane FPLQ in regard to PQ. Returning again to fig. 7, where g_e, g_i, represent the centres of gravity of the indefinitely small volumes emerged and immersed, we have shown that $g_e g_i$ is parallel to $G_d G'_d$.

Stability of Floating Bodies.

$$\therefore \frac{G_d G'_d}{g_e g_i} = \frac{V_d}{v} = \frac{\phi k}{V_d};$$

and ϕ being the angle between two consecutive normals, then $MG_d = \frac{G_d G'_d}{\sin \phi} = \frac{G_d G'_d}{\phi}$, since ϕ is exceedingly small, and the sine may be taken equal to the arc, and $g_e g_i$ is the same as the value of $g g'$ (given above) at the limit; hence

$$MG_d = \frac{k}{V_d} = \frac{\varrho k}{W} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad \text{(I.)}$$

We have seen that the condition of *stable* equilibrium is $MG_d > GG_d$; so that if h denote the distance GG_d, the condition is

$$\frac{k}{V_d} > h, \text{ or } \frac{\varrho k}{W} > h \quad . \ . \ . \ . \quad . \ . \ . \ . \quad \text{(II.)}$$

THEOREM VIII.—*The moment of inertia of the plane of flotation must be greater than the product of the volume of water displaced, and the distance between the centres of gravity of the body and its displacement.*

The value of k may be found by Art. 6.

$$\text{From (I.) } G_d M = GG_d + GM = \frac{\varrho k}{W}$$

$$\therefore GM = \frac{\varrho k}{W} - GG_d \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad \text{(III.)}$$

ART. 13.—*To determine the line of intersection of the plane of flotation of the vessel, when in a vertical position with the plane of flotation, when the vessel has been inclined through any angle;* or to determine the point P (fig. 7) of the intersection of FL and F′L′.

Through O (fig. 7), the middle point of FL, draw fl, making the angle $FOf = LOl =$ given angle ϕ. Let the volumes, of which FOf and LOl are sections, be represented by V_1 and V_2 respectively; also, let v_1 and v_2 represent the volumes of which $EPOf$ and $\overline{L}POl$ are sections, and $v =$ volume emerged or immersed; then

$$V_2 = v + v_2;$$

$$\text{and } V_1 = v - v_1$$

$$\therefore V_2 - V_1 = v_1 + v_2$$

$$= \text{area of plane } fl \times OE \text{ (nearly) where OE}$$

is drawn perpendicular to F′L′.

$$\text{But } OE = OP \sin \phi$$

$$\therefore OP = \frac{V_2 - V_1}{\text{area plane } fl \sin \phi} \quad . \ . \ . \ . \ . \quad \text{(I.)}$$

Various methods have been recommended for the calculation of the solids V_2 and V_1 as well as for the volume v, all three of which are obtained in the same way. The following plan will guide the reader to find v:—

1st. Join FF′ and LL′, and the areas of the triangles FPF′; or LPL′ $= \frac{FP \, . \, F'P \sin \phi}{2}$; or $\frac{LP \, . \, L'P \sin \phi}{2}$.

2d. The curves FCF′ and LCL′ may be considered as parabolas, and the areas lying between FF′ or LL′ and the curves are equal to $\frac{2 \, FF' \, . \times \text{perpendicular height of segment } FCF'}{3}$, and $\frac{2 \, LL' \times \text{perpendicular height of segment } LC'L'}{3}$; or we may employ 3*d* instead of 2*d* to find the areas of the segments just mentioned.

3d. When ϕ is very large, ordinates may be measured at right angles to FF′ and LL′ (seven will always be sufficient), and at equal distances apart, and the area found by Rule (III.) Art. 1. (or by Rule I.)

4th. Having found the areas FPF′ and LPL′ made by each vertical section, introduce these as ordinates in Rule (I.), and proceed as therein stated.

Remark.—Several writers have proposed to draw the ordinates, mentioned in (3), parallel to the plane of flotation. There is, however, little labour saved by such a plan.

For a very large number of vessels, which are *full* below the load-water plane, the following method may be applied, and will, it is believed, be found almost as accurate as those just recommended. Bisect the angle FPF′ by the line CC′, and with radii PC, PC′, describe the arcs HCH′ and NCN′; then the sectors will, in general, be very nearly equal in area to the portions FPF′ and LPL′. If $CP = r$, and $C'P = s$, then the area of the sector HPH′ $= \frac{r_1^2 \phi}{2}$, and area NPN′ $= \frac{s_1^2 \phi}{2}$. Summing these areas (by Rule

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[1] We here suppose that the volumes emerged and immersed are solids of revolution, that is, solids described by the revolution of the planes FPQ and LPQ round PQ. This assumption will be accurate enough when the angle ϕ is very small, as we have assumed it to be.

Stability of Floating Bodies.

I.) from stem to stern, and writing r_1, r_2, r_3, &c., for the 1st, 2d, 3d, &c., radii, with similar expressions for s, &c., we have

$$\text{Volume emerged} = \frac{h\phi}{6}\left\{r_1^2 + r_n^2 + 4(r_2^2 + r_4^2 + \&c.) + 2(r_3^2 + r_5^2 + \&c.)\right\}$$

$$\text{Volume immersed} = \frac{h\phi}{6}\left\{s_1^2 + s_n^2 + 4(s_2^2 + s_4^2 + \&c.) + 2(s_3^2 + s_5^2 + \&c.)\right\}$$

Calling the lines CP, C′P, measured on each vertical section, ordinates, we have the following approximate rule to find the volumes of the solids emerged or immersed:—

Rule XV.—*To the sum of the squares of first and last ordinates add four times the sum of the squares of all the even ordinates, and twice the sum of the squares of all the odd ordinates; multiply this result by the common distance and by the angle through which the ship has rolled—divide by* 6, *and we obtain the volume required* (*nearly*).

Art. 14.—Returning to Art. 8, and referring to fig. 7,

Draw GT parallel to MG_d and GG′ parallel to G_dR.

Then, $G^dR \cdot \varrho \cdot V_d = p_1q_1 \cdot \varrho \cdot v$;

And $GG' = G_dR - G_dT$

$$= p\frac{{}_1q_1 \cdot \varrho \cdot v}{\varrho V_d} - GG_d \sin\phi.$$

$$\because \quad \varrho V_d \cdot GG' = p_1q_1 \cdot \varrho \cdot v - GG_d \cdot \varrho \cdot V_d \sin\phi;$$

$$\text{Or,} \quad W \cdot GG' = (p_1q_1 \cdot w - GG_d \cdot W \sin\phi) \quad . \quad . \quad . \quad \text{(I.)}$$

w representing the weight of water emerged or immersed; Formula (I.) measures the *statical stability*, Def. (I.) of a vessel as given by Atwood in his paper published in the *Transactions of the Royal Society* for the year 1796.

Art. 15.—The rule most frequently used by naval architects to determine the centre of gravity of a vessel, when fully equipped for sea, is due to Chapman, and is as follows:—

Suppose any weight (or weights) W_1, either on the upper deck or elsewhere, is moved from its position at W_1 (fig. 7) to another position, as W'_1, and that by this change of position the ship has been inclined through the angle ϕ. From W'_1 (the centre of gravity of the weight or weights) draw W'_1E parallel to F′L′, and W_1E perpendicular to W'_1E; then $W'_1E = W_1W'_1 \cos\phi = c \cos\phi$; if $W_1W'_1 = c$.

So long as the disturbing weight W_1 remains in its new position W'_1, the vessel will remain in equilibrium, and therefore its centre of gravity must lie in the line G'_dM by the second condition of equilibrium. Hence it has been transferred a distance GG′ parallel to the plane of flotation F′L′, while W_1 has been moved through a distance W'_1E in a parallel direction. Taking moments, we have

$$W \cdot GG' = W_1, c \cos\phi.$$

From Equation I. of last article—

$$GG' = \frac{p_1\,q_1\,w - GG_d \cdot W \sin\phi}{W}.$$

Writing this latter value of GG′ in the former equation, we get

$$GG_d = \frac{p_1q_1\,w_1 - cW_1 \cos\phi}{W \sin\phi}$$

which determines the centre of gravity of the ship, when the centre of gravity of displacement has been determined.

Mr Abethell, master-shipwright of H.M. Dockyard, Portsmouth, proposed the following method, in the second volume of the *Papers on Naval Architecture*:—

"It is applicable whenever a ship is taken into dock with the under side of her keel deviating from parallelism with the upper surface of the blocks. This is almost always the case; and it also not unfrequently occurs that ships are docked 'all standing,' and with so large a portion of their armament and stores on board, that the correction necessary to be made to the result which would be obtained by the experiment and investigation about to be described, in order to make that result agree with the circumstances of any additional armament and equipment, would be comparatively easy. We will now quote from the article in question.

Stability of Floating Bodies.

"'We will suppose, by the falling of the tide in the dock, the after-extremity of the keel to come first in contact with the blocks; then, as the tide continues to fall, the after-body is gradually forsaken by the water, and the fore-body further immersed, a constant equilibrium being maintained between the total weight of the ship and the pressure of the water against the immersed part of the body, until the ship is aground fore and aft. At any intermediate instant the ship may be considered as a lever of the second kind, of which the fulcrum is the transverse line or point of contact of the keel and after-block, and the power and weight, the weight of the immersed volume and that of the ship respectively, each acting in the vertical line passing through its centre of gravity. As we can, by mensuration and calculation from the draught of the ship, easily find its weight, that of the immersed volume, and the perpendicular distance of the line of pressure from the fulcrum: in the equation of the moments, the distance of the vertical line passing through the centre of gravity of the ship is the only unknown quantity, which is therefore readily determined. AN (fig. 9) represents the water-line corresponding to the floating position of the ship, and KL the observed water-line just previously to the fore-part of the keel touching the blocks. The line PBO, perpendicular to AN, passes through the centre of gravity of the displaced volume AFMN, and consequently through that of the ship. Draw QH through the centre of gravity of the volume KFML, perpendicular to KL, and FG through the fulcrum F, parallel to QH. Then, putting the total displacement AFMN = V, KFML = v, and GH = b; if the line SEO, parallel to QH, be drawn at the distance GE from G equal to $\frac{bv}{V}$, it will, as well as PBO, pass through the centre of gravity of the ship, which will be in O, the point of their intersection.

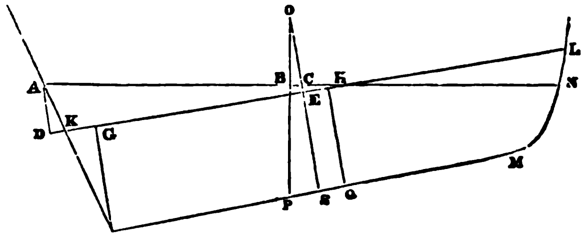

Fig. 9.

"'To obtain from these considerations a general expression for the perpendicular distance of the point O from the water-line AN, draw AD perpendicular to EG, and meeting it, when produced, in D; and having calculated the values of AB and GE, put AB = a, DE or DG + GE = d, and the angle of inclination between the water-lines AN and KL = Δ; then $BO = \left(\frac{d}{\cos} - \sim a\right)\frac{1}{\tan\Delta}$; which must be set off upon the perpendicular PBO, above or below AN, according as $\frac{d}{\cos\Delta}$ is greater or less than a.'"

Dynamical Stability.

Art. 16.—When a vessel is inclined through any angle by a force acting parallel to the surface of the water, the centre of gravity of the body and its centre of buoyancy will generally, as has already been stated, receive vertical displacements. If during the motion we use the same convention in regard to signs as is done in the determination of *Virtual Velocities*, our results will be attended with greater simplicity. That is, if the point of application of any force is moved in *the same direction as that in which this force acts*, then the distance through which the point of application has been moved must be considered *positive*; whereas, *if the point of application is moved in the opposite direction to that in which the force acts*, the distance this point has been moved during the motion must be considered *negative*.

Let h and l be the absolute vertical displacements of the centre of gravity of the vessel, and its centre of buoyancy respectively, after the ship has been heeled through a given angle, then

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[1] See Moseley's paper, p. 619.

Stability of Floating Bodies.

$\pm$ Wh is the work done on the vessel due to its weight, the upper sign being taken when the centre of gravity *descends*, and the lower sign when the centre of gravity *ascends*.

Likewise, $\pm$ Wl is the work done by the upward pressure of the water, the upper sign being taken when the centre of buoyancy *ascends*, and the lower sign when it *descends*. Consequently, the total work done in heeling the vessel through the given angle,

$$= W\,(\pm h \pm l),$$

the signs depending upon the directions of the motions of the centre of gravity and the centre of buoyancy.

Make the same construction as in fig. 7, and draw GX and G_dY perpendicular to fl, meeting F′L′ in x and y respectively; through G'_d draw G'_dZ, parallel to F′L′, intersecting YG'_d, produced in Z.

Here it is easily seen, that while W, the weight of the water displaced, has been moved through the distance G'_dR, the weight of that portion of the water *emerged* has been moved through a distance

$g_ep_1+g_iq_1$ in the same direction[1]. Taking moments,

$$G'_dR\,.\,W = w\,(g_ep_1+g_iq_1) = w.z, \text{ (if } z = g_ep_1+g_iq_1) \quad . \quad (1.)$$

Then, in the case in which GO is greater than Gx, we have

$$\begin{aligned} GO - Gx &= GO - (GX - Xx) \\ &= GO - GO\cos\phi + Xx \end{aligned}$$

If GO be less than Gx, then

$$Gx - GO = GO\cos\phi - GO - Xx$$

Hence $\qquad \pm\,(GO\text{ vers }\phi + Xx) \quad . \; . \; . \; . \; . \; . \; . \; . \quad (2.)$

is the vertical distance through which the centre of gravity has been moved.

Also, when G'_dU is greater than G_dO,

$$\begin{aligned} G'_dU - G_dO &= G_dy + G_dZ - G_dO \\ &= G'_dR + G_dy - Xx - G_dO \\ &= G'_dR + G_dO\cos\phi - GO - Xx \\ &= G'_dR - G\ O\text{ vers }\phi - Xx \end{aligned}$$

And when G'_dU is less than G_dO

$$G_dO - G'_dU = G_dO\text{ vers }\phi + Xx - G'_dR$$

$$\therefore \qquad \pm\left\{ G'_dR - (GO\text{ vers }\phi + Xx) \right\} \quad . \; . \; . \quad (3.)$$

is the vertical distance through which the centre of buoyancy has been moved.

Hence the total work done on the vessel is, where U_d represents the dynamical stability,

$$U_d = W\left[\pm\,(GO\text{ vers. }\phi + Xx) \pm \left\{ G'_dR - (G_dO\text{ vers. }\phi + Xx) \right\} \right] \quad (4.)$$

Suppose the centre of gravity of the vessel to ascend, and the centre of buoyancy to descend, then

$$U_d = W\,(GG_d\text{ vers }\phi - G'_dR)$$

by taking the sign + in the first and − in the second member of the right-hand side, and if we take the contrary signs

$$\begin{aligned} U_d &= W\,(G'_dR - GG_d\text{ vers }\phi) \\ &= W\left\{ (g_ep_1+g_iq_1)\frac{w}{W} - GG_d\text{ vers }\phi \right\} \\ &= wz - W.GG_d\text{ vers }\phi \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5.) \end{aligned}$$

We may readily obtain a relation between the *dynamical* and *statical* stability, for by Equa. 1, Art. 14, the statical stability

$$U_s = W.GG' = (p_1q_1.w - GG_d.W\sin.\phi)$$

$$\therefore \quad GG_d = \frac{p_1q_1.w - U_s}{W\sin\phi}$$

And if we employ Equa. 5, and write this value of GG_d therein

$$\begin{aligned} U_d &= zw - \frac{(p_1q_1.w - U_s)(1-\cos\phi)}{\sin\phi} \\ &= zw - p_1q_1w\tan\frac{\phi}{2} + U_s\tan\frac{\phi}{2} \end{aligned}$$

$$\therefore \qquad U_d - U_s\tan\frac{\phi}{2} = zw - p_1q_1w\tan\frac{\phi}{2} \quad . \; . \; . \quad (6.)$$

Canon Moseley, in his paper on Dynamical Stability, gives

$$U_{(\phi,\,\eta)} = -W\,GG_d + wz$$

as the vessel's stability in regard to rolling or pitching. He takes a prismatic element of the emerged volume, the base of which $= dx\,dy\cos\phi$, and height $= y\sin\phi$; then $w.g_ep_1$, in respect to the element just mentioned, $= \frac{\varrho}{2}y^2\sin^2\phi\cos\phi\,dx\,dy$, and in regard to the whole space represented by the sections E′PQ and L′PQ′, by

$$\begin{aligned} &\tfrac{1}{2}\varrho\sin^2\phi\cos\phi\int y^2\,dx\,dy \\ &= \tfrac{1}{2}\varrho\sin^2\phi\cos\phi\,I \end{aligned}$$

Time of performing an Oscillation.

Where I represents the moment of inertia of the inclined load-water plane, about an axis through P, and inclined at the angles η and $\frac{\pi}{2}-\eta$ to the principal axes of that plane, where η denotes the inclination of line through P (in which the planes FL and F′L′ intersects), to that line about which the plane F′L′ is symmetrical. If h = the perpendicular distance of the line through P from the centre of gravity of the plane F′L′, and A and B denote the moments of inertia of the same plane about its principal axes, A′ = area of this plane, and ψ the value of wz in regard to the spaces FQF′, L′Q′L

$$wz = \frac{\varrho}{2}I\sin^2\phi\cos\phi + \psi$$

$$\text{where } I = A\cos^2\eta + B\sin^2\eta + A'h^2$$

$$\begin{aligned} \therefore \quad U_{(\phi,\,\eta)} = \pm\,W.GG_d\text{ vers }\phi + \frac{\varrho}{2}(A\cos^2\eta + B\sin^2\eta + A'h^2) \\ .\sin^2\phi\cos\phi + \psi \quad . \; . \; . \; . \; . \; . \quad (7.) \end{aligned}$$

the minus sign being taken when GO is greater than G_dO.

Time of Performing an Oscillation.

ART. 16.—There is much difficulty attending the investigation of the times of rolling and pitching of vessels through large angles, inasmuch as the *axis* about which the motion takes place is *instantaneous*. This axis can, however, be determined at any instant, providing the *direction* in which the ship is rolling or pitching be *given*.[1] All methods hitherto given are incomplete, yet all tend to show, that no matter what may be the amplitudes (the angles through which the vessel revolves, providing the position of the ballast, cargo, and other weights retain their original positions), the *time* of performing a complete oscillation, in smooth waters, is the same.

Writers on Hydrostatics, in investigating the time of an oscillation, have usually considered the plane of flotation as constant throughout the motion. The Rev. Canon Moseley, in his paper already quoted, endeavoured to obtain new results for the time of performing an oscillation, as well as for the dynamical stability of the vessel. Notwithstanding that several corrections have been made in the paper, as published in his second edition of *The Mechanical Principles of Engineering and Architecture*, the results are still open to the same objection, since they are made to depend upon the *moment of inertia of the plane of flotation*, which is itself a *variable* quantity throughout the motion. It would seem that the Calculus of Variations might be advantageously applied to the question, or, at all events, Canon Moseley's paper might be made available, providing *we were to calculate the amount of probable error in assuming the plane of flotation constant within given limits.*

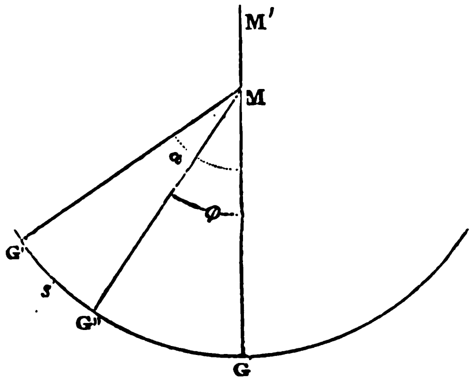

Fig. 11.

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[1] See Moseley's paper.

Time of performing an Oscillation.

ART. 17.—As we shall have to refer to the motion of a *simple pendulum*, we shall here lay before the reader the method by which the time of a complete oscillation is obtained.

In the case of a simple pendulum oscillating *in vacuo*, we imagine a heavy particle suspended from a fixed point by means of an inextensible string without weight.

Let G (fig. 11) be the lowest position of the particle, GM vertical, G′ the initial position of the particle from which it sets out with the velocity v_0, G″ its position after any time t, MG $= l$, $<$ GMG′ $= \alpha$, $<$ GMG″ $= \phi$, arc G′ G″ $= s$. Then the tangential component of the accelerating force is expressed by $\frac{d^2s}{dt^2}$, both in regard to magnitude and sign, the sign + referring to the case where s increases, and — to the case where s decreases.

Now, $s = l(\alpha - \phi) \therefore \frac{ds}{dt} = -l\frac{d\phi}{dt}$, and $\frac{d^2s}{dt^2} = -l\frac{d^2\phi}{dt^2}$, and the tangential component of the weight being $g \sin \phi$, we have

$$\frac{d^2\phi}{dt^2} = -\frac{g}{l}\sin\phi.$$

Multiply by $2\frac{d\phi}{dt}$, and integrate

$$\therefore \left(\frac{d\phi}{dt}\right)^2 = 2\frac{g}{l}\cos\phi + \text{C}.$$

$$\text{But when } \phi = \alpha,\ -l\frac{d\phi}{dt} = v_0,\ \therefore \text{C} = \frac{v_0^{\,2}}{l^2} - \frac{2g}{l}\cos\alpha,$$

$$\text{And } \left(\frac{d\phi}{dt}\right)^2 = \frac{v_0^{\,2}}{l^2} + \frac{2g}{l}(\cos\phi - \cos\alpha,$$

$$\text{And} \qquad dt = -\frac{l d\phi}{\sqrt{v^2_0 + 2gl(\cos\phi - \cos\alpha)}};$$

or, if we suppose the initial velocity zero,

$$dt = -\sqrt{\frac{l}{2g}}\frac{d\phi}{\sqrt{\cos\phi - \cos\alpha}}$$

$$= -\tfrac{1}{2}\sqrt{\frac{l}{g}}\frac{d\phi}{\sqrt{\sin^2\frac{\alpha}{2} - \sin^2\frac{\phi}{2}}} \because \cos\phi = 1 - 2\sin^2\frac{\phi}{2}$$

$$= -\sqrt{\frac{l}{g}}\frac{d\phi}{\sqrt{\alpha^2 - \phi^2}},$$ when the angles α and ϕ are very small.

$$\therefore t = -\sqrt{\frac{l}{g}}\int\frac{d\phi}{\sqrt{\alpha^2 - \phi^2}}$$

$$= \sqrt{\frac{l}{g}}\cos^{-1}\frac{\phi}{\alpha} + \text{C},$$

when, $t = 0$, $\phi = \alpha$, $\therefore \text{C} = 0$

and, $\qquad t = \frac{\pi}{2}\sqrt{\frac{l}{g}}$,

which gives the time for a semi-oscillation.

$$\therefore \text{T} = \pi\sqrt{\frac{l}{g}} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad \text{(T.)}$$

Though the amplitudes have been here considered small, it is not absolutely necessary to make this assumption, as the integral may be found approximately for given values of ϕ, from tables inserted in Legendre's *Traité des Fonctions Elliptiques*; the result of the integration in a series is—

$$t = \frac{\pi}{2}\sqrt{\frac{l}{g}}\left\{1 + \left(\frac{1}{2}\sin\frac{\alpha}{2}\right)^2 + \left(\frac{1\cdot 3}{2\cdot 4}\sin^2\frac{\alpha}{2}\right)^2 + \text{\&c.}\right\}$$

$$\text{But,} \qquad \left(1 - \sin^2\frac{\alpha}{2}\right)^{-\frac{1}{2}} = 1 + \frac{1}{2}\sin\frac{\alpha}{2} + \frac{1\cdot 3}{2\cdot 4}\sin^2\frac{\alpha}{2} + \text{\&c.}$$

Hence we perceive that the terms which enter into t are the squares of the latter terms, and we can thus conclude that the expression for t is a convergent series.

Remark.—The only Tantochronous curve, or the curve in which the times are all equal, whatever may be the amplitudes, gravity only acting, is the *cycloid*, whose equation from the lowest point is

$$y = \sqrt{2ax - x^2} + a \text{ vers}^{-1}\frac{x}{a}.$$

Compound Pendulum.—When a rigid body oscillates about a fixed horizontal axis, not passing through the centre of gravity, the time of an oscillation is determined as follows:

Time of performing an Oscillation.

Let C A D (fig. 12) be a section of the body made by the plane of the paper, which is supposed to pass through the centre of gravity G, and intersecting the axes of rotation at right angles on A. Let P be the projection of any particle on this section, Ax vertical, AG $= h$, AP $= r$, $<$GA$x = \phi$. PA$x = \phi'$, then, by well known principles,

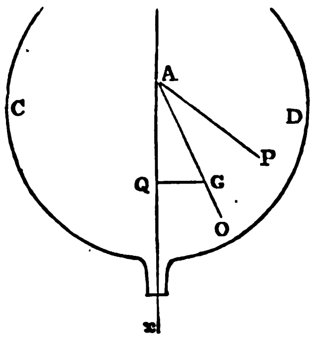

Fig. 12.

$$\frac{d^2\phi}{dt^2} = \frac{\text{moment of forces}}{\text{moment of inertia}}.$$

If Mk^2 be the moment of inertia about an axis through G, and parallel to the given one, then M$(h^2 + k^2)$ (Art. 6, prop. i.) is the moment of inertia of the body about the axis through A, and the moment of the forces about the axis $=$ W$h \sin\phi =$ M$gh \sin\phi$;

$$\therefore \frac{d^2\phi}{dt^2} = -\frac{\text{M}gh\sin\phi}{\text{M}(h^2 + k^2)} = -\frac{g\sin\phi}{l} \text{ if } l = \frac{h^2 + k^2}{h},$$

Multiply by $2\frac{d\phi}{dt}$, and integrate

$$\therefore \left(\frac{d\phi}{dt}\right)^2 = \frac{2g}{l}\cos\phi + \text{C},$$

and if $\frac{d\phi}{dt} = 0$, when $\phi = \alpha$, $\therefore \text{C} = -\frac{2g}{l}\cos\alpha$.

$$\therefore \frac{d\phi}{dt} = \sqrt{\frac{2g}{l}(\cos\phi - \cos\alpha)} = \sqrt{\frac{2g}{l}\left(2\sin^2\frac{\alpha}{2} - 2\sin^2\frac{\phi}{2}\right)}$$

$$= \sqrt{\frac{g}{l}(\alpha^2 - \phi^2)},$$ when α and ϕ are small.

$$\therefore \ \text{T} = \sqrt{\frac{g}{l}}\int_{\alpha}^{-\alpha}\frac{d\phi}{\sqrt{\alpha^2 - \phi^2}} = \pi\sqrt{\frac{l}{g}} = \pi\sqrt{\frac{h^2 + k^2}{gh}} \qquad \text{(I.)}$$

Whence we conclude that the oscillations of such a body are performed in the same manner as if the body were a material particle, and oscillating at a distance, $l = \frac{h^2 + k^2}{h}$ from the axis.

Now, if AO $= \frac{h^2 + k^2}{k}$, then A is the *centre of suspension*, and O the centre of oscillation.

If L $=$ length of the simple *isochronous pendulum*,—that is, the simple pendulum which oscillates in the same time,—

$$\text{then, L} = \frac{k^2 + \text{OG}^2}{\text{OG}} = \frac{k^2}{l - h} + l - h \because \frac{k^2 + h^2}{h} = l$$

$$= \frac{lh - h^2}{l - h} + l - h = l;$$

whence we conclude that the centres of suspension and oscillation are *reciprocal*,—that is, if the body be conceived to oscillate about an axis through O, and parallel to the former axis, then A becomes the centre of oscillation.

The following manner of obtaining the time of an oscillation of a vessel in rolling is due to the Rev. Dr Woolley, and will be the most intelligible to the practical man; and if the times of rolling through different amplitudes be nearly isochronous, as Dr Woolley states, the result is exceedingly simple:—$\pi = 3{\cdot}14159$, &c.

"Suppose GG′ to be an arc described by the centre of gravity, corresponding to the half-angle through which the vessel rolls, and let M, M′, be the limits within which the normals to the curve cut, G M, the former corresponding to the upright position of the vessel, G the centre of gravity of the vessel, then the time of rolling, supposing M to be fixed during the motion, is too great; and if M′ were the point of suspension, the time would be too small; but taking intermediate points, and calculating the time for each, supposed fixed, let T be the true time, α_1, α_2, α_3, &c., the errors, t_1, t_2, t_3, &c., the calculated times, then—

Time of performing an Oscillation.

$$T+a_1=t_1$$
$$T+a_2=t_2$$
$$T+a_3=t_3$$
$$T+an=tn$$
$$\therefore T=\frac{t_1+t_2+t_3+\&c.+tn}{n}-\frac{a_1+a_2+a_3+\&c.+.}{n}$$

Now, since some of these errors are negative and some positive, we may make this result as small as we please, by taking n sufficiently great.

$$\therefore\ T=\frac{t_1+t_2+t_3+\&c.\ tn}{n}\text{, very nearly.}$$

When the distance between M and M′ is very small, as is the case in most vessels for a moderate amplitude, then the question is reduced to the case of a simple pendulum, the length of which is GM. Therefore K being the radius of gyration of the ship round a longitudinal axis through its centre of gravity.

$$T=\frac{\pi K}{\sqrt{g.\mathrm{GM}}}\quad.\ .\ .\ .\ .\ .\ .\ .\ .\quad\text{(I.)}$$

K is obtained by multiplying each of the elementary weights of the vessel by the square of its distance from the horizontal axis through the centre of gravity, and extending the summation throughout the whole ship. Divide this result by the total weight of the ship when ready for sea, and extract the square root of the quotient, which gives K.

We see from (I.), that the time of a natural oscillation varies directly as the radius of gyration, and inversely as the square root of the distance between the centre of gravity of the vessel and its metacentre. Hence, by increasing K, which may be done by moving the weights on board further from the axis about which the ship revolves, the time of oscillation is increased; also K remaining constant, if GM be diminished, T is also increased, and *vice versâ.*

Dr Woolley here supposes the centre of suspension to move in a straight line, but a more accurate way of considering the question is as follows:—

Suppose the metacentric evolute to be found, and the curve described by the centre of gravity is known, we have then to calculate the time of an oscillation of a simple pendulum, whose centre of gravity moves on the metacentric evolute the length of the inextensible thread, which has a material particle at its other extremity, varying between given limits.

The general solution of this question is attended with great difficulties; but, in particular cases, the time of an oscillation may be accurately obtained.

The following is a very similar question, except as far as the reaction of the curve and string is concerned:—

An inextensible flexible thread, of given length, and without weight, is fixed at a given point on the arc of a given curve, which lies in a vertical plane, and to the other extremity is attached a heavy particle; find the time of an oscillation, the particles being acted on by gravity only.

The following is the method given by the Rev. Canon Moseley to find the time of an oscillation when the body is rolling. Let D (fig. 7) be the projection of the axes about which the ship is rolling, and O′ the centre of curvature of the surface traced out by the planes of flotation at the point where the plane F′ L′ touches this surface. Assume R = this radius of curvature, then since the axis about which the ship is rolling is perpendicular to the plane of the paper, its moment of inertia is

Time of performing an Oscillation.

$$W\left\{k^2+(H_1-R)^2\sin{}^2\varphi\right\}\left(\frac{d\varphi}{dt}\right)^1$$

where H_1 represents the depth of the centre of gravity in a vertical position of the ship.

And from the principle of *Vis viva,*

$$W(H_1-H_2)(\cos\varphi-\cos\varphi_1)+\frac{\varrho}{2}A(\cos{}^2\varphi-\cos{}^2\varphi_1)=W\left\{k^2+(H_1-R)^2\sin{}^2\varphi\right\}\left(\frac{d\varphi}{dt}\right)^2$$

Where H_2 is the depth of the centre of buoyancy when the ship is in an upright position,

$$\therefore t(\varphi_1)=\frac{1}{2g}\int_{-\varphi_1}^{+\varphi_1}\sqrt{\frac{k^2+(H_1-R)^2\sin{}^2\varphi}{(H_1-H_1)+\frac{\varrho A}{2W}(\cos\varphi+\cos\varphi_1)(\cos\varphi-\cos\varphi_1)}}\,d_\varphi$$

If $\cos\varphi+\cos\varphi_1=2$, or φ and φ_1 be small,

$$t(\varphi_1)=\frac{1}{2g}\int_{-\varphi_1}^{t+\varphi}\sqrt{\frac{k^2+(H_1-R)\sin{}^2\varphi}{(H_1-H_2)+\frac{\varrho A}{2W}(\cos\varphi-\cos\varphi_1)}}\,d\varphi$$

$$t(\varphi_1)=\frac{1}{\sqrt{2g(H_1-H_2)+\frac{\varrho A}{W}}}\int_{-\varphi_1}^{+\varphi_1}\sqrt{\frac{k^2+(H_1-R)^2\sin^2\varphi}{\operatorname{vers}\varphi_1-\operatorname{vers}\varphi}}\,d\varphi\,;$$

and if R be supposed constant between the limits $-\varphi_1$ and φ_1, we get

$$t_{(\varphi_1)}=\frac{\pi k}{\sqrt{g(H_1-H_2)+\frac{\varrho A}{W}}}\left\{1+\frac{4(H_1-R)^2+k^2}{4k^2}\sin\frac{{}^2\varphi_1}{2}\right\}$$

And since $\sin\frac{{}^2\varphi_1}{2}$ is small,

$$t(\varphi_1)=\frac{\pi k}{\sqrt{\left(H_1-H_2+\frac{\varrho A}{W}\right)g}}$$

and the oscillations are nearly tantochronous.

Throughout these investigations, ϱ = weight of cubic unit of water.

But $H_1=\mathrm{GO}$, and $H_2=G_dO$, also $\frac{\varrho A}{W}=G_dM$ by form (III). Theorem VIII. p. 155;

$$\therefore t(\varphi_1)=\frac{\pi k}{\sqrt{(\mathrm{GO}-G_dO+G_dM)g}}=\frac{\pi k}{\sqrt{(G_dM-G_dG)g}}=\frac{\pi k}{\sqrt{g\,.\,\mathrm{GM}}},$$

which agrees exactly with the result obtained by Dr Woolley; and since t is independent of the angle, we are thus led to the tantochronism of the oscillations which he has assumed.

Calculation of the Displacement of a Yacht.

TABLE I.—*Calculation of the Displacement of a Yacht similar to the Titania.* (See Plate V.)

MAIN BODY.

½ volume of portion below the main body, including the keel, = 100 cub. ft.	Horizontal Ordinates taken at 5·8125 feet apart. Vertical Ordinates taken at 2 feet apart.															Horizontal Areas.
	g	C	Y	U	Q	M	H	D	X	4	8	12	16	20	24	
	1·4	2·75	4·5	6·3	·8	9·4	10·2	10·75	10·75	10·75	10·4	9·5	7·75	4·5	·5	621·744
	·75	1·9	2·3	5·0	6·5	7·7	8·	9·7	9·7	9·5	8·5	7·75	4·0	1·4	·2	485·828
	·4	·8	1·7	2·5	3·5	4·4	5·	5·5	5·5	5·3	4·4	2·75	1·25	·3	·0	250·519
	·0	·5	·8	1·2	1·4	1·7	2·	2·0	2·0	1·75	1·5	1·2	1·0	·0	·0	96·875
	·0	·0	·5	·8	·9	·1	1·4	1·4	1·4	1·0	·9	·8	·75	·0	·0	61·419
Vertical areas........	3·46	9·3	13·86	24·6	31·6	37·86	41·06	46·63	46·63	44·9	40·06	34·4	19·6	7·13	·86	Volume = 2343·3

SMALL PORTION AT THE BOW.

½ volume of knee, &c., = 15 cub. feet.	Horizontal and Vertical Ordinates, each taken 1 foot apart.					Horizontal Areas.
	2	·3	·5	·9	1·4	2·46
	·05	·1	·4	·7	1·0	1·683
	·00	·05	·2	·5	·75	1·116
	·0	·0	·05	·2	·5	·45
	·0	·0	·0	·0	·2	·0
Vertical areas.....	·135	·25	·90	1·85	3·03	Volume =4·45

SMALL PORTION AT THE STERN.

½ volume of rudder, post, &c., = 20 cub. ft.	Horizontal and Vertical Areas, each taken at 1 foot apart.					Horizontal Areas.
	·5	.25	·1	·0	·0	·53
	·2	.1	·05	·0	·0	·216
	·0	.0	·0	·0	·0	·0
	·0	.0	·0	·0	·0	·0
	·0	.0	·0	·0	·0	·0
Vertical areas.....	·43	216	·1	·0	·0	Volume =·464

2343·3 = half volume of main body.
19·45 = volume of small portion at the bow, including knee, &c.
20·464 = volume of small portion at the stern, including rudder-post, &c.
100·000 = volume of small portion above the keel, including the keel.
2483·214 = half volume of water displaced.
2
4966·428 = displacement.
64 = lbs. weight of 1 cubic foot of sea-water.

Number of lbs. in 1 ton = 2240)318363·392(142 = number of tons of water displaced = weight of vessel as she floats at the load-water line.

REMARK.—The reader will have no difficulty in understanding the above calculations, and the manner in which ordinates are measured on the plan of the horizontal water-lines given in Plate V. The sectional areas are found by Rule I. page 29, and these areas are introduced into Rule IV. page 33.

TABLE II.—*Calculation of the Centre of Buoyancy.*

MAIN BODY.

Horizontal Areas multiplied by 0, 1, 2, 3, &c.	Functions.
621·744 × 0 =	000·000
485·828 × 1 =	485·828
250·519 × 2 =	501·308
96·875 × 3 =	290·625
61·418 × 4 =	245·672

000·000 1st function.
245·672 last do.
245·672 sum of 1st and last.

485·828 2d function.
290·625 4th do.
776·453 sum of even functions.
4
3105·812 four times even do.
1002·076 two do. odd do.
245·672 first and last
4353·560
4=(common interval)².
3)17414·240
Displacement of main body = 2343·4)5804·746(2·47

501·038 3d function.
2
1002·076 twice *odd* do.

Vertical Areas multiplied by 0, 1, 2, 3, 4, &c.	Functions.
3·46 × 0 =	·000
9·30 × 1 =	9·300
13·86 × 2 =	27·732
24·60 × 3 =	73·800
31·60 × 4 =	126·640
37·86 × 5 =	189·300
41·06 × 6 =	246·360
46·63 × 7 =	326·410
46·63 × 8 =	373·040
44·90 × 9 =	404·100
40·06 × 10 =	400·600
34·40 × 11 =	378·400
19·60 × 12 =	235·200
7·13 × 13 =	92·690
·86 × 14 =	12·040

These functions introduced into Rule VIII. art. 5, page 35, bearing in mind that the common interval is 5·8125 and ½ volume of water displaced = 2343·3 gives 42 feet nearly for the distance of the centre of gravity of the displacements of the main body from the first vertical section, marked No. 24, at the bow.

Calculating the centres of gravity of the small portions at the bow, stern, and near the keel in the same way, we obtain

Horizontal distance of main body from the section marked No. 24 at the bow .... = 42 feet.
Horizontal distance of portion at the stern, including rudder, port, &c.. = 85 „
Horizontal distance of portion at the bow, including knee, &c. .... = −3 „
Horizontal distance of portion above the keel, including keel... = 60 „

$$\therefore \frac{2343{\cdot}3 \times 42 + 20{\cdot}464 \times 85 + 100 \times 60 - 19{\cdot}45 \times 3}{2483{\cdot}214} = 42{\cdot}7 \text{ ft.} =$$

Distance of centre of gravity of displacement from first section at bow.

Vertical distance of centre of gravity of main body below load-water section .... = 2·47
Vertical distance of centre of gravity of portion at stern, including rudder, &c.. = 5·00
Vertical distance of centre of gravity of portion at bow, including knee, &c.. = 3·00
Vertical distance of centre of gravity of portion above keel, including keel, &c.. = 9·40

$$\therefore \frac{2343 \times 2{\cdot}47 + 20{\cdot}464 \times 5 + 100 \times 9{\cdot}4 + 19{\cdot}45 \times 3}{2483{\cdot}214} = 2{\cdot}7 \text{ feet} =$$

Vertical distance of centre of gravity of displacement below the load-water section.

TABLE III.—*Calculations necessary to determine the Point* P (See Fig. 7.)

To find the volume V_1, Art. 13, p. 45.							To find the volume V_2, Art. 13, p. 45.							To find the area of the plane *f l*.			
Ordinates such as FO from stem to stern.	Ordinates such as *f*O from stem to stern.	Chords F*f*.	Heights of parabolic segments F*f*.	Triangular areas.	Parabolic areas.	Total areas.	Ordinates such as FO from stem to stern.	Ordinates such as *l* O from stem to stern.	Chords L *l*.	Heights of parabolic segments.	Triangular areas.	Parabolic areas.	Total areas.	Ordinates such as *f* O from stem to stern.	Ordinates such as *l* O from stem to stern.	Ordinates *f l* from stem to stern.	
·8	·7	·3	·00	·096	·000	·096	·8	·8	·2	·00	·109	·000	·109	·8	·7	1·3	But OP $=\dfrac{V_2 - V_1}{\text{area plane } f l \sin\phi}$ $=\dfrac{980-636{\cdot}5}{1142{\cdot}2 \times {\cdot}342} = {\cdot}893$ feet.
1·5	1·3	·5	·00	·334	·000	·334	1·5	1·7	·6	·05	·436	·020	·456	1·7	1·3	3·0	
2·1	17	·6	·00	·611	·000	·611	2·1	2·6	1·0	·05	·934	·033	·967	2·6	1·7	4·3	
3·0	2·4	1·0	·00	1·231	·000	1·231	3·0	3·6	1·4	·10	1·846	·093	1.939	3·6	2·4	6·0	
3·8	3·2	1·4	·05	2·079	·047	2·126	3·8	4·8	1·7	·15	3·119	·170	3·289	4·8	3·2	8·0	
4·8	3·7	1·6	·05	3·037	·053	3·090	4·8	5·9	2·1	·16	4·843	·224	5·067	5·9	3·7	9·6	
5·6	4·5	2·0	·05	4·310	.067	4·377	5·6	6·9	2·5	·17	6·608	·283	6·891	6·9	4·5	11·4	
6·5	5·2	2·4	·06	5·780	·096	5·876	6·5	7·9	2·7	·18	8·780	·324	9·104	7·9	5·2	13·1	
7·4	5·6	2·7	·06	7·086	·108	7·194	7·4	8·7	3·1	·18	11·009	·372	11·381	8·7	5·6	14·3	
8·3	6·3	3·2	·06	8·941	·128	9·079	8·3	9·4	3·2	·20	13·341	·427	13·768	9·4	6·3	15·7	
8·9	6·7	3·5	·08	10·199	·187	10·386	8·9	9·8	3·4	·20	14·915	·453	15·368	9·8	6·7	16·5	
9·5	7·2	3·7	·10	11·696	·247	11·943	9·5	10·2	3·5	·20	16·570	·466	17·036	10·2	7·2	17·4	
10·0	7·5	3·9	·10	12·825	·260	13·085	10·0	10·6	3·6	·25	18·126	·504	18·630	10·6	7·5	18·1	
10·5	7·7	4·1	·10	13·825	·273	14·098	10·5	10·8	3·7	·25	19·391	·617	20·008	10·8	7·7	18·5	
10·75	8.0	4·2	·20	14·706	·560	15·266	10·75	10·9	3·8	·30	20·037	·760	20·797	10·9	8·0	18·9	
10·75	8·2	4·2	·20	15·074	·560	15·634	10·75	10·9	3·8	·35	20·037	·887	20·924	10·9	8·2	19·1	
10·50	7·8	4·1	·20	14·005	·547	14·552	10·50	10·8	3·7	·40	19·391	·987	20·378	10·8	7·8	18·6	
10·20	7·5	4·1	·30	13·082	·820	13·902	10·20	10·7	3·6	·50	18·662	1·267	19·929	10·7	7·5	18·2	
9·80	7·0	4·1	.30	11·731	·820	12·551	9·80	10·5	3·6	·35	17·696	1·483	19·179	10·5	7·0	17·5	
9·00	6·4	4·0	·20	9·850	·533	10·383	9·00	10·2	3.6	·30	15·698	·680	16·378	10·2	6·4	16,6	
8·60	5·8	3·6	·20	8·531	.480	9·011	8·60	9·9	3·6	·25	14·559	·567	15·126	9·9	5·8	15·7	
7·70	5·2	3·4	·10	6·487	·227	7·074	7·70	9·6	3·5	·20	12·640	·467	13·107	9·6	5·2	14·8	
6·80	4·4	3·0	·08	5·116	·160	5·276	6·80	9·2	3·5	·15	10·698	·350	11·048	9·2	4·4	13·6	
5·70	3·6	3·5	·00	3·509	·000	3·509	5·70	8·4	3·6	·14	8·178	·336	8·523	8·4	3·6	12·0	
4·40	2·5	2·2	—·2	1·881	—·293	1·588	4·40	7·4	3·9	·10	5·568	·260	5·828	7·4	2·5	9·9	
1·80	1·4	·7	—·1	·431	—·046	·385	1·80	6·1	3·8	·05	1·878	·126	2·004	6·1	1·4	7·5	
·6	·4	·2	·0	·410	·000	·410	·6	·7	— ·2	·00	·872	·000	·072	·7	·4	1·1	
Ordinates taken at 3·3 feet apart.						Volume =636·5 cubic ft.	Ordinates taken at 3·3 feet apart.						V_2=980 cubic ft.	Area of *f l* = 1142·2 square ft.			

TABLE IV.—*Calculation of the Metacentre when the Vessel is in an Upright Position, also when the Vessel has been inclined through an angle of* 20°.

UPRIGHT POSITION.

TABLE I.	
Ordinates on the Half-Breadth Plan at the Load-water Line taken at 5·8125 feet apart.	Cubes of Ordinates to Two Places of Decimals.
1·4	2·74
2·75	20·80
4·5	91·13
6.8	250·05
8·0	512·00
9·4	831·00
10·2	1060·00
10·75	1242·30
10·75	1242·30
10·75	1242·30
10·40	1120·00
9·50	851·00
7·75	465·48
4·50	91·13
·50	·13

INCLINED POSITION.

TABLE II.	
Ordinates measured from P on the inclined Plane of Flotation, taken at 3·3 feet apart.	Cubes of Ordinates to two Places of Decimals.
·7	·34
1·9	6·86
3·0	81·00
4·4	85·18
5·2	140·61
6·2	238·33
7·1	357·91
7·8	474·55
8·2	551·37
8·7	658·50
9·1	753·57
9·4	830·58
9·4	830·58
9·2	778·69
8·7	658·50
8·5	614·12
8·2	551·37
7·5	421·87
7·0	343·00
6·0	216·00
5·0	125·00
3·0	27·00
2·5	15·62

TABLE III.	
Ordinates measured from P′ on the inclined Plane of Flotation, taken at 3·3 feet apart.	Cubes of Ordinates to Two Places of Decimals.
·5	·13
1·4	2·74
2·2	10·65
3·0	27·00
4·5	91·12
4·6	97·34
5·8	195·11
6·8	314·43
7·0	343·00
7·4	405·22
8·7	658·50
9·0	729·00
9·2	778·69
9·4	830·58
9·0	729·00
8·8	681·47
8·6	636·06
8·2	551·37
8·0	512·00
7·0	343·00
6·0	216·00
5·0	125·00
4·0	64·00

The cubes of the ordinates given in the first of these tables introduced into Simpson's rule, gives 44800·81; this result multiplied by ⅔, and divided by 2483·2, or half the displacement, gives 12·3 feet nearly for the distance between the metacentre and centre of buoyancy. (See Rule XIV. p. 44.)

It has been more convenient to take the ordinates at 3·3 feet apart in the second and third of these tables.

The cubes of the ordinates in Table II. introduced into Rule I. p. 29, gives 28829·58.

The cubes of the ordinates in Table III. introduced into the same rule gives 27316·95.

∴ 28829·58 + 27316·95 = 56146·53 = the moment of inertia of the inclined plane of flotation.

Hence, $\frac{2 \times 56146{\cdot}53}{3 \times \frac{1}{2}\,\text{displacement}} = \frac{2 \times 56146{\cdot}53}{3 \times 4966{\cdot}428} = 7{\cdot}53$, height of metacentre above the centre of buoyancy when the ship has been inclined through an angle of 20°. The latter centre must be calculated in the same way as was done in Table II.; whence the position of the metacentre in the inclined state of the vessel becomes completely determined.

TABLE V.—*Calculation of the Volume of Immersion when the Ship is inclined through an angle of* 20° *Nat. Sin* 20° = ·342 – *Ordinates at* 3·3 *feet apart.*

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
Lines similar to PL from stem to stern.	Lines similar to PL′ from stem to stern.	Chords LL′	Heights of parabolic segments.	Distance of centres of gravity of Δ areas from axis.	Distance of centres of gravity of parabolic areas from axis.	Triangular areas similar to PLL′ area $=\frac{PL \times PL' \sin \phi}{2}$	Parabolic areas, area $=\frac{2}{3}$ of LL′ × height.	Total areas.	Areas multiplied by 0, 1, 2, 3, 4, &c., respectively.	Areas of triangles multiplied by distance of centre of gravity from axis.	Areas of parabolic segments multiplied by distance of their centres of gravity from axis.	Column 11 + Column 12.	Column (13) ÷ Column (9) = distance of centre of gravity of sectional areas from axis.	Column (14) multiplied by $\cos\frac{\phi}{2} = \cdot 9484$.	Column (9) multiplied by column (15).
·6	·7	·2	·00	·4	·60	·072	·000	·072	·000	·029	·000	·029	·40	·379	·027
1·4	1·9	·8	·05	1·1	1·7	·455	·027	·482	·482	·501	·046	·547	1·13	1·072	·517
2·3	3·0	1·2	·10	1·7	3·0	1·180	·080	1·260	2·520	2·006	·240	2·246	1·78	1·688	2·127
3·3	4·4	1·7	·10	2·4	4·0	2·483	·113	2·596	7·788	5·959	·452	6·411	2·47	2·343	6·882
4·2	5·2	2·1	·10	3·0	4·9	3·735	·140	3·875	15·500	11·205	·686	11·891	3·07	2·912	12·284
5·2	6·2	2·5	·10	3·7	5·6	5·513	.167	5·680	28·400	20·398	·935	21·333	3·75	3·557	20·204
5·8	7·1	2·7	·10	4·4	7.0	7·042	·180	7·220	43·320	30·985	1·260	32·245	4·46	4·230	30·540
6·7	7·8	2·8	·20	4·8	7·3	8·936	·373	9·309	65·163	42·893	2·723	45·616	4·90	4·647	43·259
7·5	8·2	3·0	·20	5·2	7·9	10·516	·400	10.916	87·328	54·683	3·160	57·843	5·30	5·026	54·864
8.0	8·7	3·0	·22	5·5	8·3	11·902	·440	12·342	111·078	65·461	3·652	69·113	5·61	5·321	65·671
8·5	9·1	3·2	·30	5·8	8·8	13·227	·640	13·867	138·670	76·716	5·632	82·348	5·94	5·633	78·113
8·9	9·4	3·3	·30	6·1	9.3	14·306	·660	14·966	164·626	87·267	6·138	93·405	6·24	5·918	88·369
9·3	9·4	3·4	·30	6·3	9·4	14·949	·680	15·629	187·548	94·179	6·392	100·571	6·43	6·098	95·306
9·4	9·2	3·5	·40	6·0	9·2	14·788	·933	15·713	204·352	88·728	8·584	97·312	6·19	5·871	92·251
9·1	8·7	3·4	·30	6·0	9·1	13·478	·680	14·158	198·212	80·868	6·188	87·056	6·14	5·823	82·442
8·7	8·5	3·3	·30	5·8	8·8	12·645	·660	13·305	199·575	73·341	5·808	79·149	5·95	5·643	75·080
8·5	8·2	3·2	·40	5·7	8·7	11·909	.853	12·772	204·352	67·881	7·421	75·302	5·90	5·626	71·855
7·5	7·5	3·2	·50	5·4	8·4	9·619	1·067	9·686	164·662	51·943	8·963	60·906	6·28	5·956	57·690
7·0	7·0	3·1	·50	4·6	7·2	8·379	1·033	9·412	169·416	38·543	7·438	45·981	4·88	4·628	43·559
6·0	6·0	3·1	·50	4·0	6·3	6·156	1.033	7·189	136·591	24·624	6·508	31·132	4·33	4·107	29·525
5·0	5·0	3·2	·40	3·4	5·3	4·275	·853	5·128	102·560	14·535	4·521	19·056	3·71	3·519	18·065
4·0	3·0	3·1	·30	2·4	3·7	2·051	·620	2·671	56·091	4·922	2·294	7·216	2·70	2·561	6·840
2·5	2·5	3·1	·20	1·7	2·6	1·069	·413	1,482	32·608	1·817	1·074	2·891	1·90	1·802	2·670
								Volume immersed = 622·84 feet; w. = 81 ton.	Distance of centre of gravity from 1st vertical sect. = 401 feet.						$\frac{3210{\cdot}8}{622{\cdot}84}$ = 5·15ft.

Observations on the preceding Tables

Observations on the preceding Tables.

Table VI.—*Calculation of the Volume of Emersion.*

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
Lines similar to FP taken from stem to stern.	Lines similar to F′P taken from stem to stern.	Chords FF′.	Heights of parabolic segments.	Distances of centres of gravity of Δr areas from axis.	Distances of centres of gravity of parabolic areas from axis.	Triangular areas, such as FPF′ area = $\frac{FP \cdot F'P \sin \phi}{2}$.	Parabolic areas, area = $\frac{2\,FF' \times \text{height}}{3}$.	Total sectional areas.	Total areas multiplied by 0, 1, 2, 3, 4, &c. respectively.	Moment of each triangular area about the axis.	Moments of parabolic areas about the axis.	Moments of sectional areas about the axis.	Distance of centres of gravity of sectional areas from the axis.	Column (14) multiplied by $\cos\frac{\varphi}{2} = \cdot 9484$.	Column (9) multiplied by column (15.)
·6	·5	·3	·00	·4	·60	·051	·000	·051	·000	·020	·000	·020	·39	·370	·019
1·4	1·4	·8	·05	·9	1·42	·335	·027	·362	·362	·302	·038	·340	·94	·892	·323
2·3	2·2	1·3	·10	1·4	2·14	·865	·087	·952	1·904	1·211	·186	1·397	1·46	1·385	1·219
3·3	3·0	1·4	·10	2·0	3·04	1·693	·093	1·786	5·358	3·386	·283	3·669	2·05	1·944	3·452
4·2	4·5	1·5	·10	2·8	4·24	3·232	·100	3·332	13·328	9·050	·424	9·474	2·84	2·693	8·973
5·2	4·6	2·0	·12	3·2	4·85	4·090	·160	4·250	21·250	13·088	·776	13·864	3·26	3·092	13·141
5·8	5·8	2·5	·12	3·8	5·75	5·752	·200	5·952	35·712	21·858	1·150	23·008	3·87	3·670	21·844
6·7	6·8	3·0	·14	4·4	6·66	7·791	·280	8·071	56·497	34·276	1·865	36·141	4·47	4·239	34·213
7·5	7·0	3·0	·16	4·8	7·26	8·978	·320	9·298	74·384	43·094	2·323	45·417	4·88	4·628	43·031
8·0	7·4	3·0	·18	5·2	7·87	10·123	·360	10·483	94·347	52·640	2·833	55·473	5·29	5·017	52·593
8·5	8·7	3·2	·20	5·8	8·78	12·645	·427	13·072	130·720	73·341	3·749	77·090	5·90	5·596	73·151
8·9	9·0	3·4	·20	6·0	9·04	13·697	·453	14·150	155·650	82·182	4·095	86·277	6·09	5·776	81·730
9·3	9·2	3·4	·30	6·2	9·42	14·631	·680	15·311	183·732	90·712	6·406	97·118	6·34	6·013	92·065
9·4	9·4	4·0	·30	6·2	9·42	15·110	·800	15·910	206·830	93·682	7·536	101·218	6·36	6·032	95·969
9·1	9·0	4·0	·30	6·0	9·12	14·004	·800	14·804	207·256	84·024	7·296	91·320	6·17	5·852	86·633
8·7	8·8	3·8	·20	5·8	8·78	13·092	·507	13·599	203·985	75·934	4·451	80·385	5·91	5·604	76·209
8·5	8·6	3·7	·20	5·6	8·48	12·500	·493	12·993	207·888	70·000	4·181	74·181	5·71	5·415	70·357
7·5	8·2	3·6	·20	5·0	7·58	10·520	·480	11·000	187·000	52·600	3·638	56·238	5·11	4·846	53·706
7·0	8·0	3·0	·15	5·0	7·56	9·576	·300	9·876	177·768	47·880	2·268	50·148	5·08	4·818	47·583
6·0	7·0	2·0	·12	4·4	6.65	7·182	·160	7·342	139·498	31·601	1·064	32·665	4·45	4·221	30·991
5·0	6·0	2·0	·10	3·8	5·74	5·130	·133	5·263	105·260	19·494	·763	20·257	3·85	3·652	19·122
4·0	5·0	1·5	·10	3·2	4·84	3·420	·100	3·520	73·920	10·944	·484	11·428	3·24	3·073	10·817
2·5	4·0	1·0	·00	2	3·00	1·710	000	1·710	37·620	3·420	·000	3·420	2·60	1·897	3·244
								Volume by *Simpson's Rule* = 600 feet w_2 = 17·1 tons.	Distance of centre of gravity from a vertical section = 41·6 feet.						$\frac{30181 \cdot 745}{600}$ = 5·03 feet.

Observations on the preceding Tables.

It ought to be remarked, that in the foregoing tables extreme accuracy has not been aimed at, either in taking off the lines of the yacht, or the multiplications, &c.: the results are offered to the practical man, merely as illustrations of the rules already given. No remarks are needed on tables I. and II., except that in the latter, the centres of gravity of displacement of the small portions near the bow, stern, and keel, have been assumed instead of calculated; but it will be found that the distances given therein are very nearly correct. Table III. determines the position of the point P (*vide* Art. 12, p. 45). The reader will understand how the necessary data are obtained from the observations appended to Table V.

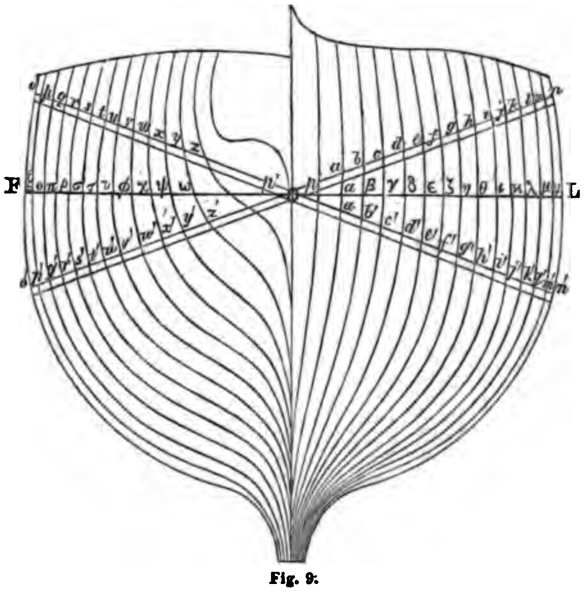

Fig. 9.

Having determined P, set off a distance OP′ = OP (*vide* fig. 7), and through the points P and P′ draw the lines $o'n$ and on' respectively, making angles of 20° with the line FL., then referring to Table V.

The first column is obtained by measuring, on the same scale, the ordinates $P\alpha$, $P\beta$, $P\gamma$, &c. up to PL, and then by measuring $P'F$, $P'\xi$, $P'o$, $P'\pi$, up to $P'a$.

Column (2) is obtained by measuring the ordinates Pa, Pb, Pc, &c., up to Pn, and then $P'o$, $P'p$, &c., up to $P'z$.

Column (3) is got by measuring the right lines $a\alpha$, βb, $c\gamma$, &c., up to nL, and then FO, ξp, &c.

Column (4) is obtained by measuring the perpendicular heights of the small parabolic segments, $a\alpha$, $b\beta$, &c.

Column (5) is got by bisecting the right line joining Ln, joining the point of bisection to P, and measuring all the *bisectors* of the triangles $Pa\alpha$, $Pb\beta$, and by taking two-thirds of these results from stern to stern, as was done in columns (3), (4), since the centre of gravity of a triangle lies in the bisector of a side at a distance of two-thirds of the length of the bisector from the vertex.

In column (6), it has been assumed that the centres of gravity of the parabolic and triangular areas lie in the same right lines, namely, the bisector of the bases of the triangles (produced for the parabolæ). This supposition will be very near the truth. If, then, we add the length of each bisector to two-fifths of the height of each corresponding para-

Observations on the preceding Tables.

bola, we obtain the results contained in this column. The centre of gravity of a parabola, it ought to be observed, is at three-fifths of the length of the axis from the vertex, and, consequently, at two-fifths of the length of the axis from the point where the double ordinate cuts the axis.

Column (7) is obtained by taking the product of the corresponding horizontal numbers, given in columns (1) and (2), and multiplying the result by $\frac{1}{2}$ the natural sine of 20° $= \frac{\cdot 342}{2} = \cdot 171$. Because the area of a triangle $= \frac{1}{2}$ the product of any two sides, multiplied by the natural sine of the included angle.

Column (8) is got by multiplying together the corresponding numbers in the horizontal rows of columns (3) and (4), and then taking two-thirds of the products, since the area of a parabola = two-thirds of the circumscribed rectangle.

Column (9) is obtained by adding together the corresponding areas in columns (7) and (8). These areas are introduced into Rule I. for the volume.

The results in column (10) are obtained by multiplying the results of column (9), by the numbers 0, 1, 2, 3, 4, &c., and these numbers are introduced into Rule VIII., in order to obtain 40·1 feet for the distance of the centre of gravity of the immersed wedge-like portion from the first section at the bow.

The results of column (11) are the areas of the triangles multiplied by the distances of their respective centres of gravity from the axis passing through P.

The results of column (12) are the moments of the parabolic areas about the same axis.

The results of column (13) are obtained by adding together those of columns (11) and (12), that is, $m_1 x_1 + m_2 x_2$ where m_1, m_2 represent the areas of the triangle and parabola respectively, and x_1, x_2 the distances of their centres of gravity from the axis.

The results given in column (14) are obtained from the formula $\bar{x} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$, where m_1, m_2 represent the areas of the triangle and parabola respectively, and x_1, x_2 the respective distances of their centres of gravity from the axis, and $\bar{x}$ the distance of the centre of gravity of the whole area from the same axis.

The results given in column (15) furnish us with the distance of the centre of gravity of each mixtilinear area measured along the inclined plane of flotation P*a*.

Column (16) gives us the moment of each of these areas in regard to the same plane of flotation, and these results introduced into Rule (I.), and divided by the wedge of immersion, gives 5·15 feet, the distance of the centre of gravity of the whole volume of the wedge of immersion measured from the axis along the inclined plane of flotation P*n*, that is the distance $p_1 q_1$.

In Table VI. the same methods are pursued as in Table (V.), the ordinates P*a'*, P*b*, &c.; P'*o'*, P'*p'*, &c., being taken.

The reader will readily perceive how the work in columns (15) and (16) may be curtailed, since each horizontal row is multiplied by the common factor ·9484. He will now have no difficulty in calculating the dynamical stability of the vessel when inclined through the same angle. The results of such calculations are too laborious and lengthy to introduce into the present work after what has already been given.

Adding the results given at the bottom of Tables (V.) and (VI.)

Column (16) we obtain $p_1 q_1 = 10{\cdot}18$ feet.

We have next to ascertain the exact position of G, the centre of gravity of the ship, as she floats at the load-water line, for in the present case all our calculations have been based on this assumption.

Observations on the preceding Tables.

"The position of the vessel's centre of gravity G depends partly on the construction and partly upon the distribution of the lading and ballast, which circumstances therefore determine the distance GG_d, or the distance between the centre of gravity of the vessel and that of the displaced volume."[1]

The centre of gravity may be found by the method enumerated in Art. (4); but as the centres of gravity ought to lie in or a little below the load-water section, we shall *assume* it to be one foot below that section. Then, since

$MG_d = 12{\cdot}3$ feet, *vide* Table IV.
and $OG = 2{\cdot}7$ „ „ Table II.
$\therefore MO = 9{\cdot}6$ „ and $MG = 9{\cdot}6 + 1 = 10{\cdot}6$ feet.
and $GG_d = 2{\cdot}7 - 1 = 1{\cdot}7$ feet.

It will readily be seen, from these results, that equations (I.), (II.), (III.), Art. 11, are satisfied, and hence the vessel is in a *stable* portion of equilibrium after she has been inclined through an angle of 20°.

Atwood, in the paper just quoted, takes GG' as the measure of stability; hence, by Equation (I.), Art. 4,—

$$GG' = \frac{p_1 q_1 w - GG_d \,.\, W \sin\phi}{W}$$

$$= p_1 q_1 \left(\frac{W}{w}\right) - GG_d \sin\phi$$

$$= \frac{10{\cdot}18 \times 17{\cdot}6}{142} - 1{\cdot}7 \times \cdot 342, \text{ where } 17{\cdot}6$$

tons is taken for *w*,—that is, the mean value of the weight of the volumes of water emerged and immersed,

$$\therefore GG' = 1{\cdot}2638 - \cdot 5814 = \cdot 6824 \text{ feet.}$$

If we multiply this result by the weight of the vessel, we obtain the moment of the vessel's stability.

Atwood states that, in some vessels built in his time, the distance between the points G and $G_d = \frac{1}{8}$th of the greatest breadth at the load-water line.[2]

The determination of the stability herein given refers to the rolling motion only of the vessel, though, generally speaking, when a vessel is in a sea-way, there will be both a pitching and rolling motion.

"The force, or measure of stability here given, is entirely independent of the water's resistance, which cooperates with the vessel's stability only while it is inclining, and wholly ceases as soon as the vessel has attained to the greatest inclination, at which it is supposed permanently to remain in a state of equilibrium; the inclining force being exactly balanced by the force of stability."[3]

The time of an oscillation may readily be obtained from Equation (I.), Art. 17.

$$\text{For } T = \frac{\pi k}{\sqrt{g \,.\, GM}}$$

$$= \frac{3{\cdot}1416 \times k}{\sqrt{32{\cdot}2 \times 10{\cdot}6}},$$

when *k* may be calculated when the position of the weights on board are known, inasmuch as the axis about which the vessel is rolling is supposed to be known.

ART. 18.—Naval architects employ a method for delineating the immersed portion of a ship by means of a curve of vertical sectional areas, as well as for determining the position of the centre of buoyancy, &c. The principles employed are those enunciated in Rules I., II., VIII., IX., &c., where the areas, moments, &c., are set off at their respective distances on the base-line,—that is, the load-water

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[1] Atwood's "Disquisition on the Stability of Ships," *Phil. Trans.* of 1798.

[2] Ibid., p. 296.

[3] Ibid., p. 305.

Conclusions deduced from Theory.

line, divided by a constant quantity corresponding to the depth of the volume of water displaced.

Thus the displacement is considered as divided longitudinally into two equal portions, which is equivalent to dividing the base-line of the sectional areas into two equal portions. Thus, if FL (fig. 10) be the load-water line, which is bisected in A, F B L A F is taken to represent half the displacement. If we set off the vertical areas as ordinates at equal distances apart, the curve F B L, passing through their extremities, will be that of the curve of sectional areas, and the centre of buoyancy may be determined by the usual methods. See Peake's *Rudimentary Treatise on Shipbuilding;* London, John Weale.

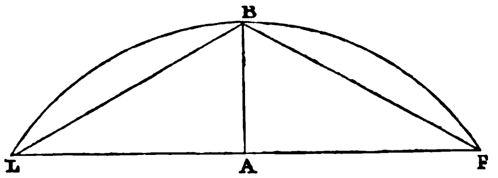

Fig. 10.

Conclusions deduced from Theory applicable to Ship-Building.

Before a naval architect lays down the lines of a vessel, he is aware of the purposes for which she is intended; he knows the armament, cargo, &c., which it is intended she should carry. These being known, as well as her weight at launching, since the specific gravity of the materials of which she is composed is known, the first requirement is to make the total weight and corresponding displacement, when ready for sea, agree with the required draught of water. We know that the displacement depends on the product of the three dimensions, *length, breadth,* and *depth;* the naval architect therefore proceeds to form a rough design, probably in comparison with some well-known ship of the same class, and he will then proceed to adapt this design, as far as practicable, to his own calculations, at least as far as is necessary.

Length. One of the first dimensions he ought to fix on is the *length;* but great care is here required, as one of the dimensions cannot be determined, without, to some extent, determining the others also, in order that the requisite stability may be secured. When the length is too great, there is a great difficulty to be overcome in steering, owing to the effect of the winds and water on the bow, stern, and hull generally.

Breadth. If care is required in fixing the length, still greater caution is required in fixing the breadth, inasmuch as, to a great extent, though not entirely, her stability during a rolling motion depends on this dimension. Dr Inman, in his notes appended to Chapman's *Architectura Novalis Mercatoria,* pp. 273, 274, says that "a straight of breadth, extending as far as possible fore and aft, and above and below the load-water line, is no doubt the most advantageous to the stability at any finite angles of heeling," and also that the vessel ought to be stiff at a small angle, and neither increase too rapidly nor too slowly in the resistance to heeling at larger angles.

If the breadth is not sufficiently great, the weights on board could not be removed sufficiently far from the axis passing through the centre of gravity, and, during a rolling motion, the time would thus be diminished, inasmuch as the moment of inertia of the vessel about the same axis would be diminished, other things remaining the same. (See Equation I., art. 17.) In consequence of this uneasy rolling, it might become necessary in a heavy sea to cut away the masts, &c., in order to ease the ship, since their times of oscillating would not synchronize with those of the vessel. On the other hand, when the weights are placed at a greater distance from the axis of rotation, the moment of inertia, and therefore the time, is, *cæteris paribus,* increased. Generally speaking, the rolling under these circumstances will be easier than in the former case, as the times of oscillation of the masts, &c., will more nearly synchronize with those of the vessel. (See below.)

Conclusions deduced from Theory.

Draught. Much, too, depends upon the draught of water of vessels, for a vessel with too great a draught of water must necessarily meet with great resistance from the pressure of the water on the lower part of the bottom, especially on a wind, and she will therefore tack and wear with difficulty and uncertainty. A greater draught is generally given at the stern than at the bow, since a finer run is thus obtained, and the rudder becomes more deeply immersed in the water. Moreover, in sailing-vessels, the effect of the wind on the sails will generally be to immerse the fore-body more deeply than the after-body, and thus to counterbalance the increased draught of water aft.

Having assumed a length, breadth, and draught of water, the constructor must in the next place determine the position and form of the greatest transverse or midship section. Every naval architect will adhere to his own opinions in regard to the position of this section; but as the vessel has to cleave her way through the water, the position and form of this section, as well as the form of the fore and after bodies, ought to be such as to transmit the displaced fluid with the greatest facility to the right, left, or to the stern. It was with this object in view that Mr Scott Russell proposed his "Wave-Line Theory," by which plan he endeavoured to throw each particle of water, as it came in contact *with the vessel,* just far enough to the right or left, so as to admit of the midship section of the vessel passing through without the same particles of water again coming in contact with her sides. A vessel ought to be so constructed, that when it is made to roll through small angles, all the centres of gravity of the planes of flotation should lie in the midship section; which section should also contain the centre of gravity of the ship, and that of the displaced fluid; for, if these conditions be not fulfilled, the vessel will not roll about an axis parallel to its length; and then for every rolling motion there will also be a corresponding pitching motion.[1]

As has already been remarked, the straining of a vessel depends upon the oscillations of the various portions of the vessel synchronizing with each other, and upon the times of rolling or pitching. *Cæteris paribus,* the more slowly a vessel rolls, the less strain will there be on the masts and timbers; because in quick rolling the masts, on account of their inertia, are not put in motion at the same time as the ship; and by the time the vessel begins to roll back again the masts are still being carried forward, so that this cause will often account for the masts and yards being carried overboard in a heavy storm. In order to make a vessel roll more slowly, the weights ought to be removed to a greater distance from the axis about which she rolls—by running up the yards, for instance; and the more quickly will she roll when the weights are brought nearer to the axis, as when the guns are run back in a heavy sea.[2]

We see by Equation, Art. 17, that the time of rolling depends on the moment of inertia of the ship, and the distance between the metacentre and centre of gravity of the ship. This time varies directly as the former, and inversely as the square root of the latter. Four cases will thus present themselves when the same vessel is immersed to the same draught fore and aft:—

(1.) "The time of natural oscillation may be increased both by reason of the increase of K, Equation (I.), p. 47,

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[1] See Moseley's *Paper on Dynamical Stability.*

[2] Ibid.

Conclusions deduced from Theory.

and the raising of the weights of the ship. This can scarcely be expected except in the case of a very broad vessel with comparatively high masts and yards.

(2.) The time of a natural oscillation may be diminished by the diminution of K, and increased by raising the weights of the ship, and in that case there may result little or no change in the time. .

(3.) It may be increased by the increase of K, and diminished by the lowering of G, the centre of gravity. Here, again, there may be little or no change in the time of oscillation.

(4.) It may be diminished both by the diminution of K, and by the lowering of the centre of gravity.

A ship laden with a very heavy cargo—iron or copper, for instance—will roll more rapidly on both these accounts, if the iron or copper be placed in the hold near the kelson than if raised on a stage; and if it be stowed near the sides of the ship, this circumstance will tend still further to make the vessel roll more slowly.

If G is fixed, it is evident that G G_d will be smallest in those vessels which are full about the water-line and lean below; such ships must therefore, *cæteris paribus*, be quick rollers. If G G_d be increased by lowering G_d—*i. e.*, by making the vessel comparatively full below, and therefore of less depth—M G will be diminished, and the time of oscillation is increased. It is hence evident that the form of a vessel below the water-line must naturally affect its rolling qualities."[1]

Canon Moseley remarks,[2] "That form of vessel in which the surfaces subject to immersion and emersion, when intersected by planes perpendicular to the vessel's length, have *circular sections*, having their centres in a common axis, is, *cæteris paribus*, eminently a *stable form;* because, in a vessel of such a form, the centre of gravity of the portion of the displaced fluid which is included within the solid of revolution formed by all these circular sections, does not in the act of rolling *rise.*

"If it be not practicable to give to the vessel, throughout its whole length, a form subject to these conditions, this is practicable with regard to the midship section, which is the governing section."

On the whole, as might have been expected, vessels with paddles may be built of less breadth than those fitted with the screw, as the paddle-wheels will tend to increase the stability when inclined through a finite angle. This remark ought, however, to be received with some caution.

There cannot be a doubt that, as far as speed goes, the best form of vessel has not yet been obtained, though daily experience seems to show that naval architects are gradually advancing in this respect. To prove this we need only instance the performances of the new Dublin and Holyhead, and Dover and Calais steam-packets, as well as the performances of other fine vessels, as given hereafter in this article, and also in the article STEAM NAVIGATION.

Some further remarks on these points will be found when treating of the forces acting on a ship in motion.

The Forces which act upon a Ship in motion, as they influence her general dimensions, form, and qualities.

Forces affecting a Ship in motion.

The methods by which the displacement of a ship is found, and those by which the positions of her centres of gravity are determined, having been described, and the principles on which her stability depends having been pointed out, it is now proposed to consider the forces which affect her speed through the water.

Laws of resistances.

It was at a very early period pointed out by mathematicians, that the velocity with which water will run out through a small orifice in the bottom of a vessel is the same as that which would be acquired by a body falling from a height equal to the depth from the surface of the water to the hole. The truth of this has been at various times tested by many experiments, and has been confirmed by all that have been made. Euler, in his work, *Theorie Complette de la Construction des Vaisseaux*, took this as the basis of his investigations of the theory of the resistances which solid bodies moving in a fluid have to overcome. A passage in the English transltaion of his work is giventhus:—

> "We know, both from theory and experience, that the water contained in a vessel, whose height is $= h$, will run out through a hole in the bottom with the same velocity that a body falling from the same height, h, would acquire. And if the letter g denotes the height through which a body falls in one second, we also know the velocity will be such that it would run through a distance $= 2\sqrt{g\,h}$ in the same time. Since, therefore, this velocity is supposed $= c$, or $2\sqrt{g\,h} = c$, and, by taking the square, $4\,g\,h = c^2$; whence we have the height sought, $h = \frac{c^2}{4g}$; consequently, the force of the resistance which a supposed plane surface $= f.^2$ will experience by moving in water, with the velocity c, will be $= \frac{c^2 f^2}{4g}$; and by this force the surface will be acted on, in a direction contrary to its motion. Hence, we see that this resistance is always proportioned to the square of the velocity, and also proportional to the area of the surface itself, so that by this means the resistance is perfectly determined."

The truth of this fact may also be made apparent by ordinary reasoning. For if a body be moved in water with a velocity of 1 foot per second, a column of water having the same area for its base as the direct surface or midship section of the body in motion will be moved out of the way, or impelled with a velocity of 1 foot per second, and the weight of this quantity of water will be the measure of the resistance; but if the body be moved with a velocity of 2 feet per second, the column of water will not only be 2 feet long, but each foot in length of fluid must now be moved in half a second, as each particle is moved with double the former velocity. The measure of the resistance therefore is first doubled on account of the doubled velocity, and is again doubled or made fourfold, that is squared, on account of each particle, or the whole of the double quantity, having to be moved at this doubled velocity. The resistance, therefore, which with a velocity of 1 foot per second was $= 1$, will with a velocity of 2 feet be equal to 4, or the square of the velocity. In the same manner, if the velocity be increased from 1 foot to 4 feet per second, the amount of water to be displaced in one second will be four times the quantity; and, again, each particle of water must be moved with four times the original velocity. The measure of the resistance in this case, therefore, will be $= 16$, which again is the square of the velocity; and thus it may be shown, that to whatever degree the velocity may be increased, the resistance will always be increased in the ratio of the square of this velocity.

In all these cases, as the columns of water to be moved always have for their bases the same areas as the areas of the direct surfaces of the moving bodies, so the resistances which are respectively represented by the weights of these columns of water will always be proportional to the areas of the surfaces, or midship sections of the bodies.

Amount of resistance is diminished by form of body.

If the resistance to the motion of a vessel through the water were not lessened and modified by her form, the degree of it, by the foregoing considerations, would be ascertained by finding the weight of a column of water whose base is equal to her midship section, and whose height is equal to that from which a body must fall to acquire the velocity at which she is propelled; and the resistances of similar vessels, when moved with the same velocity, would be proportional to their midship sections. The direct resistance, however, to any plane surface will be diminished by placing a triangular or other form of body before and

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[1] From a paper by Dr Woolley.

[2] Moseley's Paper, &c., p. 634.

Forces affecting a Ship in motion.

behind it. Many experiments have been made on the forms to be added in this manner, with a view to discover the law of the diminution of this resistance, and thus to be able to approximate to the form of least resistance. All attempts to reconcile the theory of the resistances on plane surfaces, as established by experiments, with those on oblique surfaces presented to a fluid, have as yet failed. Bossut[1] was the first to give the theoretical resolution of the resistances on the sides of a wedge-shaped body, which he did as follows; he then showed that this is found by experiment not to be true with respect to bodies with sharp ends moving in water:—

Resistances on oblique surfaces.

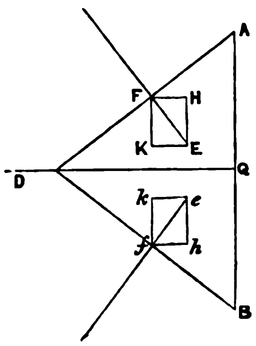

Fig. 12.

Let ADB (fig. 12.) be an isosceles triangle, moving in a fluid of infinite extent in the direction of its height QD. The face AD is subject, according to theory, to a resistance in the direction FE perpendicular to itself, such that in calling ϖ the perpendicular and direct resistance experienced by the half-base AQ. When moved with the same velocity as the triangle, we have force

$$\mathrm{FE} = \varpi \times \frac{\mathrm{AD} \times (\sin \mathrm{ADQ})^2}{\mathrm{AQ} \times (\mathrm{AD})^2}$$

$$= \varpi \times \frac{\mathrm{AD} \times \mathrm{AQ}^2}{\mathrm{AQ} \times \mathrm{AD}^3}$$

$$= \varpi \times \frac{\mathrm{AQ}}{\mathrm{AD}};$$

and in a similar manner we have, for the other force BD, force $e = \varpi \times \frac{\mathrm{BQ}}{\mathrm{BD}} = \varpi \times \frac{\mathrm{AQ}}{\mathrm{AD}}$. Resolving each of the two equal forces FE and fe into the two others, FH, FK and fh fk, the one perpendicular and the other parallel to the base AD of the triangle, it is evident that the two forces equal and directly opposed to each other, FK and fk, destroy each other, and that the triangle is simply acted on in the direction QD by one force $= \mathrm{FH} + fh = 2\,\mathrm{FH} = 2\,\mathrm{FE} \times \frac{\mathrm{AQ}}{\mathrm{AD}} = 2\,\varpi \times \frac{\mathrm{AQ}^2}{\mathrm{AD}^2}$. Hence, if we call this force $2\,\mathrm{FH} = p$, and call the perpendicular and direct force which acts upon the base AB, when moved with the same velocity as the triangle $= \mathrm{P}$, we have $p = \mathrm{P} \times \frac{\mathrm{AQ}^2}{\mathrm{AD}^2}$. Comparing this formula with his experiments, Bossut found the following results in four instances of experiments with different models:—

Distinguishing No. of Model Experimented upon.	Angle of Incidence.	Value of p in Marcs.	
		By Experiment.	By Theory.
9	45°	12·96 nearly.	12
10	33° 41′	10·80 „	7·38 nearly.
11	26° 34′	8·39 „	4·80
12	21° 49′	8·32 „	3·31 nearly.

These differ in theory and in practice.

From the above it is seen that the results of theory differ further and further from those of experiment, the smaller the angle of incidence, that is, the finer the angle of entrance of a ship, is made. Further experiments have been made with a view to discover the law of this branch of the theory of resistances, but as yet without any results such as will enable any calculation to be made to determine beforehand, with any accuracy, the extent to which the resistance of a body of any given form will be diminished from that due to the base or midship section of the body. Even if a law were discovered for different angles of incidence, the difficulty of the investigation would still be great, when it is considered how constantly this angle varies on every portion of the fore-body of a ship. Every one conversant with the practice of naval architecture is well aware, that if a model of a vessel be made in wood, a very slight amount of paring away at the bows will make a very material alteration in the speed, while the alteration upon the angles of incidence would be so small as not to affect, in any material degree, any calculations based upon them as a whole.

Forces affecting a Ship in motion.

Accuracy of theory tested by experiments on plane surfaces.

Theory therefore fails, by any abstract calculations founded on the angles of incidence, to give any rule by which to ascertain the resistance of a vessel of any given form, and consequently to ascertain the velocity that she will obtain by the exertion of any given amount of power to propel her; and the naval architect is thus driven to ascertain these points by comparison with the results obtained from vessels of known form and power.

On bodies of various forms.

It has already been shown, that the resistances experienced by the same body, when moved at different velocities, vary as the squares of the velocities, and that the resistances of vessels similar in form, but of different magnitudes, when moved at the same velocity, are proportional to the areas of their midship sections. Many experiments have been made to test the accordance or otherwise of these theoretical deductions with the actual results obtained in practice. M. Bossut reported, as the result of the experiments conducted for the Royal Academy of Sciences at Paris in the year 1776, that the resistances of the same surface, moved with different velocities through a fluid infinite in extent, follow nearly the proportion of the squares of the velocities, and also that the perpendicular and direct resistances of several plane surfaces, moved with the same velocity, are very nearly proportional to the areas of the surfaces; and, consequently, that experiment and theory may be said to agree on these points. The experiments made in 1796 and 1798 in this country by the Society for the Improvement of Naval Architecture, and conducted by Colonel Beaufoy, lead to the same conclusion. These latter experiments were made with bodies of various forms, and at velocities varying from 1 to 8 nautical miles per hour. The relative proportion or degree in which the resistances and velocities varied in bodies of different forms, differed comparatively slightly, being in some cases above the square or second power, and in other cases below it; in one instance it reached as high as the power of 2·2061, and in another instance as low as 1·7914, but the average of the results obtained from these experiments may safely be taken as corroborative of the theory, and as evidence that it is sufficiently accurate for all practical purposes, and is applicable to vessels of the different forms used in practice by naval architects.

Exception has been taken by some to the results of these experiments, because the bodies were entirely submerged; but the reasons for so conducting the mappear to be stronger than those for conducting a series of experiments on bodies only partially submerged, and then subject to other influences than the action of the water through which they are passing. Deductions based upon the grounds thus established, as furnishing correct data on the subject of resistances, are of great practical value to the naval architect, though the actual or absolute resistances per square foot of surface or of midship section remains undetermined on account of the ever-varying forms given to the bodies of ships before and abaft the midship section.

The relation of power to velocity.

The direct resistances to which any body is subject while moving at different velocities have been shown to be as the squares of the velocities; that is, if R represent the resistance at one velocity called V, and r represent the resistance at another velocity called v, then

$$\mathrm{R} : r :: \mathrm{V}^2 : v^2$$

The power expended to overcome any resistance for any definite distance, or, what is the same thing, the amount of work done within any given time, may be represented by the product of the resistance overcome, multiplied into the velocity, or by the product of the weight representing the resistance, multiplied into the distance passed over by it.

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[1] *Nouvelles Expériences sur la Resistance des Fluides.* Paris, 1777.

Forces affecting a Ship in motion.

If R then be multiplied by V and r by v, the products will respectively represent the powers employed in each case, and $RV=P$ whilst $rv=p$.

Reverting to the formula—

$$R : r :: V^2 : v^2$$

it is evident that by multiplying both sides by the proportional $V : v$, we obtain

$$RV : rv :: V^3 : v^3,$$

and by substitution of equals or equality of ratios,

$$P : p :: V^3 : v^3.$$

In calculations respecting the speed of vessels, the power taken is generally the indicated horse-power, or the gross power exerted in the cylinders; and to denote this, IHP is generally used instead of P. This will make the formula stand thus:—

$$IHP : ihp :: V^3 : v^3.$$

From this it will be seen that the horse-powers vary as the cubes of the velocities, or the velocities vary as the cube roots of the powers required to produce them. If the velocity, therefore, of any vessel with any given amount of horse-power is known, the velocity she will attain with any other amount of power, or any other velocity being assumed, the power necessary to drive her at that velocity may be computed.

Examples.

Example.—A vessel having been proved to have a speed of 8·328 knots per hour, with 813 indicated horse-power, it is desired to know what velocity she would attain with 2000 indicated horse-power; the vessel being supposed in every case to have the same draught of water, so that there is always the same body to be propelled, the formula would stand thus:—

$$813 : 2000 :: 8{\cdot}328^3 : v^3.$$

V, the required speed, is thus found to be equal to 11·25 knots.

Or, with the same vessel it is desired to know what indicated horse-power would be required to give her a velocity of 11·25 knots—

$$8{\cdot}328^3 : 11{\cdot}25^3 :: 813 : ihp;$$

ihp, the required indicated horse-power, is thus found to be 2000 horses.

Comparison of vessels of different sizes and powers.

The speed or the power thus obtained, even though in practice it may be impossible to carry out the conditions, will be a mathematical truth, and will afford perfectly sound grounds from which to draw conclusions with respect to other vessels in which these conditions will be possible. For instance, in theoretical calculations, a large amount of power may be supposed to be put into a vessel of so small a size that she could not carry it, but the velocity found by calculation as due to this small vessel with this large amount of power may be used as a ground of comparison, if it be desired to compare her performance with the performance of a vessel of sufficient capacity to carry this power. A comparison in this way may even be carried so far that the performances of H. M. yacht Fairy, of 312 tons measurement, may be used to predict the speed attainable by a vessel of the size of the Great Eastern if built with a midship section, and with lines of the same character, so as to be as near as may be mathematically similar. This mode of comparison has been most successfully carried out by Mr Atherton, who has investigated the subject of comparative steam-ship capability at great length, and in a most able and valuable manner.[1]

Such comparisons are mathematically correct.

Forces acting on a Ship in motion.

The mathematical correctness of the comparisons between similar vessels, though of different sizes and propelled by engines of different powers, may be demonstrated by reverting to the fact that the resistances of two different areas are directly as these areas when both are moved at the same velocity; and that the velocities of the same vessel, or of two vessels of the same size and similar in all respects, are as the cube roots of the powers, the areas or midship sections of the two vessels being the same, and therefore equal. When the areas or midship sections are not equal, it is evident that the cubes of the velocities will be to each other as the ratios of the powers to their respective areas, thus:—

$$V^3 : v^3 :: \frac{P}{A} : \frac{p}{a} \text{; and therefore,}$$

$$V^3 : v^3 :: Pa : pA, \text{ or}$$

$$\frac{V^3A}{P} = \frac{v^3a}{p}$$

A coefficient may be employed.

In using this formula, a coefficient C may be introduced thus—

$$\frac{V^3 \times A}{P} = C \text{ and } C = \frac{v^3 \times a}{p}$$

for the purpose of saving labour in the calculations.

The velocity, area of midship section, and horse power of any vessel being known, the coefficient for that vessel may thus be found; and if it be proposed to build a larger vessel, similar in proportions to the existing vessel, of which all the particulars are known, and which is called the type of the larger one, then the coefficient, the area of midship section and the horse-power of the proposed vessel being known, the speed she will attain is found as above.

A ratio of displacement may be used instead of midship section.

In practice a ratio of the displacement of ships to be compared is frequently used in preference to the ratio of their midship sections, because it is considered that there is likely to be a nearer approach to a mathematical similarity in this case. If two vessels of different displacements, D and d, and different midship sections, A and a, be mathematically similar, then the displacements vary as the cubes of any one of their like dimensions,—their breadths, for instance; whereas, the areas of the midship sections vary as the squares of the same dimensions; that is, if B and b denote the breadths of two similar vessels at the load-water line,

$$\begin{array}{ll} & B^3 : b^3 :: D : d, \\ \text{and} & B^2 : b^3 :: A : a. \\ \text{Hence,} & B^6 : b^6 :: D^2 : d^2, \\ \text{and} & B^6 : b^6 :: A^3 : a^3; \\ \text{therefore,} & A^3 : a^3 :: D^2 : d^2, \\ \text{and} & A : a :: D^{\frac{2}{3}} : d^{\frac{2}{3}}. \end{array}$$

Any other dimensions—viz., the lengths or the depths—might have been employed. The principles here made use of are generally stated thus:—

The volumes of similar solids are as the cubes of their like dimensions, and the areas of similar figures are to each other as the squares of their like dimensions. Hence, then, $D^{\frac{2}{3}}$, or $\sqrt[3]{D^2}$ may be used instead of the areas of the midship section, and the formula $\frac{V^3 \times A}{P}$ (or $\frac{V^3 \times \text{mid. sec.}}{IHP}$, as it is generally written), may be substituted by the formula $\frac{V^3 \times D^{\frac{2}{3}}}{IHP} = C$.

Example of the application of the formula.

As an example of the practical use of this formula, let it be supposed that there is a vessel in existence whose velocity is 8·328 knots, with the exertion of 813 indicated horse-power, and whose displacement is 3080 tons. The coefficient for this vessel is therefore found thus,

$$\frac{8{\cdot}328^3 \times 3080^{\frac{2}{3}}}{813} = C = 150{\cdot}4.^{[2]}$$

It is now desired to find what will be the speed of a vessel similar in form to this vessel, but so much larger as to have a displacement of 5760 tons, and with an indicated horse-power of 2000 horses. In this case

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[1] *Steamship Capability*, by C. Atherton, Grant, Woolwich, 1854.

[2] In Mr Atherton's work, previously quoted, tables of the cubes of the velocities, or v^3, and of the cube roots of the squares of the displacements, or $D^{\frac{2}{3}}$, otherwise written $\sqrt[3]{D^2}$, will be found, which will materially lessen the labour of these calculations.

Forces acting on a Ship in motion.

$$\frac{V^3 \times 5760^{\frac{2}{3}}}{2000} = 150{\cdot}4$$

$$\therefore V = \sqrt[3]{150{\cdot}4 \times \frac{2000}{5760^{\frac{2}{3}}}} = 9{\cdot}78 \text{ knots.}$$

Hogue and Duke of Wellington compared prior to completion of the latter.

These figures are not imaginary, the results given as those of the smaller vessel are the results which were obtained from H.M. ship Hogue, on trial at the measured knot in Stokes Bay, at Portsmouth, and the particulars of the larger vessel are those which were assumed for H.M. ship Duke of Wellington in 1852, before she or any vessel of her class had been fitted or tried with a screw propeller and steam power. On actual trial the Duke of Wellington realised a speed of 9·891 knots, with a displacement of 5829 tons, and an indicated horse-power of 1699·2 horses. The coincidence of the actual results with the speed, as calculated by the formula, is remarkable; but many instances of similar correctness might be quoted. In using the formula, however, it must never be forgotten that the vessels, though of different sizes, must be mathematically similar, in order that the results may be true, and that otherwise the results must only be looked upon as approximations nearer or farther from the truth, as this condition is more or less nearly fulfilled, care being taken that the propelling power in both cases is applied with equal efficiency. It is scarcely necessary to remark, after what has been said, that the higher the coefficient or index number of any vessel is, the better is her relative performance, taking into account her size, power, and speed.

For correct comparison, vessels must be mathematically similar.

Actual resistances per foot difficult to determine.

It has before been shown that calculations founded on the angles of incidence at the bows of a ship to determine the exact resistances, do not correspond with the results obtained by experimental researches or with practice. Attempts are still being made to determine the exact resistances to ships of different forms, moving at different velocities, and valuable additions to our knowledge, in this respect, may yet be looked for; but the subject is one which is beset with many difficulties. The state of the surface of the immersed body will always affect this question greatly; and, after the utmost care, it is most difficult to ensure that two vessels brought together for rigid comparison, or that two or more results obtained from the same vessel at different periods of time, shall be equally affected in this way. The speed of a vessel has been found by observation to be reduced as much as 20 per cent. by the foulness of the bottom. It must be observed, however, that whilst this last-mentioned fact proves the extent of the influence which the friction of the water upon the surface of the vessel exercises upon her speed, it in no way invalidates the foregoing calculations, because similar vessels, with their surfaces in a similar state, no matter what that state may be, whilst within the limits of roughness or foulness found in practice, will still have their speeds to vary as the cube roots of the powers.

The amount of frictional resistance influenced by state of surface.

Formulæ founded on the angles at bow and stern, and on friction of surfaces

The following formulæ were submitted to the Institution of Civil Engineers in 1857, as the results of some experiments instituted by Mr Hawksley, and as the results of experience up to that time on the subject:—

$$\text{“}H = V^3 \left\{ \frac{a}{174} \sin^2 \frac{\theta}{2} \times \sin^2 \frac{\theta'}{2} + \frac{S}{25125} \right\} \quad . \quad . \quad . \quad \text{No. 1.}$$

$$V = 29 \left(\frac{H}{144\, a \left(\sin^2 \frac{\theta}{2} + \sin^2 \frac{\theta'}{2} + S \right.} \right)^{\frac{1}{3}} \quad . \quad . \quad . \quad \text{No. 2.}$$

In which H was the effective horse-power, and equal about $\frac{5}{8}$ths of the indicated horse-power, and a the area of the midship section in square feet, θ the angle of the bow lines, θ' the angle of the stern lines, and s the immersed or wetted surface of the vessel in square feet. The value of the coefficient of s had been ascertained from numerous experiments made to determine the friction of water passing through pipes, and, from the consistency of the results, might be regarded as practically correct for surfaces of iron. At a velocity of 15 feet per second, the resistance of water amounted to 25 ounces per foot superficial.

Forces acting on a Ship in motion.

The precise value of the coefficient of a was somewhat less certain, inasmuch as the theoretical and experimental results were not altogether coincident, or in perfect agreement amongst themselves, and it was therefore proposed to institute a further course of experiments, which would, in due time, be laid before the Institution. In their present form, however, the equations would give a near approximation to actual experience; for instance, when applied to the Atrato, a large steamer having upwards of 3000 indicated horse-power on board, the formula gave a speed of 15 miles per hour, while, upon the measured mile, the actual speed appeared to be 16 miles per hour. It was quite useless to attempt equations for curved forms, nor was it necessary to do so, as by dividing the immersed solid into four parts, by five equidistant planes taken parallel to the load-water line, and calculating each part by three or more angles, formed by the intersection of tangents to the respective curves of the bow and the stern lines, any required degree of exactitude might be obtained. In general, with regard to sharp vessels, a single calculation would be sufficient for ordinary practical purposes, and especially after a little experience had been gained, in estimating the angles at the head and stern, capable of approximating to the results of curves.”

Comparison with a type preferred.

It is believed, however, that the results before shown as being so easily obtained by comparison with the known performances of any known vessel, even though she may not be in all respects an exact type of the proposed vessel, will still be found in practice to be a safer guide than any calculations founded on such assumed amounts of actual resistance and friction, when it is desired to obtain the speed, or any other element of performance, to be expected from any hypothetical vessel.

Ratio of indicated co-effective horse-power affects the results of foregoing calculations.

Another element affecting the correctness of the resulst of all these calculations to determine the speed due to any vessel, is the difference between the indicated horse-power, or the gross power exerted in the cylinder of a steam-engine, and the net horse-power really effective in propelling the vessel—that is, the power left for this purpose after deducting the amount expended in the friction, and in working the parts of the engine itself. Engineers have not, as yet, succeeded in devising any ready and satisfactory method by which the amount of effective horse-power in any ship may be measured separately from the gross horse-power as shown by the indicator to be exerted in the cylinder. Dynamometers have been fitted to some ships, but their action has been so irregular and anomalous that no reliance can be placed on the results obtained from them. A very beautiful instrument as a dynamometer for this purpose was fixed in the dockyard at Woolwich, designed by Professor Colladon of Geneva, and some valuable results have been obtained from it, showing a much greater difference between the indicated and effective horse-power than that assumed by Mr Hawkesley in the formula by him, as previously quoted. It is usual, however, to assume that the ratio between the indicated and the effective horse-power, whatever that ratio may be, remains constant, and is the same in all cases; and the gross indicated horse-powers are therefore taken as proportional to, and a measure of, the effective powers. In many cases this assumption is no doubt correct, but in many others its correctness may be questioned; and the results, therefore, which are obtained with the indicated horse-power as the measure of the propelling power, must not be argued upon as definite, or as anything more than an approximation sufficiently accurate for most practical purposes.

Naval architects and engineers must work together.

The form of the engines and boilers to be used in the propulsion of a vessel is generally left by the naval architect to be determined by the engineers; but at the same time, the amount of power to be placed in the vessel, the weight and the positions of the centres of gravity, both vertically and longitudinally, of the machinery, must be duly considered and determined in concert with the naval architect. The form of the vessel at the place where the paddle-wheels or where the screw are to act, also requires special consideration on the part of the naval architect, otherwise the power exerted by the engine may be wasted,

Forces acting on a Ship in motion.

as it formerly was in churning the water when the paddle-wheels were boxed up in sponsons.

Propulsion of Vessels by Sails.

Resultants of forces acting on a ship under sail,

The arrangements for the propulsion of vessels by the agency of the wind come within the province of the naval architect, and much consideration has been given to the subject in many works.

and centres of effort.

When the ship is under sail, there are two forces acting on it—the one, the force of the wind on the sails, to propel the ship; and the other, the resistance of the water to oppose her motion. These forces, immediately the ship has acquired the velocity due to the strength of the wind, are equal, and, as is the case with all forces, may each be reasoned on as if acting only on one point of the surface over which its effect is diffused. This point is that in which, if the whole force were to be concentrated, its effect would be the same as when dispersed over the whole area: it is usual to call these concentrated forces "resultants of forces," and the points on which they are supposed to act, "centres of effort."

Action of wind on the sails, and water on the hull.

From what has been before said, the resultant of the force of the wind on the sails, and the resultant of the force of the water on the hull, are equal; the one acting on the weather-side of the ship, in the direction into which the force of the wind resolves itself, and the other opposed to it, acting on the lee-side, in the direction into which the force of the water resolves itself. The action of the wind upon a ship will be understood from the annexed figure.

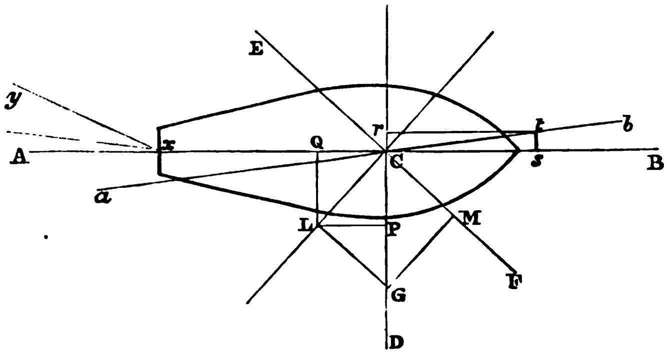

Fig. 00.

Let A B be the centre line of the ship, and let D C represent the direction of the wind, and E F the sail. If the length of G C is taken to represent the force exerted by the wind, the force upon the sail will be represented by the line L C at right angles to it, the length of L C having been found by completing the parallelogram L C M G; the force M C being in the direction of the sail is lost. The force L C may now be resolved into the two forces L P and L Q, or Q C and P C; the one acting to propel the vessel in the line of her keel, and the other at right angles to it. It is evident that the motion of the ship resulting from these two forces will not be in the direction L C, on account of the body of the ship, from its form, offering much less resistance to the force Q C than to the lateral force P C. The relative degree of this resistance cannot be determined by calculations,[1] though attempts to do so have been made. If, however, the relative resistances be supposed to be such that the motion from A towards B may be taken to be represented by C S, while the motion away from the wind or to leeward is represented by C r, then the motion of the ship will be along the diagonal C t. The course of the ship will thus be represented by the line ab, and the angle b C B is called the angle of lee-way. The direction of the wind may be more ahead of the ship than shown in the figure; the position or trim of the sail would then be altered, and its force may be resolved in the same manner as before. It is evident that the more acute the angles B C F or B C D are made, the less will be the propelling power longitudinally, and the greater will be the lateral effect.

If the resultants of the force of the wind on the sails and of the water on the hull are equally distant from the centre of gravity of the ship, they will balance each other, and the ship will keep her course correctly, without requiring to be guided by the action of any other force. If, however, the resultant of the resistance of the water passes before the resultant of the wind, the ship will turn to the wind; but if the resultant of the wind passes before that of the water, the effect will be the contrary, and the ship will fall off from the wind. In either of these cases, in order that the ship may be made to keep her course, it will be necessary to equalize these forces by the action of the water on the rudder, on its lee-side to bring the resultant of the water more aft, and on its weather-side to destroy a part of the effect of the wind. This is the principle of the action of the wind on the sails, and of that of the water on the hull, with respect to the course of the ship through the water; and it is on these considerations only that the various alterations can be regulated, which it may from time to time be necessary to make in the trim either of the sails or of the ship; and hence the accurate determination of the positions and directions of these two forces is a point of great importance in naval architecture. The position of the centre of effort of the wind on the sails may be found under certain reservations; and that being known, enough is determined to lead to correct conclusions on the other circumstances attendant on the subject.

Centre of effort of wind before centre of gravity of ship,

determines positions of masts.

The centre of effort of the wind is always placed some distance before the centre of gravity of the ship; and in order to find this distance in any ship, the moment of each sail is calculated by multiplying its area by the horizontal distance of its centre of gravity from that of the ship; the sum of the negative moments, or those abaft the centre of gravity of the ship, is then subtracted from the sum of the positive moments, or those before the centre of gravity of the ship; the remainder is then divided by the total area of the sails, and the result gives the required distance of the centre of effort of the wind on the sails before the centre of gravity of the ship. The situation of this point with respect to the length of the vessel must determine in a considerable degree the positions of the masts; for experience has proved that it is among the most essentially requisite good qualities of a ship that she shall carry a weather-helm.

Effect and position of the rudder during continuous motion.

With respect to ships carrying a weather-helm, Mr Creuze assumed that the particles of water have a motion at the stern of the vessel, the direction of which forms an acute angle (A xy, fig. 00) with the middle line of the ship produced aft, which angle will evidently be dependent on the fulness or the fineness of the after-part of the body, and on the angle which the line of the ship's course, or that of the lee-way, makes with the middle line of the ship; consequently, the inactive position of the rudder will be when it forms this angle with the middle line of the ship, that is, when the rudder is to leeward, and, consequently, the helm a-weather. And this position should be the theoretic limit of the degree of weather-helm a ship should carry, as in any other position there must be a force acting on the rudder, which must increase the resistance the ship experiences in her passage through the water.

It may perhaps tend to illustrate these views further, if it be supposed that the ship is at rest, and that the water

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[1] See article SEAMANSHIP (*Ency. Brit.*), where this subject will be found treated at length.

Forces acting on a Ship in motion.

strikes her in the direction of her true course, A B, fig. 00, including the lee-way; and then as the angles of incidence and reflexion are equal, the particles of water which strike the ship at an angle varying with the angle of lee-way will be reflected off the lee-side at the same angle, and this angle will be that of the inactive position of the rudder. A practical confirmation of the correctness of the view, that the advantageous position of the rudder is a-lee of the middle line of the ship, may be drawn from the common observation, that when a ship is in good trim, the helm being a-weather, and the ship keeping her course steadily, the helm has a very perceptible tremulous motion, which must arise from the rudder being in a position in which it is not acted upon on either side by any constant force. This method of considering the direction of the flow of the water to the rudder considerably diminishes the estimate of the excess of its effect on the lee-side of the rudder over that on the weather.

Weather-helm.

But there are several other considerations which operate in increasing the effect of the weather-helm. From the direction in which the water flows past the ship, there will be a much greater reduction of pressure on the weather-side of the rudder when the helm is to windward, and therefore a greater positive pressure on its lee-side to turn the ship, than will occur under the opposite circumstances, or when the helm is a-lee. Also, the broken and disturbed state of the water on the after-part of the weather-side of the ship, arising from the water having to acquire a motion to leeward to fill up the void made by the ship as she goes ahead and to leeward, and the consequent various degrees of resistance it opposes must lessen its effect when the helm is a-lee.

Ships with lee-helm leewardly.

Effect mistaken for cause.

It has been said to be proved by practice, that ships which carry lee-helms cannot be weatherly; that is, will fall faster to leeward than those which carry weather-helms. But though the fact is correct, the reason assigned is in some degree mistaking the effect for the cause. It has before been said, that a part of the force of the wind acts in driving a ship bodily to leeward; of course its effect will be greater or less in proportion to the lateral resistance opposed to it, and the ship which opposes less lateral and greater longitudinal resistance to the water than another, will in the same period of time have fallen furthest to leeward, and the line of her course will have made a larger angle with her middle line, by which the effect of the water on the after-part of the lee-side is increased, while that on the fore-part, both of the lee and weather sides, is diminished, and the helm must consequently be kept less a-weather. A practical proof of the correctness of this reasoning may be drawn from the practice of the older class of merchant vessels, which are generally, from form, more leewardly than men-of-war. They have their foremast placed much nearer the centre of the ship than is usual in sharper and finer formed bodies. This has evidently arisen from the operations of the cause above mentioned, which has shown that they require the resultant of the effort of the wind on the sails to be proportionately farther aft to ensure their carrying a weather-helm.

Disadvantage of lee-helm.

There is another disadvantage arising from a ship's carrying a lee-helm, which is, that the action of the water on the weather-side of the rudder acts in conjunction with the force of the wind in forcing the ship bodily to leeward; while, on the contrary, while the helm is a-weather, the action of the water on the rudder is in opposition to the force of the wind.

The ardency of a ship, which is her tendency to fly to the wind, depends on the relative positions of the resultant of the effort of the wind on the sails, and the resultant of the resistance of the water on the hull.

Sails assumed to be plane surfaces.

The position of the centre of effort of the wind on the sails is calculated under the supposition that the sails are plane surfaces, and equally disposed with regard to the longitudinal axis of the ship; but when a ship is on a wind, as the force of the wind acts in a direction oblique to the surface of the sails, a greater proportion of the sail is carried to leeward of this axis, and the whole sail assumes a curved surface, the curvature of which increases from the weather to the lee-side.

Effect of their curvature.

From these circumstances, the centre of effort is in fact carried gradually farther aft as the action of the wind takes place on the sails. Also, as the force of the wind inclines the ship, the centre of effort of the wind on the sails is carried, by this inclination, over to the lee-side, by which, as also by the effect produced on the resultant of the water, which has been before mentioned, the distance between them is farther increased.

Of increase of wind.

It therefore appears that, the quantity and disposition of the sail set remaining the same, the ardency will increase as the force of the wind increases, and diminish as that force diminishes. The defect of a vessel carrying a lee-helm may be lessened by those means of trimming either the sails or the ship, which will tend to increase the distance of the resultant of the water before the centre of effort of the wind. Great caution is necessary before altering the position of the masts, with a view to remedy this defect, because her working quickly depends on the proportion of sail before and abaft the axis of rotation, and not on the position of the centre of effort of the whole surface of the sails. Up to the year 1852 the topsails of ships were reefed and unreefed by the seamen going aloft and out on the yards. About this period Henry D. P. Cunningham, an officer of Her Majesty's navy, invented a plan for reefing and unreefing the topsails, and other square sails of ships, from the deck, without sending any one aloft. He accomplished this by using the yards as rollers, fitting them to turn round in their different fastenings, and so rolled up and unrolled the sails upon them, employing the gravitation of the yards as the motive power for turning them, thus also greatly economising labour, as well as giving security to life. This new method, which is known generally as the "Cunningham System," is now in extensive use in the mercantile marine and troop ships of Her Majesty's navy, and is rapidly superseding the old and dangerous mode of reefing. The limits of this article will not permit the subjects of masting, or rigging, or sail-making, to be gone into. Much valuable information on the subject of the effect of the wind upon the sails, the angle of lee-way, the position of the centre of effort, and other points, will be found in the article SEAMANSHIP.

Pitching and scending.

The motion of pitching and scending is generally the most violent action to which a ship is subjected, and the most injurious, both to the connection between the parts of her structure and the velocity of her sailing. It is the longitudinal motion caused by the variable support afforded to the body by the waves as the vessel meets and passes over them; pitching being dipping of the bows into the water, and scending the dipping of the stern. To obtain ease of motion in this respect, Mr Henwood advocated, in a paper published in the *Papers on Naval Architecture*, that the after-part of the ship, or that part abaft the centre of gravity, should be constructed so as to have precisely the same cubic contents as the fore-body, and that its centre of gravity should be at the same distance from the centre of gravity of the ship as that of the fore-body. The disposition of the weights, and especially of the masts, influences this motion in a powerful degree; because, though the weights in the fore and after bodies may balance each other while at rest—a greater weight, perhaps at a less distance, balancing a less weight at a greater distance—yet, when the ship is set in motion the balance will no longer hold, because the moments of the weights in motion will be according to the squares of their distances from the common centres of gravity. If a vessel pitches heavily, the moments of the weights forwards are too great, and the contrary if she scends heavily abaft. An uneasy motion in pitching is much more common than in scending, and this no doubt arises from the generally very forward position of the fore-mast, especially in men-of-war. The importance of a little attention to this subject on the part of naval men will be at once apparent, when it is considered that the effect of moving or placing 5 tons at a distance of 120 feet from the centre of gravity of the ship is represented by the number $72,000 = 120^2 \times 5$, while it would be necessary to move 720 tons to a distance of 10 feet on the opposite side of the centre of gravity to produce the same effect on the pitching and scending motions of a ship.

Rolling.

The rolling motion of a ship is caused more by the undulations of the waves than by the shock of a wave striking the side of a ship. The principles on which the rolling of a vessel depends have been already investigated, and a few practical remarks will only be added here. The remark is common, and it is true, that the crank ship is the easy ship—that is, the more easily a vessel rolls, the easier will be the rolling motion. Mr Wilson, late of the Admiralty Office, in an able article on the *Papers on Naval Architecture*, says, "If stability is too great, the most efficacious way of diminishing the rolling is to bring up the ballast, because it raises the centre of gravity, and it increases the distance of the centre of oscillation from the axis of rotation. The ballast removed from near the keelson to the wings, even if placed as high as the deck, is as far from the metacentre as when it was in the hold, and consequently, its weight multiplied into the square of that distance is the same as before; the rollings, therefore, will be slower." The cables, shot, stores, &c., in any ship, if placed near the side, while this will not affect the stability, will increase the distance between them and the axis of rotation, and will consequently lengthen the time of vibration. Mr Wilson proceeds to say, that it is by no means a difficult task to reduce a ship of extraordinary stability, which is always an uneasy one, to a state of easy rolling by increasing the masts and yards, and increasing the weights above and putting them in the wings, and removing some ballast, if she has any on board.

Fincham, in his *History of Ship-Building*, gives a remarkable instance of the extent to which the qualities of a ship may be influenced by other circumstances than her form. "The Mutine, an experimental brig, built to compete with others, was beaten on the first experimental cruise, but she afterwards beat the others, alterations having been made in the trim of her sails and in her stowage. After the alterations, instead of rolling the shot out of the racks and the wind out of the sails, as before, she rolled little, and neither deep nor quick. At first her weights were carried too low down."

Motion as influenced by general dimensions or form.

Length.

The motions of a vessel are much affected by the proportions which the general dimensions bear to each other. An increase of length gives an increase of displacement, or if this is not desired, it allows of finer lines forward and aft, and it also increases the stability and the resistance to leeway. The power of turning, tacking, wearing, or making any other change in her course, is lessened by an increase of length; but this effect may be much modified by diminishing the amount of fore-foot, or of dead-wood forward, which will alter the position of the resultant of the action of the water, and will consequently also require a corresponding alteration in the amount or position of the forward and aft sails. A vessel need not necessarily pitch more heavily on account of any increase of length; but it is necessary in long vessels to take greater care that the weights of the fore and aft bodies are properly balanced in regard to their moments. It will be evident that the moments of small weights when placed well forward or aft, become very much greater in long vessels, when it is considered that all weights are multiplied by the squares of their distances from the centre of gravity of the ship for their moments.

The friction upon the sides of a vessel from any additional length of parallel body amidships, appears to be very trifling, if we may judge from the results of cases where vessels have been cut in midships, and lengthened, without any other alteration in their form having been made. The following is a statement of the results obtained by lengthening the Canada, a vessel belonging to the Peninsular and Oriental Company, by putting 35 feet into her amidships:—

	Trial before being lengthened, May 31, 1855.	First trial after being lengthened, Aug. 8, 1857.	Second trial after being lengthened, Aug. 12, 1857.
Draft forward	18 ft. 6 in.	18 ft. 2 in.	18 ft. 2½ in.
" aft	18 ft. 6 in.	19 ft. 5 in.	19 ft. 7 in.
" mean	18 ft. 6 in.	18 ft. 9½ in.	18 ft. 11 in.
Area midship section	536 feet.	551 feet.	556 feet
Displacement	2,435 tons	3,036 tons	3,069 tons
Nominal horse-power	450	450	450
Indicated horse-power	1,415	1,250	about 1,400
Revolutions	34½ to 37	31	33
Pressure	22 lb.	16 lb.	20 lb.
Vacuum	26½	26	26½
Speed	12,651	11,675	12,443
Pitch of screw	20 feet	21 ft.	21 feet
Diameter of ditto	15 ft. 6 in.	15 ft. 6 in.	15 ft. 6 in.
Blades	3	3	3

Breadth.

Effect thereof on the stability of a ship.

By increasing the breadth amidships, as well as the average breadth throughout the whole length of the vessel, while the length and depth are kept the same as before, the stability, which varies as the cube of the breadth, is increased. As the angular momenta of the weights, estimated from the axis of rotation, vary as the squares of their distances from that axis, and the momentum of the action of a wave is increased in the same proportion, therefore the increase of stability is accompanied by increased violence in the motions, and consequent increased strain on the combinations and materials of the structure, and especially danger to the masts, by which the safety of the vessel may be compromised. The stability of a ship of war, being the quality on which the efficiency of her armament is essentially dependent, and which also, by enabling her to carry a press of sail in circumstances of danger, as a lee-shore, or an enemy of superior force, is essential to her safety; the only limit to its increase is involved in the consideration of easiness of motion. But if this consideration be neglected, and the breadth be such that the moment of stability in proportion to the moment of sail is so large, or of such sudden increase, that the masts are endangered or the combinations of the structure prematurely destroyed, the object for which a large moment of stability was desirable is frustrated. The breadth, therefore, is limited by easiness of motion. The best mode of ensuring stability is to give a large area and great fulness and similarity of form immediately above and below the average water-line, as by this means the centre of gravity of the displacement will be kept at as short a distance as possible below the surface of the water.

Depth.

The depth of a ship, or her draught of water, may vary according to local circumstances, or the objects for which she is to be employed, or by a judicious arrangement of her other proportions and of her form, and the positions of the centre of gravity. Good ships may be produced varying considerably in the proportions of their depth to their breadth.

Alteration of seat in water from consumption of stores.

An important consideration connected with the forming the design of a ship is involved in the gradual alteration of the vessel's seat in the water from the consumption of stores. It is not only essential that a ship should be possessed of stability combined with easiness of motion, be weatherly and quick in manœuvring when she is stored and completed for foreign service as a ship of war, or fully laden as a merchant-ship, but it is equally essential that she should be possessed of these qualities towards the expiration of her cruise, or on her return light from her voyage.

The loss of stability which results from the diminution of draught of water cannot be compensated by a proportionate arrangement of sail, without incurring other evil consequences. If the quantity of sail, which at all times is comparatively small in a merchant-ship, be lessened, the wind on the increased hull might so counterbalance its effect that she would be utterly unable to beat off a lee-shore, or make any way on a wind.

causing diminution of stability, and increased uneasiness.

A ship is not only subject to a loss in stability when lightened, but becomes laboursome, on account of top-hamper: her rolling motion is more violent as her diminished depth in the water decreases the resistance which is opposed to the inclination, and she also generally becomes more leewardly, owing to the difference made in the resultant of the resistance, the diminution of the lateral resistance, and of her power of carrying sail.

Difference of draught of water.

It is almost a universal custom in all vessels to give a greater draught of water abaft than forward. In steam-vessels this is not necessary, and in sailing-vessels occasional attempts have been made to discontinue this practice, as involving a supposed unnecessary increase in the water required for floating a ship; but the increased draught of water for the after-body has been reverted to as essentially requisite in practice, in this class of vessels.

Its advantages.

There are several minor advantages which result from this arrangement; such as the more easy and unchecked flow of the water to the rudder, and its consequent increased effect in governing the motions of the ship; also the diminution of the negative resistance which the vessel would otherwise experience from the greater difficulty with which the flow of water would fill the vacuity caused by the passage of the vessel, if the fulness of the after-body were such as would be required to preserve an even draught of water; and again, the adjustment of the resultant of the resistance of the water to that position of the masts which experience has determined to be requisite for the facility of manœuvring the sails. But the principal reason for the inequality in the draught of water appears to be the advantage which results from it to the more easy regulation of the motion of the vessel by an adjustment of the resultant of the resistance of the water on the lee-side when on a wind.

DESIGNING OF VESSELS.

Designing of vessels.

The considerations which lead to a settlement of the general dimensions of a vessel, and which must vary greatly according to the purpose for which she is intended, having been touched upon, it is proposed to give an outline of the course pursued in designing the form, or making the *constructive drawing*, as it is termed, of any vessel. Three plans are required in all designs of vessels—the body-plan, the sheer-plan, and the half-breadth plan (see Plate III.) The form of the midship section, or a vertical cross-section at the point of greatest breadth, is generally the first portion of a ship that is designed; the outline of the sheer-plan may then be delineated, and after that the half-breadth plan may be begun. The vessel is supposed to be divided into a certain number of horizontal sections, and these are represented by the lines on the sheer-plan, marked 1st, 2d, 3d, 4th, and 5th water-line. The sheer-plan is either a vertical longitudinal section, or a side-plan of the ship, and on it may be delineated any point in her length or height. On the half-breadth plan are delineated the outlines of the horizontal sections previously referred to, and marked water-lines. These horizontal sections may either be parallel to the keel or to the intended water-line of the vessel, if she is intended to draw more water abaft than forward. When parallel with the keel, they are sometimes called level-lines. The midship section is not necessarily in the middle of the length; it is called dead-flat, and is always marked as shown on the plate. The length of the vessel is divided into any desired number of sections, and these sections are marked forward and aft from dead-flat with distinguishing letters and figures. The water-lines being also drawn upon the midship section or body-plan, the form of the body at each section in the half-breadth plan is obtained by finding the distance from the centre-line at each water-line, and transferring it to the body-plan, showing the sections of the fore-body and of the after-body on different sides of the middle line. In addition to these lines, the vessel is supposed to be cut into various longitudinal sections, at given distances from the centre-line; these lines of section are shown on the half-breadth and body-plans; and the form of the body where these cut the exterior surface of the ship are shown on the sheer-plan; they are marked 1v, 2v, 3v, on all the plans. The sections represented on all these plans must be fair and of easy curvature, and many little alterations will probably require to be made by the draughtsman, to get them to coincide.

The constructor or designer is now in a position to test his work by making the necessary calculations. These will be comprised in ascertaining the area of the midship section, the area of the load-water section, the displacement, the positions of the centres of gravity of these two sections, and also the position of the centre of gravity of the displacement.

The areas of the two sections, and the positions of their respective centres of gravity, are required to be determined, on account of the influence of these areas and their positions on the content of the displacement, and the position of its centre of gravity, and also in consequence of their influence on the stability of the ship. If the results of these calculations do not accord with the intentions of the constructor, or are inadequate to the development of his design, he must make such alterations in his curves or in his dimensions as he may consider necessary, before proceeding further with his design; and if he shall have sufficiently informed himself on the theory of ships, he will be enabled to do so with considerable confidence at this stage of his progress, as to the final result of his work.

These calculations are no doubt laborious, but they have been previously explained, and there is no difficulty in them, and any moderately educated subordinate may soon be taught to assist greatly in working them out. The labour will be greatly facilitated by tabular forms, and further examples will be found in Mr Peake's work on Ship-building, and in one of a series of articles on Ship-building in the *London Mechanics' Magazine* for 1859.

Before the design can be considered complete, it is necessary to ascertain the weight of the hull and of the whole of the proposed contents of the ship, and compare these with the calculated displacement. It is seldom that these weights can be obtained with perfect accuracy, and it is therefore scarcely necessary in practice to go to any undue labour to bring out results to fractions.

Scale of displacement.

It is usual to delineate the results of the calculations of the displacement in the form shown in Plate IV.,—the curved line representing the displacement of the ship at any draught.

Proportion of circumscribing parallelopipedon.

As a guide in commencing a design, it is also usual, and very useful, to know what proportion the circumscribing the parallelopipedon will bear to the body of the ship—that is, multiply the intended length, breadth, and draught of water of the ship together, and deduct such portion as will leave a body of a form of any desired fineness. The amount to be deducted, or the decimal fraction by which the parallelopipedon is to be multiplied, varies, of course, for every class of ship.

Influence of form on rolling.

The form of the midship section, and of the other sections near it and therefore influenced by it, affects the question of rolling, by affecting the position of the centres of gravity of the displacement and of the ship and her weights; but there is no doubt but that if it were possible to keep these centres of gravity relatively in the same position with different forms of bodies, the rapidity and extent of rolling would still be influenced by the form, and be different.

Form and Tonnage of Vessels.

No rules can be laid down definitely on this subject; but ships with a form of midship section approaching a semicircle have a bad reputation for rolling; as also those with a very rising floor, if accompanied with great beam, or such beam that the half-breadth exceeds the draught of water by more than 1 or 2 feet. A flat floor is also injurious, as tending to keep the centre of gravity of the displacement too low. Some good midship-sections of ships of various classes will be found in Fincham's *Outlines of Ship-building;* but the great length now given to the fore and after bodies of ships renders the effect of the form of the midship-section much less influential on the general properties of a vessel than formerly, when the proportion of length was so much less.

Forms of water-lines.

For the water-lines of vessels no definite instructions have been attempted to be laid down that have been of any practical value. A few general remarks may be made, to the effect that certain degrees of sharpness seem suited for different degrees of speed—the faster the vessel the finer are the lines required; and if a moderate amount of power only be applied to a vessel, so that her speed cannot be great, it will be of little avail to give her finer lines than those suited to her actual speed. Hollow-water lines below the surface of the water seem to be beneficial for high velocities, but not at the water-line or above it, as the waves seem then to dash into the hollow and obstruct the vessel's way, by their being confined and not passing freely away.

Vertical lines.

In all the plates given with this article, vertical lines are shown. The form of vessels, in respect of the sections shown by these lines, would appear to have been too much neglected by naval architects. It is considered that the form of vessels at the bows or at the stern may be looked upon as made up of lines representing a wedge with its face vertical, and dividing the water sideways, combined with other lines representing an inclined plane, as in the Thames barges. Bodies of a wedge form were experimented upon by Colonel Beaufoy, as also others, with an inclined plane forward and aft to compare with them, and the results were decidedly in favour of the inclined plane; the inclined plane in the after-body having been proved decidedly superior.[1] The bodies which gave these results were those designated *m*, *b*, *m*, and *p*, *b*, *p*, and the experiments were conducted at the surface, and not with the bodies totally submerged.

Tonnage.

The tonnage of a ship is her assumed capacity for carrying cargo of any description. The capacity of space required for a ton of iron being very different from that required for a ton of light goods, a certain number of cubic feet are necessarily taken as the measure of a vessel's tonnage. An empirical rule, founded upon obsolete proportions of a vessel's dimensions, continued in use for many years, serving as a measurement, not only of builder's tonnage, but also of the register tonnage for regulating the dues payable by the ship. This rule is still continued by builders as the measure by which ships are bought and sold; but as the price per ton may be varied in the same proportion as the dimensions, and are known at the time of purchase or sale, no evil results arise from this adherence to the old rule, however far the measurement may be from the truth.

Builder's measurement.

This rule for old or builder's measurement was established by act of Parliament in the reign of Geo. III. It enacted, that "the length shall be taken in a straight line along the rabbet of the keel of the ship, from the back of the main stern-post to a perpendicular line from the fore-parts of the main-stem under the bowsprit. The breadth also shall be taken from the outside of the outside plank, in the broadest part of the ship, either above or below the main wales, exclusive of all manner of doubling planks that may be wrought upon the sides of the ship." If the ship be afloat, the directions are, "to drop a plumb-line over the stern of the ship, and measure the distance between such line and the after part of the stern-post, at the load water-mark; then measure from the top of the said plumb-line, in a parallel direction with the water, to a perpendicular point immediately over the load water-mark at the fore-part of the main-stem; subtracting from such admeasurement the above distance, the remainder will be the ship's extreme length, from which is to be deducted 3 inches for every foot of the load draft of water for the rake abaft; from the length, taken in either of the ways above mentioned, subtract ⅗ths of the breadth taken as above, the remainder is esteemed the just length of the keel to find the tonnage; then multiply this length by the breadth, and that product by half the breadth, and, dividing by 94, the quotient is deemed the true contents of the lading."

Existing rule for measurement of tonnage.

The existing act for ascertaining the tonnage is a great improvement upon the above, and its directions are as follow:—Divide the length of the upper-deck, between the after-part of the stem and the foremost part of the stern-post, into six equal parts. Depth,—at the foremost, middle, and aftermost of these points of division, measure in feet, and decimal parts of a foot, the depths from the under-side of the upper-deck to the ceiling at the limber-strake. In case of a break in the upper-deck, the depths are to be measured from a line stretched in a continuation of the deck. Breadths,—divide each of these three depths into five equal parts, and measure the inside breadths at the following points; viz., at ⅕th and at ⅘ths from the upper-deck of the foremost and aftermost depths, and at ⅖ths and ⅘ths from the upper-deck of the midship depth. Length,—at half the midship depth, measure the length of the vessel from the after-part of the stem to the foremost part of the stern-post; then to twice the midship depth add the foremost and aftermost depths for the sum of the depth; add together the upper and lower breadths at the foremost division, three times the upper breadths and the lower breadth at the midship division, and the upper and twice the lower breadth at the after-division, for the sum of breadths; then multiply the sum of breadths by the sum of the depths, and this product by the length, and divide the final product by 3500, which will give the number of tons for register. If the vessel have a poop, or half-deck, or a break in the upper-deck, measure the inside mean length, breadth, and height of such part thereof as may be included within the bulkhead. Multiply these three measurements together, and dividing the product by 92·4, the quotient will be the number of tons to be added to the result as above found. In order to ascertain the tonnage of open vessels, the depths are to be measured from the upper edge of the upper strake. In vessels propelled by steam, the tonnage due to the cubical contents of the engine-room is to be deducted from the gross tonnage thus found. It is enacted that the tonnage due to the cubical contents of the engine-room shall be determined in the following manner: that is to say, measure the inside length of the engine-room in feet, and decimal parts of a foot, from the foremost to the aftermost bulkhead, then multiply the said length by the depth of the ship or vessel at the midship division aforesaid, and the product by the inside breadth at the same division, at two-fifths of the depth from the deck, taken as aforesaid, and divide the last product by 92·4, and the quotient will be deemed the tonnage due to the cubical contents of the engine-room.

DESCRIPTION OF PLATES.

Description of Plate.

Among the plates will be found vessels of the highest character of the present day. The Pera of the Peninsular and Oriental Company's fleet is a well-known vessel, and one whose results are looked upon as of the highest character; and if the form of her body, as shown by the vertical lines on the sheer plan, be examined and compared with those of any of the other vessels, it will be seen that she excels in this particular. The kindness of the different owners and builders in permitting the lines of their different vessels to be

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[1] Beaufoy's *Nautical and Hydraulic Experiments*, Introduction, p. 43.

Performances.

published, has been great; and it is to be hoped that so much public spirit as is now manifested in this respect may be rewarded by still further improvements upon the forms of vessels.

The clipper sailing-ship Schomberg, represented in Plate III., is a specimen of a first-class Aberdeen clipper, built by Messrs Hall of Aberdeen.

The Lord of the Isles is a very fine iron vessel, built by Messrs Jn. Scott and Company of Cartsdyke, near Greenock. Although a sharp ship, she carries a good cargo of weight and measurement goods combined. On her first voyage from Clyde to Sydney she had 1300 tons of weight and measurement cargo on board, and made the passage in 70 days—a passage which, it is believed, has not yet been surpassed. Her register tonnage is 691$\frac{88}{100}$ tons; and her tonnage, by builders' measurement, is 770 tons. She also made a passage from Shanghae to London in 87 days, with 1030 tons of tea on board. On one voyage she averaged 320 nautical miles for five consecutive days; and on her last voyage to China, in crossing the N.E. trades, her average way was over 12 knots.

Plates V^A. and VI. represent the rival yachts Titania (now Themis) and America, the prize having been carried off from all England by the latter. The sections of the vertical lines are shown upon the drawings of both of these yachts; and if the vertical lines on the sheer-plan of the one are traced and laid upon those of the other, a marked difference in favour of the America will be apparent. The original Titania which ran against the America was subsequently burnt; but being of iron her hull was saved, and was restored under the name of Themis. A new Titania of larger dimensions was then built (Plate V.); and a marked improvement in her lines as a whole is evident, though the America still excels her in the easy slope of the lines of the vertical sections at the bow and at the stern.

Plate VII. is a representation of a paddle-steamer, the Delta. The engines in this vessel were taken out of a vessel of 500 tons, and put into the Delta, of nearly four times this tonnage, and the result is a specimen of what may be achieved by fine lines with a judicious application of power; the larger vessel having nearly a knot more speed.

Plates VIII. and IX. represent the Great Eastern, and from the fineness of her lines there can be no doubt of her success, if the engines do their duty.

Plate X. is a representation of the Bremen, a vessel whose performances have been such as to attract special attention, and to lead the Committee appointed by the British Association for the Advancement of Science to make the following report concerning her:—

"This Committee are assured, on authority which they believe to be unquestionable, that a certain vessel, the Bremen,[1] of 3440 tons displacement at the time of trial, propelled by engines working up to 1624 indicated horse-power, attained the speed of 13·15 nautical miles per hour. Now, if we estimate the dynamic duty thus performed by the formula $\frac{V^3 D^{\frac{2}{3}}}{\text{Ind. H.P.}} = C$, we shall hav the co-efficient, $C = \frac{(13{\cdot}15)^3 \times (3440)^{\frac{2}{3}}}{1624} = \frac{2274 \times 227{\cdot}88}{1624} = 319$, and this co-efficient of dynamic duty, resulting from the mutual relation of displacement, speed, and power, appears, from the statements which have been communicated to this Committee, nearly 50 per cent. higher than that realised by the average performance of the steamships of the present day. The following are the co-efficients of dynamic duty deduced by the foregoing rule from the performances of mercantile steamers of high repute, of which the trial data have been communicated to this committee, viz. 325, 294, 291, 288, 259, 248, 231, 230, and 204, and many others below 200.

"This Committee, therefore, regard the Bremen as being a felicitous exemplification of naval architecture as respects type of form adapted for easy propulsion; and as we conceive that the promulgation of some of the constructive elements of this vessel may be of public importance, we are happy in being authorised and enabled, by Messrs Caird and Company, of Greenock, the constructors of the ship and of the engines, to communicate to the British Association the following statistical data as to the elements of construction of the Bremen:—

Performances and Tonnage.

	Length between perpendiculars of stem and rudderpost	318 feet.
	Breadth of beam	40 „
	Depth of hold	26 feet.
	Mean draught of water at the time of trial	18 ft. 6 in.
	Displacement (D) at trial draught	3440 tons.
	Area of maximum immersed section (A) at the trial draught	606 sq. ft.
	Distance of maximum section (A) measuring from the stem	159 feet.
	Constructors' load draught, forward	18 feet.
	Constructors' load draught, aft	19 „
	Displacement at constructors' load draught	3440 tons.
	Rate of ships' displacement at constructors' load draught	25 tons per inch.
Data for laying off Peake's curve of sections.	Area of immersed vertical section at the distance of ⅛ length measuring from stem	256·5 sq. ft.
	Do. ¼ do. do.	486 „
	Do. ½ do. do.	606 „
	Do. ¾ do. do.	489 „
	Do. ⅞ do. do.	253·5 „
Data for laying off curve of Displacement.	Displacement at draught of 4′ 7½″, being ¼ load draught	300 tons.
	Displacement at draught of 9′ 3″, being ½ load draught	1165 „
	Displacement at draught of 13′ 10½″, being ¾ load draught	2240 „
	Displacement at draught of 18′ 6″, or load draught	3440 „

"The foregoing data afford all the particulars required for the construction of Peake's curve of vertical sections, whence may be deduced the position of the vertical line passing through the centre of gravity of displacement, and also the positions of the centre of gravity of the fore and aft bodies respectively.

"It will be observed, from the foregoing data of the constructive elements of the Bremen, that the maximum immersed section is at the middle of the length, and that the vertical sections are in such ratio to each other, with reference to their respective positions, that the curve of vertical sections will be a close approximation to a parabola.

"The ratios deducible from the foregoing particulars of constructive data, combining Peake's curve of immersed vertical sections with the curve of displacement, will give a close approximation to the type of form of the immersed hull.

"The engines of the Bremen consist of two direct-acting inverted cylinders, 90 inches diameter and 3 feet 6 inches stroke, fitted with expansion-valves capable of working expansively to a high degree. All parts of the engines are felted and lagged with wood wherever practicable, the lower 16 feet of the funnel being surrounded by a casing forming a superheating chamber, the steam entering at the lower end, and passing off at the top into the steam-pipes leading to the cylinders.

"On the important question as to the extent to which the ordinary smooth-water trial of a steamer affords a criterion of the general average performance that may be expected of the vessel at sea, this committee has not been able to obtain such an extent of returns of the comparative smooth-water trials and sea performances of the same ships as enable them fully to respond to this part of the inquiry, and they refrain from expressing any speculative opinion, because they have adopted the principle which they desire to recommend to the notice of the British Association, that shipping improvement is to be discovered by statistical record and analysis of the constructive elements of ships that have practically shown themselves to possess good sea properties, rather than by assuming the mere theories of opinionative speculation, from whatever source such opinions may emanate; in short, that experience of actual performances at sea, statistically recorded and utilized by being made the basis of comparison, is the most reliable base on which to construct an inductive system of progressive improvement in naval architecture and marine-engine construction. This committee, however, have much satisfaction in being enabled to commence this inquiry by recording the sea performance of the before-mentioned vessel Bremen, on a passage from Bremen Haven to New York and back, during the months of June and July last, during the whole of which passages indicator-cards were frequently taken, and the indicated working power of the engines ascertained. On the out-passage the mean displacement was 2878 tons, the mean indicated horse-power was 1078, and the mean speed 10·28 knots per hour, giving a coefficient by the formula referred to = 204; but on the return-passage the mean displacement was 2990, the

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[1] The Bremen is referred to as being the vessel which gave the highest co-efficient of dynamic performance of any vessel which was brought before the Committee, and of which the statistical data of construction were also given in a complete form.

Performances. mean indicated horse-power 1010 and the mean speed at the rate of 11·92 knots per hour, giving a co-efficient = 348. Hence, the mean co-efficient of the out and home passage = 276, being about 13 per cent. below the co-efficient (319) obtained on the smooth-water test-trial of the ship. The state of the weather and the sea was also recorded daily: it appears to have been adverse on the out passage, but favourable on the home passage. The committee are therefore of opinion, that by following up this course of statistical record of the smooth-water trial and subsequent sea performances of ships respectively, a tabular statement might be compiled, showing the probable ratios of the coefficients of smooth-water and sea performance, corresponding to the various rates of speed for which steamers may be respectively powered, whence the smooth-water test-trials of ships may be made available as approximately indicative of the sea service capabilities of ships as respects their dynamic properties.

"Such are the statistical data of the constructive elements and dynamic capabilities of the Bremen; and if all steam-vessels engaged in the mercantile transport service of Britain were equally effective as respects the mutual relations of displacement, speed, and power; that is, capable of producing a coefficient of dynamic capability = 319, by the formula referred to, it is probable that the prime cost expenses of steamship transport per ton weight of cargo conveyed on long passages would, on the aggregate of the foreign trade of Britain, be reduced not less than 25 per cent. as compared with the prime cost expenses incurred by steam-vessels of the average dynamic capability in present use."

Performances. Tabulated results of the performances of many vessels will be found in the article Steam Navigation; but the following results of the trials in smooth water of four of the vessels, whose lines and dimensions are given in the plates, may be quoted here:—

Name of ship.	Draught of water.	Indicated Horse-power.	Speed in knots.
	ft. in.		
Delta	15 0	1612	14·609
Ceylon	18 6	2054	13·340
Pera	18 3½	1373	12·633
Nubia	17 3	1422	12·149

Plates XI., XII., XIII., and XIV. are specimens of very fine vessels in the fleet of the Peninsular and Oriental Company. The Pera is especially celebrated for her performances, as also the Ceylon. The following table is interesting as showing the performances of the Nubia on her actual voyages at sea:—

S.S. Nubia.—*Calcutta to Suez.*

Voyage.	Sandheads to Madras, 663 Miles.		Madras to Point de Galle, 545 Miles.		Point de Galle to Aden, 2134 Miles.		Aden to Suez, 1308 Miles.		Under Weigh. Sandheads to Suez, 4650 Miles.	Under Steam. Calcutta to Suez, 4757 Miles.	Aver. Speed. Sandheads to Suez.	Coal Consumption. Calcutta to Suez per		
	Time.	Speed.	Time.	Speed.	Time.	Speed.	Time.	Speed.				Voyage.	Hour.	Mile.
No.	H. M.	K. F.	H. M.	K. F.	H. M.	K. F.	H. M.	K. F.	H. M.	H. M.	K. F.	Tons.	c. qr. lb.	c. qr. lb.
4	52 25	12 5	43 8	12 5	178 55	11 7	114 20	11 4	388 48	431 0	12 0	974	45 0 22	4 0 11
5	66 55	9 7	52 30	10 3	201 27	10 5	112 45	11 5	433 37	464 0	10 6	1140	49 0 15	4 3 5
6	67 5	9 7	56 5	9 6	244 55	8 6	124 30	10 4	492 35	530 0	9 4	1194	45 0 6	5 0 2
7	54 55	12 0	46 30	11 6	193 48	11 0	118 0	11 1	413 13	474 0	11 2	1058	44 2 16	4 1 22
8	56 0	11 7	42 20	12 7	166 28	12 6	113 58	11 4	378 43	411 0	12 2	1046	50 3 17	4 1 16
9	59 40	11 1	57 0	9 4	176 50	12 1	124 40	10 4	418 10	441 0	11 1	1090	49 1 23	4 2 9
Under weigh, 27,900 miles Under steam, 28,542 miles								Total	2525 6	2751 0		6502		
								Average	420 51	458 30	11 0	1083⅔	47 1 2	4 2 6

Suez to Calcutta.

Voyage.	Suez to Aden, 1308 Miles.		Aden to Point de Galle, 2134 Miles.		Point de Galle to Madras, 545 Miles.		Madras to Sandheads, 663 Miles.		Under Weigh. Suez to Sandheads, 4650 Miles.	Under Steam. Suez to Calcutta, 4757 Miles.	Aver. Speed. Suez to Sandheads.	Coal Consumption. Suez to Calcutta per		
	Time.	Speed.	Time.	Speed.	Time.	Speed.	Time.	Speed.				Voyage.	Hour.	Mile.
No.	H. M.	K. F.	H. M.	K. F.	H. M.	K. F.	H. M.	K. F.	H. M.	H. M.	K. F.	Tons.	c. qr. lb.	c. qr. lb.
*3	112 15	11 5	178 0	12 0	51 15	10 5	55 30	12 0	397 0	431 0	11 6	1060	49 0 21	4 1 23
5	108 10	12 1	174 40	12 2	44 50	12 1	50 45	13 0½	378 25	433 0	12 2	1092	50 1 21	4 2 10
6	112 0	11 5	190 55	11 1	48 50	11 1	52 30	12 5	404 15	443 0	11 4	1048	47 1 7	4 1 18
7	122 10	10 5	206 30	10 3	53 0	10 2	65 25	10 1	447 5	478 0	10 3	1176	49 0 23	4 3 22
8	129 40	10 1	194 15	11 0	47 25	11 4	55 15	12 0	426 35	454 0	10 7	1174	51 2 24	4 3 23
9	118 15	11 0	192 10	11 1	47 20	11 4	47 45	13 7	405 30	434 0	11 4	1082	49 3 12	4 2 5
Under weigh, 27,900 miles Under steam, 28,542 miles								Total	2458 50	2673 0		6632		
								Average	409 52	445 30	11 3	1105⅓	49 2 14	4 2 16
Under weigh, 55,800 miles Under steam, 57,084 miles								Grand Total	4983 56	5424 0		13134		
								Average			11 1$\frac{4}{15}$		48 1 20	4 2 11

Distance in calculating speed taken from Sandheads; but, in calculating consumption of coal, the whole distance to Calcutta is taken.—Coal account not available for other distances.

* Instead of Voyage 4, on which iron shaft was broken.

MATERIALS USED IN SHIP-BUILDING.

Importance of a knowledge of the properties of materials.

Nothing can be more important to the naval architect than a thorough knowledge of the properties of the materials with which he has to deal. He requires this to enable him to dispose them to the greatest advantage, and with the least possible expenditure; and thus to produce a well-proportioned structure of great and uniform strength. The introduction of iron as a material for ship-building has enlarged this field of inquiry, and has led to much discussion as to its merits in comparison with those of timber.

Timber.

Durability.

The properties of timber will be first considered. A lengthened examination into the nature and qualities of the different varieties used in ship-building cannot, however, be attempted here, as the space which can be allotted to the subject will not admit of more than a few practical observations. Deterioration and decay, in timber-built ships, may result either from the decay to which timber itself is subject, in common with all organic matter, and which may be hastened or retarded according as destructive or preservative influences are brought into action; or they may be the consequences of an injudicious combination of destructive agents with the inorganic compounds of the timber, thus inducing not only premature but unnatural decay. All large masses of timber in close contact are subject to deteriorating influences, such as a high degree of temperature, an increase of moisture, or a want of free circulation of air. These and other agencies, by promoting fermentation, lead to the first stage of decomposition, whereas the reverse of these conditions would in like manner retard its progress. Moisture as well as heat is necessary to produce fermentation, but when heat and the other agencies are at work, moisture will generally be found to exist, either left in the timber itself, or absorbed by it from the atmosphere.

Dry-rot.

Decay of timber, when accompanied by the growth of fungi upon its surface, has received the name of *dry-rot.* This term was probably applied to it in consequence of the peculiarity, that wood so decomposed becomes a dry friable mass without fibrous tenacity, the parasitical fungi robbing the timber of its substance to support their own growth. In general, decay, when it takes place in this particular form, may be traced to imperfectly seasoned material, and the inference may be drawn with a considerable degree of probability, that the natural juices of the timber are necessary to the growth of fungi, and consequently that if these juices could be entirely abstracted or destroyed, this species of decay might be prevented. It does not follow that the presence of any of these juices will necessarily produce dry-rot, should the circumstances in which the timber is placed be such as to tend to their dispersion, or to their remaining in a dormant state. But as they do undoubtedly remain in much timber that is considered seasoned, any alteration of circumstances to prevent a free circulation of air, to lead to a deposition of additional moisture, and at the same time to an increased temperature, will in all probability induce the growth of fungi, and cause the destruction of the timber.

In ships, the frequent presence of these injurious elements must necessarily tend to produce fermentation. But though these facts are perfectly well known, it is remarkable how little attention has been paid to the necessity of a free circulation of air upon the timber of such parts of a ship as are below the surface of the water. This may be effected in various ways, though it is doubtful whether in all cases the current of air produced by natural causes would induce a sufficiently rapid circulation. This subject was forcibly brought before the Admiralty by Mr Creuze in 1827, but was not taken up or acted upon. In the navy, the decrease of expense which would be occasioned by any increase of durability in ships, laid up in ordinary, would be great; and in reality, with proper care and arrangements, there is no reason why the timbers of a ship so situated should not be almost as durable as the same wood employed in houses and other structures. The expense caused by decay is even greater in ships than in houses, yet the attention paid to the subject has been in an inverse ratio. The same facilities for the prevention of decay are not available for ships in commission, and if their timbers should have been unseasoned, or have had much of the natural sap left in them, dry-rot must almost necessarily ensue. It may be especially looked for in ships sent to a warm climate immediately after their construction, and exposed to a high temperature, and of its attacking these, many instances have occurred even within the last few years.

The same evils exist to a greater degree in merchant-vessels. Private ship-builders are unable to keep their capital locked up in a large stock of the different classes of timber fit for the different ships they may be called upon to build, and as the purchaser ordinarily requires a speedy execution of his order, the use of unseasoned timber is the necessary consequence. No better arrangements for the prevention of decay seem to be made on board of merchant-men, after they are built, than on board of men-of-war. Lloyd's register of shipping may be said to have an injurious influence on this question. The register is kept by a joint-stock company, and a committee of their body composed of ship-owners, merchants, and underwriters, with a staff of professional surveyors, have laid down a code of rules for the construction of ships as a guide to their classification on survey. By these rules, a ship built of the very best species of timber, thoroughly seasoned, can be classed as a first-class ship for twelve years only; a renewal for eight years may be obtained, but not without much trouble and expense; and further extension again of four years involves another expensive survey. Sufficient inducements are apparently, therefore, not held out for increasing the durability of ships. Many teak-built ships have lasted longer than these assigned limits, and yet no attempts have been made to rival them, thus leading to the belief that Lloyd's rules have had the effect of rendering builders and owners satisfied with existing results. It has been argued that, to season a ship after she is built, by a free circulation of air, will cause shrinkage, and thus injure the good fitting and the strength of the fabric, and that it will strain the fastenings, and admit damp, and thus cause the decay it was intended to obviate. In reply to this it may be urged, that shrinkage could never be produced to this extent on the timbers of a ship by the circulation of air, had they not been in such an unseasoned state as to be totally unfit for use; and that even in such a case, it would be far better to take the chance of less certain mischief, than to leave the ship to inevitable destruction by dry-rot. These remarks show the importance of well-seasoned timber for ship-building, and have been insisted upon here, not from any supposed want of general knowledge of the fact, but to show the importance of applying the means which exist to remedy the evil.

It must be evident that when timber is to be closely jointed to other timber, to form a compact mass, the whole should not be wet with rain, or water-soaked when put in place. The importance of this is recognised by Lloyd's rules allowing one year to be added to the prescribed period of durability of any ship built under a roof. All vessels laid down in royal dockyards have this advantage.

Different qualities in different species of woods.

Different species of timber are possessed of very different qualities, both as regards their durability and their strength. Oaks and other hard close-grained woods, being the most durable, are chiefly used for the frames of ships. The juices of the oak are of an acid nature, and besides the ligneous, which it has in common with other woods, it contains the Gallic acid peculiar to itself. Oak when used in

Materials used in Ship-Building.

an unseasoned state is extremely liable to dry-rot, which in some cases has been found to destroy it in the space of a few months. Teak is a very valuable timber for ship-building, but like other woods it varies much in quality according to the soil in which it is grown, and consequently requires great care in its selection. Morning saul, green heart, morra, and iron-bark, are also valuable woods. Like teak they are extremely durable, and are more oily and resinous in their nature than oak. The whole of the foregoing are classed together by Lloyd's committee as superior woods, and are admitted for the construction of ships classed for a durability of twelve years. The general classification of woods by this committee is as follows:—

Mahogany of hard texture, Cuba Sebicu, and pencil cedar, Adriatic, Spanish, and French oak	10 years.
Red cedar, Angelly, and Venatica; other continental white oaks, Spanish chesnut, stringy bark, and blue green..	9 „
North American white oak, and American sweet chesnut	8 „
Larch, hackmatack, tamarac and juniper, pitch pine and English ash..	7 „
Cowdie, American rock elm..	6 „
Baltic and American red pine, European and American grey elm, black birch, spruce fir, English beech......	5 „
Hemlock	4 „

There are some slight variations in the durability assigned to these when used for other parts of the ship than the ribs or frames. Elm, which decays very rapidly when alternately wet and dry, is very durable if kept constantly submerged in water. On this account, as well as for its qualities of strength and toughness, it is well adapted for the keels of vessels. Other woods will be mentioned hereafter when the sources of the supply of timber for ship-building are considered.

Means of preserving timber.

Steaming and pickling timber.

Corrosive sublimate.

Chloride of zinc.

Creozote.

The difficulty of obtaining properly seasoned timber whenever it may be wanted, and the great expense attending the early decay of unseasoned timber, have led to various means being proposed for its preservation. Saturating the timber with various chemical compounds, has been the method generally suggested for its accomplishment. In India, Machonochie, by steaming his timber, and then condensing the steam in the tank, and producing a partial vacuum, endeavoured to dissolve and carry off the juices of the timber, and he then submerged it in an oil obtained from the chips and sawdust of teak. Steaming or stoving timber has always been considered advantageous for wood used in a green state. Exposing it to the action of water has been advocated with the same view, and this certainly tends to shorten the time required for weather seasoning thereafter. About 40 years ago the timber used in the royal dockyards was ordered to be submerged in salt water for some time, and then stamped with the word "salt." Pieces of sound timber with this mark are found in men-of-war up to the present day. Mr Kyan patented a process for preserving timber, by saturating it with corrosive sublimate; and Sir W. Burnett, late Medical Director-General of the Navy, patented the use of chloride of zinc, but with neither of these processes is the effect in all cases certain. Creozote appears to preserve timber with greater certainty than any other chemical material yet used. The timber is put into a close tank, the air is abstracted, and the vacuum is kept up for two or three hours by continued pumping, to allow the air to escape from the pores of the wood. The creozote is then introduced, and is forced into the tank, until a pressure of about 150 lb. to a square inch is obtained. This pressure is kept up by continued pumping during successive days for forty-eight hours, or for as long as may be required to make the timber absorb the requisite amount. This process is chiefly used for pine timber. Yellow pine should absorb about 11 lb. to the cubic foot, and Riga pine about 8 lb. The timber is weighed before it is put into the tank, and again after it is taken out, to ascertain the amount absorbed. Should this prove less than the amount required, it is returned to the tank for a repetition of the process.

Materials used in Ship-Building.

Creosoted timber has hitherto been chiefly used by civil engineers in land and sea works. The objections to its use in ship-building are its offensive smell and its great inflammability. Its power of protecting timber from natural decay, and of resisting the *toredo novalis*, or any of the other worms to whose ravages ship's timber is subject, if it be not thoroughly covered with copper sheathing, appear to render it peculiarly fit for such a purpose as doubling upon a ship. If found to answer, it might be used in thin boards as a sheathing instead of copper.

Dr Boucherie's process with sulphate of copper.

Another process which is applicable to the preservation of certain descriptions of straight-grained and porous timber, has been patented by Dr Boucherie, a French chemist of note, and been brought forward in this country by a company formed for the maintenance of the permanent way of railways. They have published the following information respecting it. Instead of using great pressure, as before explained, to impregnate the tree, a moderate pressure only is applied to one end of it; the effect is to expel the sap, and fill the tubes or pores of the timber with the preserving liquor. The tubular structure of trees has been long known, and Dr Boucherie's process shows that no connection exists between the tubes laterally. Colouring liquid applied in the form of a letter or word at one end of the tree appears in the same shape at the other. The fluid used by Dr Boucherie is a solution composed of one part of sulphate of copper to one hundred parts of water by weight. The specific gravity of the solution, when ot proper strength, at 60° Fahr., is 1·006, or nearly so. A water-tight cap is placed on one end of the tree which is to be saturated, and the solution is introduced within it by a flexible tube. The pressure required not being more than from 15 to 20 lb. on the square inch, it may be obtained in a very simple way, by raising the tank which contains the solution 30 or 40 feet from the ground. When the pressure is applied the sap runs in a stream from the opposite end of the tree; and a ready means exists of discovering when it is exhausted and the whole length of the tree penetrated, by rubbing the end with a piece of prussiate of potash, which will leave a deep brown mark when brought into contact with the copper of the solution. The sap and surplus solution, should any pass through the tree, may be pumped back into the reservoir, the sap being a better solvent of the sulphate of copper than water, if it should happen to be impregnated with lime or other impurities. There are certain kinds of timber which are impenetrable by the solution applied in the manner described. It answers best with trees that are the least costly, as beech, birch, larch, Scotch fir, alder, elm, poplar, &c. Trees felled any time between November and May may be prepared in the latter month. But when they are cut down in May or any month between then and November, they should be prepared within three weeks of the time of felling. It has been found, in the preparation by this system of vast quantities of timber for the French navy and railways, that the time necessary for the operation depends both on the length of the tree and on the description of timber. Trees of 40 feet in length, prepared at Fontainbleau for the French navy, required from eight to ten days to become sufficiently impregnated; whereas for lengths of 9 feet only, the process was accomplished in twenty-four hours. A summary of experiments made in Derby with this process is given in the following table. It will be observed from the facts there stated, that the pores of the poplar are more pervious than those of other woods; and the rapid and large absorption of the fluid by the memel timber shows, that the pores of fir timber, when the natural juices are dried up, still afford a continuous channel for its flow:—

Summary of Experiments.

No. of Experiment.	Date.	Description of Wood.	When cut down.	Length.	Average Diameter.	Cubic Content.	Amount of pure Sap forced out before Solution perceptible.	Amount of Solution used to effect this.	Time in forcing pure Sap out.	Total Amount of Solution run out of Tank during operation.	Time of Operation.	Amount of Solution used per cube foot.
				Feet.	Inches.	Feet.	Quarts.	Quarts.	Hours.	Quarts.	Hours.	Quarts.
1	April 29, 1856	Beech	January, 1856	18	12¼	14¾	33	64	4	104	8½	7·04
2	May 1, 1856	Spruce Fir	April 23, 1856	18	11¼	13¼	27	50	5	95	12	7·00
3	May 5, 1856	Poplar	April 1, 1856	18½	11¼	13¼	Copper perceptible from commencement.			130	11	9·60
4	May 7, 1856	Elm	Dec. 1855	18	11¼	13¼	—	—	—	156	23	11·52
5	May 9, 1856	Alder	Feb. 1856	18	11	12	43	58	1½	176	31	14·64
6	May 10, 1856	Memel	—	18½	11 by 11	15¼	Copper perceptible from commencement.			230	50	15·08
7	May 22, 1856	Birch	May 21, 1856	18	12¼	14¾	32	34	25 minutes.	184	3½	12·00
8	May 23, 1856	Scotch Fir	—	18	12¼	14¾	35	47	6	130	58	8·80

One great advantage attending this method, and which is likely to render its application very general, is the inexpensive nature of the apparatus required.

Weather seasoning.

Seasoning timber, by exposing it for a lengthened period without subjecting it to any other process, has received much attention, and much controversy has arisen upon the best mode of carrying it into effect. It may perhaps be stated as the general opinion, that rough timber may be improved in this country by stacking it off the ground, that it may not be injured by damp. Sided timber, thick stuff, and plank, should always be stowed under sheds, and these must be airy and well ventilated, without partial draught which could affect the ends or any one portion of the timber more than another. Two or three years are required to season these descriptions of timber to a moderate degree only. Mast spars are best protected when submerged under water, and if buried in mud they are still more effectuallly preserved. Boards of mahogany or fir are well seasoned by being stacked on end in the open air without covering, but raised a little from the ground to avoid damp. In the royal yards it was formerly the custom to allow ships to stand in frame for various periods before they were planked, but the necessity of building ships rapidly has of late years precluded the possibility of doing this; and the evil effects have been too apparent. The following tables show the results of weather seasoning, as collected by Mr Fincham, and published in his work on the *Outlines of Ship-Building*:—

A Table of the Shrinkage and Loss of Weight in Seasoning, of the principal Timbers used in Ship-building: the period of seasoning was ten years.

Species of Timber.		Green.		Seasoned.		Relative shrinkage and loss of weight.		Weight of a cubic foot.	
		Dimens.	Weight.	Dimensions.	Weight.	Dimens.	Weight.	Green.	Seasoned.
		in. in.	lb. oz.	in. in.	lb. oz.			lb.	lb.
English Oak	butt	6 by 6	7 8	6 by 5 14/16	6 7	1·000	1·000	60	51½
	top	,,	7 10	5 14/16 ,, 5 15/16	6 6	1·010	1·176	61	51
	butt	,,	8 0	5 15/16 ,, 5 14/16	6 5	1·010	1·588	64	50½
	top	,,	7 4	5 15/16 ,, 5 15/16	6 0	1·000	1·176	58	48
African Oak	butt	,,	9 2	5 12/16 ,, 5 12/16	8 0	1·068	1·059	73	64
	top	,,	8 6	5 13/16 ,, 5 13/16	7 2	1·066	1·176	67	57
	butt	,,	7 12	5 13/16 ,, 5 14/16	7 2	1·033	0·588	62	57
	top	,,	7 4	5 14/16 ,, 5 15/16	6 10	1·010	0·588	58	53
Italian Larch	butt	,,	4 15	5 15/16 ,, 5 14/16	4 8	1·000	0·411	39½	36
	top	,,	4 15	5 14/16 ,, 5 14/16	4 9	1·021	0·354	39½	36½
	butt	,,	5 0	5 14/16 ,, 5 14/16	4 9½	1·021	0·384	40	36¾
	top	,,	5 1	5 15/16 ,, 5 14/16	4 11	1·021	0·354	40½	37½
Scotch Larch	butt	,,	4 8	5 14/16 ,, 5 14/16	4 2½	1·021	0·323	36	33¼
	top	,,	4 10	5 15/16 ,, 5 15/16	4 1	1·000	0·530	37	32½
	butt	,,	4 5	5 15/16 ,, 5 14/16	4 0	1·010	0·300	34½	32
	top	,,	3 12	5 14/16 ,, 5 14/16	3 7	1·021	0·300	30	27½
Cuba Cedar	butt	,,	4 0	5 15/16 ,, 5 15/16	3 12	1·000	0·235	32	30
	top	,,	4 3	5 15/16 ,, 5 14/16	3 12½	1·010	0·411	33½	30¼
	butt	,,	3 14	6 ,, 6	3 0	0·979	0·823	31	24
	top	,,	3 10	5 15/16 ,, 6	3 5	0·989	0·300	29	26½
New South Wales Cedar	butt	,,	4 0½	5 15/16 ,, 5 14/16	3 10	1·010	0·382	32¼	29
	top	,,	3 12	5 14/16 ,, 5 15/16	3 6½	1·000	0·323	30	27¼
	butt	,,	4 6	5 15/16 ,, 5 15/16	3 8	1·000	0·823	35	28
	top	,,	4 5	5 14/16 ,, 5 14/16	3 9	1·021	0·706	34½	28½

A Table of the Transverse Shrinkage in Seasoning of Board, 12 inches square and half-an-inch thick: the period of seasoning was thirteen years.

Species of Timber.		Shrunk in Seasoning.	Species of Timber.		Shrunk in Seasoning.
English Oak	butt	1/18 the breadth.	Yellow Pine	butt	1/33 the breadth.
	top	1/18 ,,		top	1/43 ,,
African Oak	butt	1/37 ,,	Larch	butt	1/37 ,,
	top	1/33 ,,		top	1/43 ,,
Riga Fir	butt	1/33 ,,	English Elm	butt	1/34 ,,
	top	1/35 ,,		top	1/37 ,,
Dantzic Fir	butt	1/38 ,,	Canada Elm	butt	1/18 ,,
	top	1/33 ,,		top	1/37 ,,
Virginia Pine	butt	1/37 ,,	Cowdie	butt	1/34 ,,
	top	1/43 ,,		top	1/34 ,,

Seasoning timber by desiccation.

Seasoning timber by exposing it to a current of heated air at a higher velocity than is engendered by natural causes, was introduced by Mr Davison. The desiccating process, as he terms it, and as explained by him to the institution of civil engineers in 1853, consists in impelling rapid currents of air through a chamber or chambers containing the wood; spaces being left between the ranges or tiers of timber for the heated air to act uniformly upon all its sides. The moisture, as soon as it is cooled, passes instantly away through an opening in the roof of the chamber, and this appears to be a distinguishing and essential feature in the process. The wood remains in the chamber until by weighing a sample from time to time, the whole aqueous matter had been expelled from its pores. Charring wood in a sand-bath was practised in the beginning of the last century, and apparently with some success; but the heat must have been much greater than that employed by Davison, and the process probably was much more rapid. In carrying out the desiccating system, attention must be paid to the following points:—Different woods and different thicknesses of wood, require different degrees of heat; hard woods and thick logs of wood require a moderate degree of heat, from 90° to 100° Fahr. The softer woods, such as pine, may be safely exposed to 120°, or even to a still higher temperature; and when cut extremely thin and well clamped, 180° or 200° have been found rather to harden the fibre and to increase its strength. Honduras mahogany in boards of one inch in thickness may be exposed with advantage as regards colour, beauty, and strength, to a heat as great as 280° or 300° Fahr. A slab of Honduras mahogany 1½ inch thick, cut fresh from the log, was wholly deprived of its moisture, amounting to 36 per cent. by exposure to the temperature of 300° for fifty consecutive hours. In practice, however, it is found that from 115° to 120° of temperature brings almost every kind of timber in slabs or boards of moderate thickness, safely and steadily towards complete desiccation in a comparatively short space of time. For boards up to 4 inches thick, one week is sufficient for every inch of thickness, thus one week for 1 inch thick, and four weeks for 4 inches thick, but beyond this thickness the proportions require to be increased. For 6 inches thick, seven weeks should be allowed; for 8 inches ten weeks, and so on. These periods are fixed on the supposition, that the rapid forced current of heated air will be kept up only during the day of twelve hours, and that the chamber will then be closed till the following morning, that being the customary mode of working.

English oak requires more than ordinary care when thus prepared. It should never be exposed under any circumstances for any length of time to a higher temperature than 105°; more intense heat has been found to act upon the Gallic acid, or on the fibres in some peculiar way, so as to produce internal fissures. Mr Davison also stated, that still heat like that of an oven had an effect upon wood totally different from that produced by a current of heated air. In the one case the fibre is rendered short, brittle, and weak; in the other, all that is valueless is driven away, and the albumen becomes solidified or coagulated into a hard compact substance, and the fibres gain a great increase of strength and rigidity. Seasoning under ordinary degrees of temperature has a completely different effect on the albumen, which, if not previously dissolved or washed out by any of the processes previously referred to, remains, when dried, in a soft spongy state, ready to become an absorbent of moisture.

It has been found by experience that 100 feet per second is the best velocity for the current of heated air, and with a proportionate area of inlet-pipe, a sufficient quantity should be delivered into the chamber to cause a complete displacement of the air and moisture in three minutes. If a desiccating chamber contains 30,000 cubic feet of air, 10,000 cubic feet ought therefore to be propelled into it per minute, care being at the same time taken that the area of the outlet or outlets for the escape of the moisture exceed the area of the inlet-pipe, and that they be so arranged as to avoid a direct current between them.

The Board of Ordnance adopted this system for gun-stocks in 1840. Previous to its introduction, about 400,000 stocks were undergoing regularly a course of seasoning, each requiring to be turned once or twice every year to avoid the ravages of worms or decay. In a report from Mr Lovell, then her Majesty's inspector of fire-arms, he states respecting some gun-stocks subjected to the process:—"One half of the number were quite fresh cut and green wood, the other moiety had been about twelve months in store; the total weight before the process was 536 lb. 9 oz.; and after sixteen days' exposure to a current of air heated to 110°, or 114° Fahr., that weight was reduced to 413 lb. 14½ oz.; that is to say, 122 lb. 10½ oz. of moisture had been driven off. Some of the stocks had been purposely selected with seen cracks in the butts and other faults, for I expected that those cracks and faults would be exaggerated by the heat of the chamber. But the result was not so; on the contrary, they were closed considerably behind the marks that had been stamped upon the ends of them before they were put in, and the whole number of stocks came out in good condition, and fit for immediate use." He proceeds to say,—"The wood is better seasoned than when dried in the open air; 1*st*, Because the albumen being dried on the pores and in the capillary tubes, renders the fibre stronger and less liable to absorb moisture; 2*d*, The wood is stronger, tougher, and, of course, more capable of withstanding the effects of violent vibration from the lateral adhesion of the fibre being better preserved; 3*d*, It works smoother and more waxy under the chisel, and has less tendency to speel and crumble away, which is generally the great fault of steam-dried timber. I have now worked nearly 30,000 desiccated stocks, none of which had been under the process more than twenty-one days; and my opinion is very decided, that the wood is more thoroughly seasoned, and with much greater certainty, than if it had been merely exposed to the open air in the usual way for three or four years. The desiccating chamber created in the royal manufactory at Enfield continues in full activity. The heat is kept down to a medium degree, between 90° and 100°; and at this temperature it delivers the stocks perfectly seasoned in fourteen to sixteen days, according to the quality of wood, whether of sap or heart; and I propose to subject the whole of the stocks to it in future, whether they have been air-dried previously or not, in order to make sure that the whole shall have been equally seasoned."

Some bearers of Riga pine and American elm, after they had been in use for about six years, and exposed for that length of time to a temperature of 115° or 120° of heat, at which the chamber invariably stood, were examined, and were found to be perfectly sound and in excellent condition; thus proving that the process, even though continued for so long a period, did not injure in the slightest degree the fibre or the strength of the wood.

It is difficult to understand how the timber subjected to this process can be rendered more capable of sustaining a tensile strain, if this be the case, but it is natural that the albumen, when hardened in the pores, should render it more incompressible, and therefore more capable of resisting any strain when the strength depends on this property. For hard woods, to which Dr Boucherie's process is not applicable, desiccation seems to be admirably adapted, Mr Lovell's experience with the walnut-tree gun-stocks appearing conclusive.

The following table is interesting, giving the results of experiments made by Mr Davison:—

Materials used in Ship-Building.

and $\frac{25 \cdot 1}{4} = 6 \cdot 27$, or a little more than 6¼th inches = the breadth.

Example 2.—What must be the dimensions of a beam of red pine to carry a weight of 15 tons in the middle, when the distance between the supports is 30 feet? Answer—10 inches in breadth by 15 inches deep nearly.

If a beam be supported at both ends, and the load be equally distributed over its length, it will carry twice the weight; that is, the result obtained by the foregoing rule must be doubled.

If the beam be firmly fixed at both ends, so as to prevent the ends from rising, when the weight is applied in the middle, the result will be increased by its half; that is, a weight of 10 tons may be increased to 15 tons.

If the beam be fixed at both ends and loaded uniformly throughout its length, the result must be multiplied by 3; that is, a beam which will carry 10 tons in the middle when it is laid loosely upon its supports, will carry 30 tons when fixed at both ends, and the load distributed uniformly over its length.

It must always be remembered, in applying these rules to practice, that the weights found by them are the breaking weights. The proportion of the breaking weight with which it is considered safe to load a beam in actual use varies according to the nature of the material. In the case of cast-iron, which breaks without giving any warning, it is not considered safe to place more than one-third of the breaking weight upon it. In wrought iron and timber, which both show symptoms of being overstrained before they break, by becoming crippled, or by an amount of flexure so great as to be very observable to the eye, the load in practice may be one-half of the breaking weight, as found by the rules.

Experiments on the strength of materials are always valuable to practical men, as adding to the store of knowledge, and acting as a check on any rules which may be in use. A series of experiments on timber were made by Colonel Fowke, of the Royal Engineers, at Paris, during the universal exhibition held there in 1855, and the results were published at great length in the report upon that exhibition.

Mr Fincham made some experiments, with great care, on the transverse strength of timber, and the following table, showing the results, is extracted from his work on ship-building:—

A Table of a Series of Experiments on the Strength of the undermentioned species of Timber. In each case the piece was three inches square and four feet long between the supports, and the weights were placed in the middle.

Species of Timber and No. of Experiments.	Specific Gravity.	Weight at which the piece broke.
	Cwts.	
English oak, the mean of 8 experiments.....	·791	32·973
Italian oak, the mean of 4 experiments......	1·077	38·792
Dantzic oak, the mean of 4 experiments.....	·704	39·732
African oak, the mean of 4 experiments.....	1·021	59·897
Malabar teak, the mean of 4 experiments...	·724	43·723
Moulmein teak, the mean of 4 experiments...	·909	34·292
Riga fir, the mean of 4 experiments..........	·576	35·558
Dantzic fir, the mean of 4 experiments......	·708	36·718
Italian larch, the mean of 4 experiments....	·645	40·047
Scotch larch, the mean of 4 experiments.....	·561	27·750
Hackmatack larch, the mean of 4 experiments..	·708	37·886
Cowdie, the mean of 4 experiments..........	·614	33·317
Bermuda cedar..	·932	36·776
Cuba cedar, the mean of 4 experiments......	·524	24·348
Van Dieman's Land cedar.........................	·616	18·303
Mahogany, the mean of 4 experiments.......	·636	30·093
New South Wales mahogany, the mean of 4 experiments............................	1·382	36·777

Materials used in Ship-Building.

Rigidity of timber.

Rigidity, or the opposite of elasticity, is the power of resisting deflection or bending, when a weight is placed upon a beam, or when a side pressure is brought to bear against it. This power is increased in a much more rapid ratio than the power to sustain loads without fracture; thus, in order that a beam may bear 10 tons with the same degree of deflection as one bearing 5 tons, much less increase of dimensions will be required than will be necessary for a beam whose breaking weight is to be 10 tons, in comparison with one whose breaking weight is 5 tons. The possession of rigidity in a lateral direction is necessary to every beam to a certain extent, to prevent its bending side-wise and becoming crippled, and hence beams must not be too much reduced in their breadth relatively to their depth. In practice, the proportions of 2 for the breadth to 3 for the depth, and also of 3 for the breadth to 5 for the depth, are very common; but in joists of floors, and in other situations, where side props, or supports to prevent flexure, can be introduced, the depth is often made in a greater proportion, with the advantage of a saving of material, to carry the same weight.

Supply of timber.

The supply of timber for ship-building purposes is a subject that has at various periods attracted much attention, both as regards the species grown in this country and those which are imported from abroad.

Some valuable remarks on foreign woods were lately made by Mr Leonard Wray, in a paper read before the Society of Arts, and published in their journal of 6th May 1859. He called attention to the fact, that before forests of the finest timber can be brought into beneficial use, a population is required to fell and trim the trees, as well as a good shipping port, and the cheapest possible means of bringing the timber from its native forests to the port of shipment. Honduras has long had its organised bands of woodcutters, and has long been one of the most important timber-exporting countries. It now exports about 25,000 tons of mahogany and 6000 tons of logwood annually, and the woodsmen in pursuit of these two staple products continually pass and repass other species of the finest quality of timber in the world. Amongst many other fine trees found there, Mr Wray specially enumerated the following:—The green heart, the live oak (Bignonia), and other oaks; the mahoc, the bullet-tree, the Neesberry bullet-tree, the iron-wood, the locust, used for ships' planking and treenails; the dogwood, the red pine, the pitch pine (much superior to that of Carolina and the other southern states of America), the cedar *(Cedrela odorata)*, a light and durable wood, not liable to dry-rot, nor subject to the attack of insects, and of which the trunk is 70 or 80 feet long, with a diameter of from 4 to 7 feet.

The morra is described by Mr Wray as a most valuable timber, the trees often attaining a height of from 100 to 150 feet, the lowest branches being 60 feet from the ground. The wood is extremely tough, close, and cross-grained, so that it is difficult to split, and not liable to splinter, which renders it particularly adapted for ship-building, more especially in the royal navy. The trunk makes admirable keels, timbers, and beams; and the branches having a natural crookedness of growth, are unsurpassed as knees.

Sir R. Schomburgk, referring to this tree, states that it grows abundantly in Guiana, on the banks of the river Berima, which is navigable for vessels drawing 12 feet of water, so that they might load close to the spot where the trees are cut down.

Mr Wray also mentions many other fine timber trees as the growth of Guiana, and Assam, Tenassarim, and the provinces and settlements in the neighbourhood of the Straits of Malacca. He states that a quantity of teak has for many years been exported from Moulmein, and other parts along the coast, but that the field which this healthy and most pleasant country still presents is so inexhaustible

Materials used in Ship-Building.

that he considers it to stand unrivalled as a timber-producing country. Hitherto teak alone has been exported, but there are others which are considered quite equal, and even superior to it. He gives the following list of some of the best timber woods, which will serve to give an idea of the capabilities of these neglected provinces:—

Anan.—One of the hardest and most compact woods known.

Ahnaun.—Strong and very durable; used in ship-building.

Keoun-lac (Rottlera).—Excellent for rudders.

Kat-wat-na (Cedrela).—Large timber, 40 to 70 feet long; used for ship-building.

Ka-nyeng-kyaung-khyay.—For ship-builders; contains an aromatic oil, and is not attacked by insects.

Kyess-yo.—Similar to teak.

Kud-doot-alaiu.—A large tree; used in ship-building.

Kunnasoo.—A very large tree; very hard and durable timber.

May-Mayka.—Used in ship-building.

May-raug.—Said to be very durable.

May-tobek.—Used for the bottoms of ships, considered preferable to teak.

Mayam.—An indestructible, strong, heavy, dark-red wood.

Podauk.—A beautiful, compact, and hard wood, sometimes called rosewood.

Pengadoh.—Strong and durable.

Pien-mahne.—Yields very strong knee-timber.

Pyau-ga-deau.—Hard, dense, and durable; called iron-wood.

Soondra.—A very tough, elastic wood; said to be the strongest of all the Indian woods.

Thab-bau.—Fine solid timber, sometimes 70 feet long; used for boats.

Thau-kya.—A species of wood similar to Saul.

Tha-nat.—A kind of grey teak.

Tha-nat.—More resembling Saul.

Thau-That.—A capital wood, like Saul.

Theet-ya-hau.—A species of teak; close grained.

Theug-gau (Hopea odorata).—An enormous tree of the Saul tribe; yields a strong, compact, and excellent timber, considered superior to teak; also a quantity of good dammer or resin. Insects never attack this wood, nor is it liable to rot.

Tirbbac (Quercus Amberstiana).—An oak; large tree; used in boat-building.

Thounsauga.—A large tree; used in boat-building.

Thingau-kyauss.—Close grained, strong, heavy wood; used in ship-building.

Thubbae (Mimusops).—Used in ship-building.

Thubbor (Uvaria).—A large tree; used in boat-building.

Toung-byeng.—A kind of red Saul.

Thym-bro.—A good, strong, durable wood; used in boat-building.

Of the Malacca woods Mr Wray gives a long list, and of these he describes the following from his own experience while resident in the straits:—

Murbouw.—Very strong, hard, and heavy; used in shipping; not attacked by insects; will last 100 years.

Binlaugoor.—Valuable wood for ship-building, especially for planks, mast, spars, &c. It grows in great abundance, especially near Singapore, and is largely exported to Mauritius, California, &c.

Vamerlaut.—Hard, tough, and very durable.

Giham.—A pale yellow wood, close grained, hard, elastic, very durable, and generally used in boat-building.

Tampauce.—Used for house-building; hard, and exceedingly durable.

Tamboosu.—House beams; considered very durable.

Galam }
Tikoos } —Hard, tough, elastic; used in boats.

Marautes.—Very large; light resinous wood, much used for planking, and in building boats.

Australia is the next country to which he directed attention; and though distant, it may yet become an important timber-exporting country, the timber being brought here as a home freight in return for our large exports. The trees of this country which are mentioned are the iron-bark, the tuart, the jarrah blue-gum, and morrell.

The tuart is especially mentioned as adapted for ship-building, as it is most difficult to split, and not liable to splinter.

Materials used in Ship-Building.

The jarrah, whose stems average 65 feet long, nearly parallel, and without a branch or knot, is also a most important tree of this colony. It is not attacked by insects of any kind, nor has it any tendency to dry-rot.

There are forests of this wood, almost unmixed with other trees, in Western Australia, of more than 4 miles in depth, and which are known to extend for a length of 150 miles. Planks may be obtained from it 10 feet wide if desired. It is not only valuable as a ship-building timber, but also for furniture, being found of various shades of colour, and of almost every variety of grain.

A ship may therefore be loaded very advantageously with this timber after proper sawing-machinery has been erected in the country, as it may be converted into scantling and other pieces for furniture, which may be stowed along with the balk timber of any size that may be desired.

Some very fine specimens of pine have likewise been imported lately from Vancouver's Island, of immense size, of great strength, and very durable.

Specimens of foreign woods may be found in the collections at Kew; at the Kensington Museum; East India House; Somerset House, Admiralty branch; and at the Crystal Palace.

Since the publication of this paper, containing so much valuable information, and so liberally contributed by Mr Wray to the *Transactions of the Society of Arts*, and from which the foregoing extracts have been so copiously taken, contracts have been made by the government for green-heart Tuart and Jarrah timber. It is to be hoped that this is a prelude to timber from our own colonies being hereafter used in the royal dockyards in larger quantities.

The importance of ship-building timber for the merchant service is undoubtedly decreasing, on account of the increasing use of iron; and it therefore behoves the government to make its own arrangements to originate and foster this trade in those districts pointed out by Mr Wray.

Though insignificant in comparison with these magnificent trees of foreign growth, the increasing quantity of larch now grown in this country deserves attention.

The larch (*Pinus Larix*) now so much grown in England as well as in Scotland, is frequently called Scotch fir, thus being mistaken for the "Scotch fir" as so called in Scotland (*Pinus sylvestris*), which has a dark-coloured foliage. The latter is considered superior for the purposes of architecture, but larch is better adapted for ship-building purposes whenever its size is sufficient. Like most other woods, it varies extremely, according to the soil on which it is grown, and care must therefore be taken in its selection and use. It stands exposure to wet and dry better than most timber, and is hence much used for pit-props in coal mines. The late Duke of Atholl induced the government to build a vessel of larch from his forest. She was called the Atholl; and though her durability has been very great, no further attention appears to have been as yet paid to the subject by the authorities.

Weight of timber.

A knowledge of the weight of the different species of timber is necessary to the naval architect, to enable him to compute or estimate the weight of the hull of the vessel which he is designing or constructing. Mr Edye, the late assistant-surveyor of Somerset House, published an elaborate work containing tables of the weights and the displacements of the different classes of men-of-war of his day, but now rendered comparatively valueless by the introduction of steam-vessels and the great changes in the proportion of ships. The following table, containing the weight of a cubic foot of timber in a green and seasoned state, is extracted from this work; and if the weights of the different timbers be compared with their strengths as previously given, it will be seen that the heavier timbers may be used without increasing the weight of the vessel, as their scantling may be reduced, and the same strength be retained, and with advantage, also, as to durability:—

Materials used in Ship-Building.

Name of Timbers.	Green.		Seasoned.	
	lb.	oz.	lb.	oz.
English oak	71	10	43	8
Dantzic oak	49	14	36	0
African teak	63	12	60	10
Indian teak, green or seasoned, about the same...				
Malabar*	...		52	15
Rangoon*	...		26	4
Indian mast peon	48	3	36	0
Cedar	32	0	28	4
Larch	45	0	34	4
Riga fir	48	12	35	8
New England fir	44	12	30	11
Elm	66	8	37	5
Beech	60	0	53	6
Ash	58	3	50	0

* Malabar teak is the heaviest, and Rangoon the lightest of all the Indian teaks imported.

Materials in combination with timber.

Special care is required in the selection of materials to be used in combination with timber, in order that no chemical or other action, which may tend to premature decay, may take place between them and the timber. Great care is required in the use of iron for fastenings on account of the great affinity which exists between this metal and oxygen. The oxidation of the iron not only destroys the fastening itself, but has an injurious effect upon the timber surrounding it. If the nature of the wood be such that a supply of oxygen from the atmosphere can be kept up through its pores, the oxidation and destruction of the iron will be very rapid. The use of iron in combination with oak is particularly objectionable on account of the acid nature of this wood, and the quantity of oxygen which it contains. In oily and resinous woods the surface of the bolt, when driven, receives a coating of this matter, and is thus rendered less liable to oxidation. Such woods are also more impervious to the passage of a continued supply of oxygen. Iron fastenings, under copper sheathing, are also liable to be destroyed by the galvanic action which takes place between these metals. Many attempts have been made to prevent this action by driving the bolt so far into the wood that a cement of some kind could be put over the head of it, so as to break the connection between the metals, but no important results of any system of this kind are as yet known to have obtained.

Copper is therefore used largely for the fastenings of ships. This metal is liable to a very slight oxidation only upon its surface, and when this has taken place, all further oxidation ceases, and the metal is not destroyed, as is the case with iron. Copper, however, is not possessed of the same strength as iron, and is soft and ductile in comparison with it. It is therefore far from being so good a fastening, especially when driven through iron-knees and iron-riders. It is liable to be bent and crushed, or crippled at the neck, by the iron through which it has passed, if the ship be severely strained and work in any degree.

Some valuable experiments were made on the tensile strength of bolts of dockyard copper, Grenfell's copper, and Muntz's yellow metal, by Mr Jn. Kingston, of Woolwich dockyard.

The results are shown in the following table :—

Description of bolt.	Tensile strength per square inch.
Dockyard copper, average of 12 experiments	49,490 lb., or 23 tons very nearly.
Grenfell's copper, average of 11 experiments	46,592 lb., or 20¾ tons nearly.
Muntz's yellow metal, average of 11 experiments	49,945 lb., or 22¼ tons nearly.

Copper, from its ductile nature, is quite unfit to be used for any purpose where a cross-strain has to be resisted.

A late invention, by which a coating of copper is put upon iron, in the same manner that iron-plates are coated with tin, promises to be very valuable. Fastenings of this kind will then combine all the good qualities of both metals, and will tend materially to strengthen the general fabric of the ship.

Materials used in Ship-Building.

Treenails of timber, equal in quality to that through which they are to be driven, make excellent fastenings, but their strength and their power of holding are not such that they can be used to the entire exclusion of metal fastenings.

Sheathing.

The materials used for the sheathing of ships to protect them from fouling, and from the attacks of the *teredo navalis*, and other destructive worms, are chiefly copper and Muntz's metal. These metals are kept clean by the sea-water acting slightly upon them as a solvent, or by oxidation; and a gradual waste is therefore taking place continuously from their surface, thus preventing the adherence of any animal or vegetable matter. With a view to obviate this gradual wearing away, Sir H. Davy proposed to induce a galvanic action upon the sheathing by attaching protectors of iron on its surface. He succeeded to some extent; but in proportion as the iron was eaten away and the copper preserved, it became foul with sea-weed and shell-fish, so that his proposal was abandoned.

Iron for Ship-building.

The use of iron having now become common in the construction of ships instead of timber, a thorough knowledge of its properties is thus rendered necessary to the naval architect. The properties of wrought or malleable iron, as a material for the construction of the component parts of ships, will first be considered in a general point of view.

Cohesive strength.

The strength of rolled iron varies with its quality; the results given will be those due to an average quality, such as ought to be used in ship-building. The cohesive strength of bar-iron, or its power to resist a tensile strain, may be safely taken at 25 tons, or 56,000 lb. per square inch of section. Messrs Robert Napier and Sons of Glasgow have made some valuable experiments on the cohesive strength of wrought-iron, and steel bars and plates, which have been published in the *Transactions of the Institution of Engineers in Scotland*, vol. ii., 1859, and the results, along with others, by Mr Fairbairn of Manchester, on iron-plates, are given here by their kind permission.

Bar-iron.

Table of the average Strength of Steel-bars, as found by Messrs Napier and Sons.

Steel-bars.	Strength per sq. inch of section.
Cast-steel for rivets	106,950 lb.
Homogeneous metal for rivets	90,647 „
Puddled steel-forged bars	71,486 „
„ „ rolled bars	70,166 „

The average cohesive strength of rolled bars of Yorkshire iron was found by Messrs Napier to be 61,505 lb. per square-inch, this being the mean of twenty experiments on bars varying from $\frac{11}{16}$th inch diameter, up to 1 inch square. And the average strength of bars manufactured by nine different makers in different parts of the country, and purchased promiscuously in the market, was 59,276 lb.; this being the mean of 110 experiments on bars varying from $\frac{11}{16}$th up to $1\frac{1}{8}$th inch diameter, and it is most satisfactory to find that the experiments showed a remarkable uniformity of results.

Experiments on plates by Mr Fairbairn.

Mr Fairbairn of Manchester directed his attention, at a very early date, to the subject of iron for ship-building, commencing his operations by the construction of various small vessels for canal navigation. In 1830 and 1831 he built three iron steam-vessels for the Forth and Clyde Canal Company, and to be employed as coasting traders to Grangemouth. These vessels made the voyage from Liverpool to Glasgow, and showed such symptoms of strength as to induce Mr Fairbairn to enter more largely into the business.

Materials used in Ship-Building.

Within the next four years he constructed a vessel for the Lake of Zurich, and two river-steamers of about 170 tons for the navigation of the Humber; and in 1836 he commenced the building of iron-ships at Millwall, on the Thames, in company with others. With a view to the introduction of correct principles into what was then a new line of manufacture, he made some valuable experiments at Manchester in 1838, to test the strength of iron-plates and of riveted joints. The results were communicated to the Philosophical Society of that town, and have since been republished by him.[1] The results which he obtained were as follow:—

Cohesive strength of plates.

Species of Iron.	Mean breaking Weight in the Direction of the Fibre, in tons per sq. inch.	Mean breaking Weight across the Fibre, in tons per sq. inch.
Yorkshire plates……………………	25·770	27·490
„ „ ……………………	22·760	26·037
Mean……………………	24·205	26·763
Derbyshire plates……………………	21·680	18·650
Shropshire plates……………………	22·826	22·000
Staffordshire plates……………………	19·563	21·010
Mean……………………	21·350	20·553

The plates experimented upon were as nearly ¼ inch thick as could be obtained; due allowance being made, in calculating the results, for any excess or deficiency in thickness in the different specimens.

The section through AB was 2 inches wide. The plate having been made narrower there to ensure its breaking at that part. Plates were riveted on each side of the ends to stiffen them. The holes ○ (fig. 14) were bored through the ends at right angles to the plates, with their centres in a direct line along the centre line of the part AB; and the apparatus for tearing the plates asunder was attached by bolts passing through these holes.

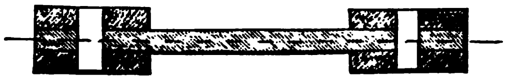

Fig. 13.

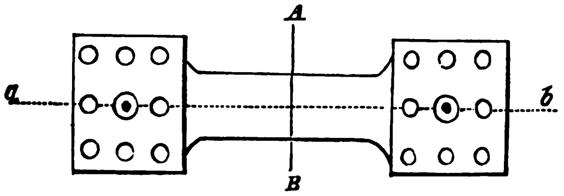

Fig. 14.

Iron-plates are supposed to be fibrous lengthwise, or in the direction in which they are rolled; but their cohesive strength ought to be nearly equal, whether the strain be applied with the fibres or across it. This uniformity of strength is attained by the shingles, or piles from which the plates are rolled, being composed of layers of bars carefully selected and laid at right angles to each other. When plates are very inferior in this respect, they may be supposed to have been manufactured from masses or blooms made up of irons and ores of different qualities, and these not sufficiently worked to amalgamate them properly. In testing iron-plates, it is therefore important to test their strength in both directions.

Messrs Napier's experiments.

The very extensive series of experiments on the strength of iron-plates by Messrs Napier have fully corroborated the results previously obtained by Mr Fairbairn. The strengths per square inch of sections were as follow:—

Materials used in Ship-Building.

Yorkshire Plates.

Lengthwise……………………	55.433 lb.
Crosswise……………………	50,462 „
Mean strength……………………	52,947 „

This result being obtained from 45 experiments upon plates varying in thickness from ¼ inch up to ¾ inch.

Ordinary best, and best best boiler-plates, as manufactured by ten different makers in different parts of the country, and purchased promiscuously in the market—

Lengthwise……………………	50,242 lb.
Crosswise……………………	45,986 „
Mean strength……………………	48,114 „

This result being obtained from ninety-three experiments upon plates varying in thickness from ¼-inch up to ¾-inch.

Glasgow Ship Plates.

Lengthwise……………………	47,773 lb.
Crosswise……………………	44,355 „
Mean strength……………………	46,064 „

This result being obtained from twelve experiments on plates, varying in thickness from $\frac{5}{16}$-inch up to ¾-inch.

Messrs Napier made some experiments upon steel-plates also, with a view to test their value for the construction of light boats for river navigation, or for any portion of iron-ships generally. The results were as follow:—

The Mersey Company's Steel-plates, for Ships.

	Per sq. in. of section.
Lengthwise……………………	101,450 lb.
Crosswise……………………	84,968 „
Mean strength……………………	93,209 „

Steel-plates for Ships—Puddled Steel—"Mild"—by the same makers.

Lengthwise……………………	71,532 lb. per sq. in.
Crosswise……………………	not recorded.

Blochairn Boiler-plates—Puddled Steel.

	Per sq. in. of section.
Lengthwise……………………	96,320 lb.
Crosswise……………………	73,699 „
Mean strength……………………	85,010 „

Homogeneous Metal.

	Per sq. in. of section.
Lengthwise……………………	96,280 lb.
Crosswise……………………	97,150 „
Mean strength……………………	96,715 „

Same Metal—Second Quality.

	Per sq. in. of section.
Lengthwise……………………	72,408 lb.
Crosswise……………………	73,580 „
Mean strength……………………	72,994 „

The portions of the plates tested by Messrs Napier and Sons were made of a similar form to those tested by Mr Fairbairn. As the result of these experiments, it may fairly be assumed, that iron-plates of good average quality should stand a strain of 56,000 lb., or 21 tons, as their breaking weight per square inch of section.

The results from the Yorkshire plates have been kept separate, because their quality and their price are such as to preclude their general use in ship-building. In boiler-making they are only used for furnaces, and those parts which require especial care.

The strength of rivets and of riveted joints, to connect plates in various ways, was also the subject of experiment by Mr Fairbairn in 1838; and as no subsequent experiments appear to have thrown any further light upon the subject in its bearing upon ship-building, the results obtained at that time will be given.

The experiments were conducted in the same manner as those to test the strength of plates.

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[1] *Useful Information for Engineers*, London, Longman & Co., 1856.

In lap-joints with a single line of rivets, the edges are made to lap over each other, thus—

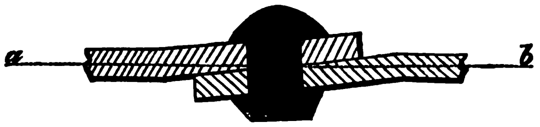

Fig. 15.

When the strain is applied to a joint of this kind, the edges of the plates turn up, and the plates themselves bend till they take the direct line of the strain, as indicated by the dotted line, *a b*.

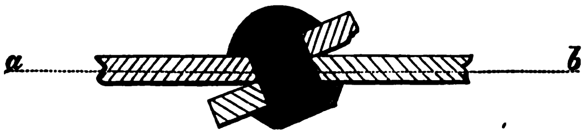

Fig. 16.

Plates may also be united by bringing their edges together to make a flush or butt-joint, putting an extra piece of plate behind the joint to which both plates are riveted by single lines of rivets, thus—

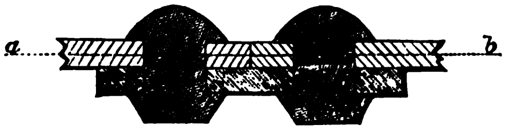

Fig. 17.

This joint also gives way by the plates bending and taking the line of strain; and no material difference of strength was found between this and the preceding joint.

Tredgold has shown that when the line of strain is not in the axis or centre of the material, the strength decreases with the divergence in a much more rapid ratio than the direct distance of the divergence. It is therefore evident that this evil is greatest in thick plates, and that the strength of thick plates will not be proportioned to that of thin plates, though the sections of each through the rivet-holes may bear the same relative proportion to the sections through the solid plates.[1]

Double-riveted lap-joints are those in which a second line of rivets is introduced. The edges are overlapped as in single riveting, but to a greater breadth, thus—

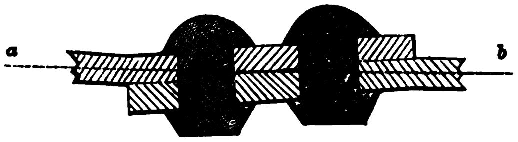

Fig. 18.

The line of rivets nearest the edge keeps it from rising.

In this joint the strength is much increased, but the plates bend as before, and take the line of tension when a direct tensile strain is brought upon them.

The edges may also be brought together flush, with a broader piece of plate behind the joints, and a double line of rivets, thus—

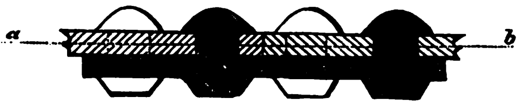

Fig. 19.

In this joint, also, the plates bend before they give way, and the strength is similar to that of the preceding double-riveted joint.

The relative strength of these joints, in comparison with the strength of the body of the plate, was found to be as follow:—

Strength of the plate	100
Double-riveted joints	70
Single do. do.	56

Countersinking the rivets, or making the heads flush on the outside, was not found to make any appreciable difference of strength.

The strongest mode of jointing plates is by bringing a lapping piece of plate upon each side, and passing the rivets on each side of the joint through the three thicknesses. In the experiments of 1838 upon this joint, double-riveting only was tested; but in subsequent experiments suggested by Mr Fairbairn, and carried out in the construction of the Menai tubular bridge, four lines of rivets were used, thus—

Fig. 20.

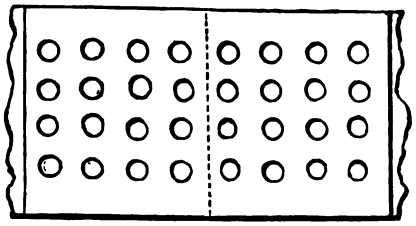

Fig. 21.

In this joint a tensile strain is directly in the line of the joint, and the material is therefore in the best position for exerting its full strength.

This joint, however, is not applicable to the sheathing of ships, on account of the necessity of keeping the exterior surface flush and smooth. But no other joint should be used in uniting plates in the construction of beams, or other parts, in the interior of a ship.

A complete system of two thicknesses of plates, for the whole surface of the plating, has been occasionally used, so as to break joint where a large flat surface of great strength has been desired, with a lapping piece on each joint, thus—

Fig. 22.

The evil, however, which results from the line of the strain not being in the centre line of the joint affects this system of double plating, and the full strength attainable from the material is not secured. The only advantage gained is, that in the event of one plate being defective, a partial remedy will thus be supplied by the second plate.

By the same series of experiments in 1838, the diameter and distance apart of the rivets, and the proper amount of lap for plates, up to ¾ inch thick, were very accurately ascertained, and the following table was formed:—

Table exhibiting the strongest forms and best proportions of Riveted Joints, as deduced from Experiments and actual Practice.

Thickness of Plates in inches.	Diameter of Rivets in inches.		Length of Rivets from the Head in inches.		Distance of Rivets from Centre to Centre in inches.		Quantity of lap in Single Joints in inches.		Quantity of lap in Double-Riveted Joints in inches.
·19 = 3/16	·38	2	·88	4·5	1·25	6	1·25	6	For the double-riveted joint add ⅔ds of the depth of the single lap.
·25 = 4/16	·50		1·13		1·50		1·50		
·31 = 5/16	·63		1·38		1·63	5	1·88		
·38 = 6/16	·75		1 63		1·75		2·00	5·5	
·50 = 8/16	·81	1·5	2·25		2·00	4	2·25	4·5	
·63 = 10/16	·94		2·75		2·50		2·75		
·75 = 12/16	1·13		3·25		3·00		3·25		

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[1] This subject has also been ably investigated in a pamphlet and report on W. Bertram's patent welding process, by Mr Renton, C.E.

Materials used in Ship-Building.

The figures 2, 1·5, 4·5, 6, 5, &c., in the preceding table, are multipliers for the diameter, length, and distance of rivets, also for the quantity of lap allowed for the single and double joints. These multipliers may be considered as proportionals of the thicknesses of plates to the diameter, length, distance of rivets, &c. For example, suppose we take $\frac{3}{8}$ plates, and require the proportionate parts of the strongest form of joint, it will be

·375 × 2 = ·750 diameter of rivet, $\frac{3}{4}$ inch.
·375 × $4\frac{1}{2}$ = 1·688 length of rivets, $1\frac{5}{8}$ inch.
·375 × 5 = 1·875 distance between rivets, $1\frac{7}{8}$ inches.
·375 × $5\frac{1}{2}$ = 2·063 quantity of lap, $2\frac{1}{16}$ inches.
·375 × 8 = 3·438 quantity of lap, for double joints, $3\frac{1}{2}$ inch.

In practice plates and rivets of certain thicknesses and diameters only are obtainable in the market, and for these the table would stand thus:—

Thickness of Plates in inches.	Diameter of Rivets in inches.	Length of Rivets from the Heads in inches.	Distance of Rivets from Centre to Centre in inches.	Quantity of lap in Single Joint in inches.	Quantity of lap in Double-Riveted Joints in inches.
$\frac{3}{16}$	$\frac{3}{8}$	$\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$2\frac{1}{16}$
$\frac{1}{4}$	$\frac{1}{2}$	$1\frac{1}{8}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{1}{2}$
$\frac{5}{16}$	$\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{7}{8}$	$3\frac{1}{8}$
$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$2\frac{1}{16}$	$3\frac{1}{2}$
$\frac{1}{2}$	$\frac{13}{16}$	$2\frac{1}{4}$	2	$2\frac{1}{4}$	$3\frac{3}{4}$
$\frac{5}{8}$	$\frac{15}{16}$	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	$4\frac{1}{16}$
$\frac{3}{4}$	$1\frac{1}{8}$	$3\frac{1}{4}$	3	$3\frac{1}{4}$	$5\frac{5}{16}$

By using these proportions, it will be found that the rivets will not be sheared in two by the plates when a strain is brought on them, and that efficient joints will be made for all vessels which require to be steam or water tight. When this is not required, some additional strength may be obtained by enlarging the rivets and increasing the distance between them.

Machine riveting.

In forming the hull of a ship, the riveting is at present entirely performed by manual labour; but in the construction of beams, or any such separate parts, considerable advantage, both as regards strength and economy, will be obtained by riveting them by machine. The rivet by the latter process is more compressed, and thus made to fill the hole; and the operation being completed while the rivet is still hot, its shrinkage in cooling draws the plates together. This adds to the strength of the joint by causing friction, when a strain is applied to pull it asunder. The extent, however, of the advantage so obtained is necessarily very variable, depending on the amount of compression by the machine in forming the head of the rivet, and on the temperature of the rivet when closed, Mr Fairbairn does not attach much importance to it, and as it certainly does not exist to any important extent in hand-riveted work, it is safest to disregard it when any calculations of strength are being made.

Rigidity of plate.

The liability of plate to yield by flexure depends upon its thickness, and upon the amount of lateral support given to it, compared with the area of its surface. To give to different plates an equal capability to resist flexure, the unsupported lengths should vary as the thickness.[1]

Transverse strength of iron.

The transverse strength of iron equally requires the attention of the iron ship-builder. It is necessary to bear constantly in mind, that in supporting a load, or resisting a transverse strain, the upper portion of a beam, which is supported at both ends, is subjected to compression, while the lower portion is in a state of tension. The line between the particles exposed to these opposite forces is called the neutral axis; but its position and direction, whether straight or curved, has not yet been definitely or mathematically determined. If the material of which a beam is composed be better able to resist compression than extension, it is evident that there may be less material in the upper than in the lower portion of the beam. The power to resist fracture is therefore looked upon as mainly concentrated in these portions; and while the duty of the centre portion, called the plate or the web of the beam, has not yet been brought clearly under the rigid laws of mathematics, its chief duty may be said to be to keep the top and bottom flanches separate from each other, and in their relative positions.

Power to resist compression.

The power of iron to resist compression is generally taken at $31\frac{1}{4}$ tons, or 70,000 lb. per square inch.

It is one of the advantages of iron over wood that it can be made of any form, and that the foregoing principles, in as far as they are known, can be brought into action.

Advantageous forms can be given to iron.

The accompanying sections may be taken as representing the sections of the beams in general use at the present day.

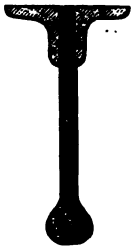

Fig. 23.

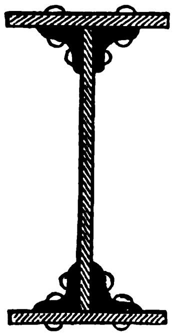

Fig. 24.

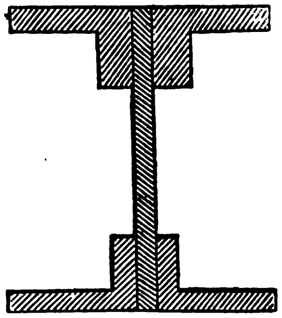

Fig. 25.

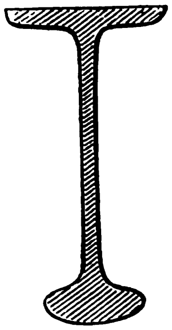

Fig. 26.

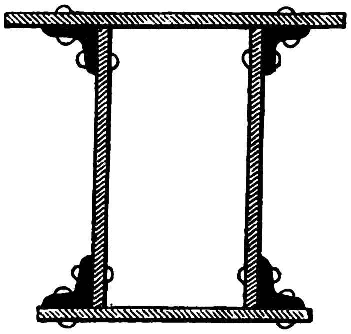

Fig. 27.

The proper proportions of iron-beams, and the consequent rules for their strengths, have been much discussed.

Box-girders were used for the paddle beams of vessels built at Millwall by Messrs Fairbairn and Co. as early as 1840. They are stronger than any of the forms of plate-beams given above; and for long spans on board ship, plate-beams should not be used on account of their want of lateral stiffness, unless they are supported by trimmers or fore and aft carlines.

The ordinary rule for the strength of iron-beams, as given by Mr Fairbairn, is applicable to all the foregoing forms, the number 80 being used as the constant to represent the strength of the box-beam, and 75 that of the plate-beam.

Let W represent the breaking weight in tons, a the area of the bottom flanche, d the depth of the beam, and l the length of the beam, C representing the constant as usual. Then the area of the bottom flanche multiplied by the depth of the beam, and by 80 for a box-beam, and 75 for a plate-beam, and the product divided by the length of the beam (all these dimensions being

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[1] See *Proceedings C. E. Inst.*, vol. xv., p. 176; and the subject will be found further investigated, vols. xi., xiv., and xvi.

taken in inches), will give the breaking-weight in tons—or $W = \frac{adc}{l}$.

It will be observed that the top flanche is not an element in this formula. Its correctness, therefore, is dependent upon the maintenance of certain relative and definite proportions in the parts, and it is not applicable to beams of indefinite forms or proportions. For beams of the ordinary length used in ships, the top and bottom flanches may be made of equal sectional area, and the greater the length of the beam the greater should be the comparative sectional area given to the top flange, to prevent its buckling or bending.

It has been argued that one-half the area of the centre web or plate should be added to the sectional areas of the top and bottom flanches, so as to include its strength as one of the elements of the formula, and a new formula be then deduced, but the rule, as given, is more simple, and may be relied upon.

From the nature of the material it is considered that wrought-iron beams may be loaded up to one-half of their breaking weight, though with cast-iron this limit is not permitted to exceed one-third.

The following are given as examples of the rule:—

(1.) What is the breaking weight of a box-beam 60 feet long, between the supports 18 inches deep, and the area of the section of the bottom flanche being 16 inches?

$$W = \frac{16 \times 18 \times 80}{720} = 32 \text{ tons.}$$

(2.) What is the breaking weight of a plate-beam 30 feet long, between the supports 10 inches deep, and the area of the section of the bottom flanche being 5 inches?

$$W = \frac{5 \times 10 \times 75}{360} = 10{\cdot}41 \text{ tons.}$$

The crushing force which malleable iron is capable of sustaining has been stated to be 70,000 lb. per square inch, but it could only sustain this great load when the force applied is so truly in the axis of the material, and when the specimen under pressure is so short that no deflection is produced. Wrought-iron, however, is very liable from its nature to give way by bending or buckling when the length bears too great a proportion to the area of the cross-section. This was previously mentioned when the relative sections of the area of the top flanches of beams which are exposed to a crushing force were recommended to be increased.

It has been found by experiment that wrought-iron is crippled, and its power of resistance destroyed by a weight of 30,000 to 40,000 lb. per square inch, whenever the length is such as to permit of its bending. The load, therefore, which it may be considered safe to put upon it in practice may be assumed at 6000 to 8000 lb. per square inch for columns of ordinary proportions. With this load the length of the column should not exceed ten times its diameter, and however short the column may be made, the load should never exceed 10,000 lb. per square inch of section.

The strength of similar columns of wrought-iron, as before stated to be the case with wooden columns, also varies as the squares of their lengths inversely. In all columns it is most important that the pressure should be applied in the line of the axis of the material.

By Hodgkinson's valuable experiments on the subject of columns, it was found that the strength of a column rounded at both ends, in comparison with one whose ends were flat, was as one to three. This result no doubt arose mainly from the strain not being correctly conveyed and kept in the axis of the material. If the strain on a column be in any degree greater on one side than on the other, this side will be unduly compressed, while the other side will be extended, and fracture or crippling will take place with a very small proportion of the load which the column ought otherwise to have sustained.

Materials used in Ship-Building.

Dr Young was the first to investigate this subject properly, and his work may still be consulted with advantage by any one who is desirous of following up this inquiry. When treating of the strength of riveted joints, the importance of attending to the line of the strain, when the material was exposed to a tensile force, was dwelt upon; and it is evident, from what has now been said, that this is equally important when it is exposed to a crushing force. In the latter case, if the column be in the least degree curved, the strain increases the deflection, whereas in the former any curvature will be diminished, the tendency being to pull the material into a straight line. Hence, it is of the greatest importance to place columns directly under the weight which they have to support, and by all means to avoid unequal strains on the sides, whether the columns be round or square. With wrought-iron it is also very evident, that by using a hollow column much greater strength is obtained from the same quantity of metal, great stiffness being obtained by the increased dimensions. Hollow wrought-iron tubes, such as those used by engineers in boiler-making, may therefore be used with great advantage. They may be rolled to almost any diameter and length likely to be required in shipbuilding. No experiments appear yet to have been made on the power of such tubes to resist a direct crushing force, but the following experiments were lately made at Portsmouth Dockyard, by Mr Lynn of that yard, to test their power of resistance when used at an angle, as a pair of sheer-legs, to raise screw-propellers on board ships. The tubes were ¼ inch thick, 4 inches external diameter, and 12 feet long. They were fitted with wrought-iron ends, the lower ends being prepared to rest on a step on the deck, and the upper ends had a double and single eye to fit into each other, and receive a pin for the shackle to carry the weight. The length was thus increased, from step to eye, to 12 feet 5 inches. At 9 feet spread at the base, one of the tubes which had been annealed in the fire for the purpose of straightening it, as it was slightly curved when received from the maker, deflected ¾ inch when the weight reached 26 tons. On removal of the weight it returned ⅜th inch, leaving a permanent set of ⅜th inch. At 7 feet spread at the base, the same tube yielded when the weight reached 29½ tons, the other tube remaining uninjured.

Strength of wrought-iron tubes.

The durability of iron is entirely dependent upon the state in which its surface is kept. Under ordinary circumstances there is probably no better preservative than good paint; but in the interior of iron-vessels it tends materially to their preservation, if the surface be coated with asphalte, or cement sufficiently thickly to cover the heads of the rivets. In some cases it is even desirable, especially in the sharp run of a ship fore and aft, in the position of the dead-wood in a wooden vessel, to fill up the entire spaces between the frames, and form a flush surface. The exterior also of an iron-vessel is easily maintained in good condition by frequent painting. Below the water-line, where the surface cannot be reached by heeling the ship to a moderate degree, the iron is not apt to corrode. There is no chemical action by sea-water upon malleable iron, and there is not sufficient oxygen present below the surface to induce oxidation. In every instance in which an iron-vessel has been rapidly destroyed, it has been by corrosion on the interior surface. Great injury has in some cases resulted from acids leaking from certain cargoes, such as sugar, and also in parts where the leakage of brine from provision casks has been allowed to lie upon the plates.

Durability of iron.

For gun-boats or vessels, which it may be desired to lay up or preserve for any lengthened time, iron is peculiarly adapted, as, under such circumstances, the whole of the surfaces can always be attended to both externally and internally.

Malleable-iron, when submerged in salt-water, rapidly becomes foul by sea-weed and shell-fish adhering to its surface; but these do not cause decay; they may rather be said to form a coating to protect the iron from decay of any kind as long as it is submerged.

Iron in contact with copper acted on.

The decay of iron externally on ships' bottoms has, however, been observed to take place in the neighbourhood of copper-pipes. This is caused by a galvanic action which takes place between the copper and the iron, tending to the preservation of the former and the destruction of the latter, on the same principle as that proposed to be brought into action by the use of Sir Humphrey Davy's protectors for the preservation of copper sheathing. A layer of zinc at the point of junction, to separate the copper from the iron, will protect the iron, but as the zinc will then be rapidly eaten away, care must be taken that it is not used in such a manner that a leak would ensue in consequence.

Preservation from fouling.

The ready fouling of iron in sea-water is still a great drawback to its use. Many applications for this purpose have been proposed, but none seem yet to have been so thoroughly successful as to require any special mention as deserving of any decided preference.

Weight of iron.

The weight of a cubic foot of wrought-iron is 480 lb. The weight of a square foot of plate ¼th inch thick, is therefore 10 lb., and this gives a ready and easily remembered standard for calculating the weight of any surfaces of iron of different thicknesses.

PRACTICAL BUILDING.

There is, perhaps, no structure exposed to a greater variety of strains than a ship, and none in which greater risks of life and property are incurred.

Strains to which a ship is liable.

A consideration of the disturbing forces in action, either to injure or destroy the several combinations embraced in its structure, is therefore most important. And a thorough knowledge of their action is necessary to a practical builder to enable him to guard against them, in whatever form they may present themselves, and to dispose and arrange the materials at his command, accordingly, in the most judicious manner. Some of these forces are always in action whether the ship be at rest or in motion. She may be at rest floating in still water, and will be at rest if cast on shore; and when there,—she may be resting on her keel as a continuous bearing, with a support from a portion of her side,—she may be supported in the middle only, with both ends for a greater or less length of her body left wholly unsupported,—or she may be resting on the ends with the middle unsupported,—or under any other modification of these circumstances; and under all these the strains will vary in their direction and in their intensity.

at rest;

in motion.

If the ship be in motion, the same disturbing forces may still be in action, with others in addition, which are produced by, and belong only to, a state of motion. When a ship is at rest in still water, it has been before explained, that the upward pressure of the water upon its body is equal to the total weight of the ship, but it does not necessarily follow that the weight of every portion of the vessel will be equal to the upward pressure of that portion of the water directly beneath it, and acting upon it; on the contrary, the shape of the body is such that their weights and pressures are very unequal.

Different sections of a ship not equally supported by the water.

If the vessel be supposed to be divided into a number of laminæ of equal thickness, and all perpendicular to the vertical longitudinal section, it is evident that the after laminæ comprised in the overhanging stern above water, and the fore laminæ comprised in the projecting head also above water, cannot be supported by any upward pressure from the fluid, but their weight must be wholly sustained by their connection with the supported parts of the ship. The laminæ towards each extremity immediately contiguous to these can evidently derive only a very small portion of their support from the water, whilst toward the middle of the ship's length a greater proportionate bulk is immersed, and the upward pressure of the water is increased.

Certain sections support others.

At some certain station from the middle of the length in each body, fore and aft, the upward pressure will therefore be equal to the weight of the superincumbent laminæ, and all the laminæ composing that portion of the body between these two stations will be subjected to an excess of pressure above their weight, tending to force them upward; which upward pressure will be the greatest at the laminæ having the greatest transverse area of section. Now, as the total pressure upward is equal to the total weight of the vessel, this excess of upward pressure to which the midship part of the body is subjected, must be equal to the excess of weight over the upward pressure in the parts of the vessel before and abaft those laminæ at which the pressure and weight have been supposed to be in equilibrio.

Strength must be equal to the severest strains.

A ship, when at sea, is subjected to severer strains than when floating at rest, and if cast on shore it may be subjected to still greater strains. Its strength, therefore, as a fabric, should be considered with reference to the severest trial of strength which may be required of it under any circumstances.

A ship at rest may be considered as a beam.

A ship floating at rest under the view just taken of the relative displacement of different portions of the body, if the weights on board are not distributed so that the different laminæ may be supported by the upward pressure beneath them as equally as possible, may be supposed to be in the position of a beam supported at two points in its length at some distance from the centre, and with an excess of weight at each extremity.

also when at sea.

At sea it would be exposed to the same strain; and if supported on two waves, whose crests were so far apart that they left the centre and ends comparatively unsupported, the degree of this strain would be much increased. The strain would be still more severe if the vessel got aground, and rested on two isolated points situated in the supposed positions in her length.

Under these circumstances, however, the strain would depend upon whether the weights in the middle or in the ends preponderated. The latter is the usual case; and then the whole of the upper portion of the vessel will be subjected to a tensile strain from the tendency of the ends to droop.

The more these two points of support approach each other, or if they come so near each other that the vessel may be looked upon as supported on one wave, or on one point only in the middle of her length, the greater will be the tensile strain on the upper portion, and the crushing strain on the lower portion of the fabric of the ship.

Importance of upper deck as a tie.

The importance, therefore, of so forming the deck and the upperworks that they may afford an efficient tie is apparent; and it is to be feared that this has been too much neglected, especially in many iron-ships.

If a vessel be weak in this respect, and touch the ground in the middle of her length, the consequences will necessarily be most disastrous, as she will open at perhaps more than one place, and her sides will tear down instantaneously after the tie of the deck and upperworks is gone. These results appear to accord with the accounts given of the manner in which several iron-vessels have broken up on their being cast ashore.

Hogging and arching.

A vessel whose weights and displacements are so disposed as to render her subject to a strain of this kind beyond what the strength of her upperworks will enable her to bear, will assume a curved form.

The centre is curved upwards by the excess of the pressure beneath it, and the ends drop, producing what is called "hogging." The main remedy for these evils, as before stated, is in the strength of the deck and upperworks, and their power to resist a tensile strain. There is seldom a want of sufficient strength in the lower parts of the vessel to resist the crushing or compressing force to which it is subjected. The decks of vessels should not, therefore, be too much cut up by broad hatchways; and care should be taken to preserve entire as many strakes of the deck as possible. The tensile strength of iron can be brought to bear most beneficially in this respect, and some continuous strakes of it laid upon the tops of the beams and below the deck-plank would add materially to the strength of all ships. Deck-planking has been sometimes laid diagonally at an angle across a ship, but it will be evident, from these remarks, that the value of the longitudinal tie is thereby much lessened, and there is no sufficient corresponding benefit of any other kind to justify the whole deck being laid in this manner.

Great sheer, or rising of the deck, fore and aft, is objectionable, from its lessening the strength of the longitudinal tie, though it is much practised, as it gives a lively appearance to a ship, and hides the defects of hogging if it should occur.

In the whole of the upper parts of a ship, as well as in the deck, every means should be taken to increase the power of resisting tension. In a wooden ship the upper part of the frame should be chain-bolted wherever the continuous range of bolts can be placed so as not to interfere with the in and out fastenings; and the shifts of the different wales, and other parts, which act as longitudinal ties, should be carefully attended to. The waterway-planks and shelf-pieces are also most important, and their continuity should be maintained throughout the length of the vessel, with as little diminution of strength as possible, at the junction of the different lengths.

In iron-vessels the parts corresponding to these are particularly important, as the plating exposes a very weak edge at the top, and is liable to be torn down if this edge be not well guarded and supported. To enable the lower part of the ship to resist the compression to which it is subject, the spaces between the frames in the best built wooden vessels are filled in solid, so as to make, as far as possible, an incompressible mass. The various abutments of this part of the body should be as closely fayed or fitted as possible. In iron-vessels, as the spaces between the frames cannot be filled in solid, the keelsons should be of great strength. The power of wrought-iron to resist compression, when it is prevented from buckling, is here of great value, as the fastening of the keelson to every frame as it passes gives stiffness and rigidity to it, and consequently great power to resist compression.

Though these are the strains to which a ship is most likely to be exposed, it by no means follows that there are no circumstances under which strains of the directly opposite tendency, when pitching and tossing, or otherwise, may be brought by recoil to act upon the parts. The weights themselves in the centre of the ship may be so great that they may have a tendency to give a hollow curvature to the form, and it is therefore equally necessary to guard against this evil. When this occurs, the vessel is technically said to be "sagged," in distinction to the contrary or opposite change of form by being hogged. The weight of machinery in a steam-vessel, or the weight or undue setting up of the main-mast, will sometimes produce sagging. The introduction of additional keelsons tended to lessen this evil, by giving great additional strength to the bottom, enabling it to resist extension, to which, under such circumstances, it became liable; and as the strain upon the deck and upperworks becomes changed at the same time, they are then called upon to resist compression. In iron-vessels, the waterway-planks and shelf-pieces are again, in this case, very important to aid in resisting this strain. The deck-planks may become shortened by the deck assuming a curved form in the middle of the length of the ship, the beams yielding and working with them; and a crushing strain is then brought to bear upon the plating of the topsides, which they are not calculated to sustain. Some light flat-bottomed river-steamers of iron with very full lines forward and aft, have given way from this cause. The best practical lesson upon the subject, and the most direct proof of the want of strength of iron-vessels at the topsides, if constructed without additional strengthening there, was given by the Nemesis when her topsides opened, as so well described by Captain Hall in his account of her voyage to India, and when he so judiciously strengthened her by attaching balks of timber longitudinally to the two sides.

A vessel may alter her form athwart-ship.

A corresponding action to that described as hogging takes place in relation to the breadth of the vessel, but more particularly in the case of men-of-war, on account of the weight of the ordnance concentrated along the sides. The central portion of the body is subjected to an undue upward pressure, while the outer portions are strongly acted upon by the weight there tending to depress and immerse them. The effects of this action may be greatly modified by the form of the vessel; longitudinally, it produces the upward curvature previously referred to; and transversely, it tends to separation of the sides, except in three-decked or very lofty ships, in which, if the tumbling home be very great, the tendency is to produce a separation at the main breadth and below it, and a collapsing of the sides above it.

Horizontal pressure of the water.

Another force tending to alter the form of a vessel arises from the horizontal pressure of the water on the sides of the vessel. The sides are compressed or forced together, and the tendency produced is to add to the curvature of the deck amidships, and increase the hogging both longitudinally and transversely.

Other forces which affect a ship in motion.

When a ship is in motion, if the surface of the sea be very uneven, so that her passage will be over the waves, the supports become very variable, and the opposing forces of upward pressure and gravitation will have a tendency to produce corresponding changes in the form of the body; and if the motion of the ship be violent, and thus produce any sudden shock or jerk, the strain upon the materials and upon the fastenings will become immeasurably increased.

Force of the waves.

When the ship is on a wind, the lee-side is subjected to a series of shocks from the waves, the violence of which may be imagined from the effects they sometimes produce in destroying the bulwarks, tearing away the channels, &c. The lee-side is also subjected to an excess of hydrostatic pressure over that upon the weather side, resulting from the accumulation of the waves as they rise against the obstruction offered by it to their free passage. These forces tend in part to produce lateral curvature. When in this inclined position, the forces which tend to produce hogging when she is upright also contributes to produce this lateral curvature. By experiments made on her Majesty's ship Genoa, in 1823, by Mr Moorsom, a member of the late school of naval architecture, he ascertained that this lateral curvature amounted to 1½ inch on each tack, making an alteration of form to the extent of 3 inches from being on one tack to being on the other.

Tension of the rigging

The strain from the tension of the rigging on the weather side when the ship is much inclined is so great as frequently to cause working in the topsides, and sometimes even to break the timbers on which the channels are placed. Additional strength ought therefore to be given to the sides of the ship at this place; and in order to keep them apart, the beams ought to be increased in strength in comparison with the beams at any other part of the ship.

Practical Building.

It has been proposed to introduce tie-rods from the channels to the step of the mast, so as to render each mast and its supports a combination of struts and ties with the strains self-contained. This may be explained by the annexed figure.

Let AB represent the deck-beam, or beams of the ship at the channels, CD the mast, and AC and CB the shrouds. Now, if the ties AD and BD be introduced, it is evident that any additional strain brought upon AC or CB will be transferred to AD or BD, and resisted independently of any strength in the sides of the ship, so long as AB the beam, and CD the mast, are rigid and do not bend. By this system, also, any excessive strain is prevented from being brought upon the step of the mast at D, producing sagging, by setting up the rigging unduly. Though the ties AD and BD cannot conveniently be introduced in ships in direct lines, as shown in the woodcuts, the principle proposed may yet be brought into play by curved ties of sufficient stiffness not to straighten under the tensile strain to which they will be exposed.

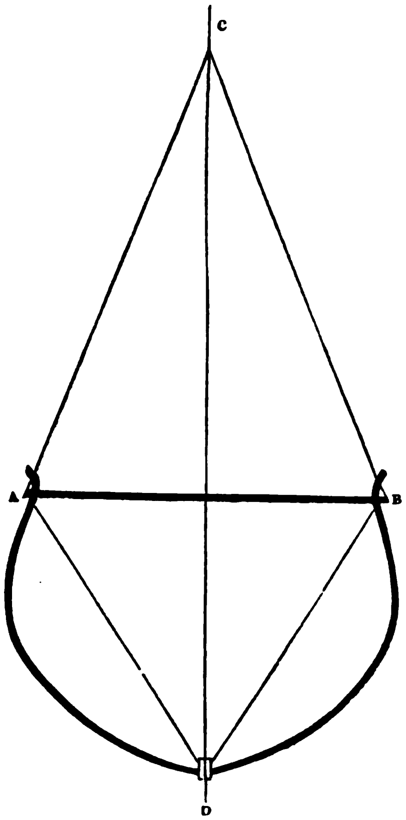

Fig. 28.

General remarks on disturbing forces.

The foregoing are the principal disturbing forces to which the fabric of a ship is subjected; and it must be borne in mind that some of these are in almost constant activity to destroy the connection between the several parts. Whenever any motion or working is produced by their operation between two parts, which ought to be united in a fixed or firm manner, the evil will soon increase, because the disruption of the close connection between these parts admits an increased momentum in their action on each other, and the destruction proceeds with an accelerated progression. This is soon followed by the admission of damp, and the unavoidable accumulation of dirt, and these then generate fermentation and decay. To make a ship strong, therefore, is at the same time to make her durable, both in reference to the wear and tear of service and the decay of materials. It is evident from the foregoing remarks, that the disturbing influences which cause "hogging," commence their action at the moment of launching the ship, and are thenceforward in constant operation. As this curvature can only take place by the compression of the materials composing the lower parts of the ship, and the extension of those composing the upper parts as more particularly explained when treating of the strength of beams, the importance of preparing these separate parts with an especial view to withstand the forces to which they are each to be subjected cannot be overrated by the practical builder. The side of a ship is, however, in a somewhat different position from the plate or web of an ordinary plate-beam, or the sides of a box-beam, on account of the horizontal pressure of the water against it; and because in deep ships, with one or more intermediate decks, some of the strain is brought upon it in the middle of its depth. The position of the neutral axis or line between those particles exposed to a crushing and those exposed to a tensile strain, is therefore very difficult to determine; but from a consideration of the circumstances just mentioned, it must be higher in a ship than theory would place it if the ship were considered in the light of an ordinary beam exposed to strains brought upon it in the ordinary way.

Diagonal trussing as a means of resisting strains.

The importance of the system of diagonal trussing and bracing in ship-building appears to have been first fully appreciated by Sir Robert Seppings, and the principle on which it should be introduced to have been first explained by him. It is obvious that if four pieces of timber be put together, so as to form a square, or a rectangular parallelogram, with their ends connected by a round pin only at each corner, they may assume the form of any other parallelogram whose sides are of the same length, but that in so doing the length of the two diagonal lines will be altered; thus—

In both of the annexed figures, the sides are of the same length, but the diagonal AC of fig. 29 is shortened into *ac* in fig. 30, and BD of fig. 29 is lengthened into *bd* in fig. 30. The introduction, therefore, of diagonals of a fixed or unalterable length into any piece of frame-work will tend to prevent alteration of form, and it will be perceived that the duty required of the two diagonals in resisting any change is different, the one being required to resist extension, and the other to resist compression. One diagonal only is sometimes considered sufficient, but in this case care must be taken that the material of which it is composed, and the manner in which it is applied, be such that it may be fit to resist either extension or compression, if the frame-work is liable to be alternately strained in either direction. In any piece of frame-work, however large, a straight wrought-iron bar is excellent as a tie, but as a strut it would be nearly useless on account of its liability to bend. Wrought-iron, however, is the material chiefly used in diagonal bracing; and it may be used with propriety for both diagonals, wherever on account of liability to a strain in both directions two are used, because each in its turn will resist extension, and that diagonal which is exposed to compression will be protected from injury by the resistance of the other to extension. The sides of a ship may be supposed to be divided into a number of pieces of frame-work of imaginary outlines or dimensions. Those embraced in the midship body may be supposed liable to be strained in both directions; but the upper portions of those composing

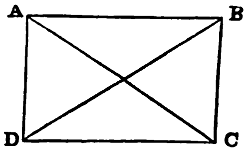

Fig. 29.

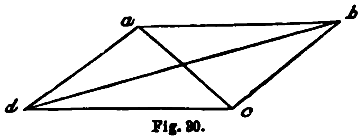

Fig. 30.

Diagonal trussing;

the fore and after bodies will be inclined to fall forward and aft respectively; and if this tendency only is to be guarded against, the ties must be placed in different directions in the two bodies sloping up from below from amidships forward and aft in parallel lines, extension being the force which they will be called upon to resist. The system is not so much required in the bottom of a ship. In the decks diagonal trussing, placed diagonally across a ship, is advantageous as tending to prevent the ship working, by one side advancing or receding alternately with the other, and here the diagonals should be made to cross each other and lie in both directions.

Diagonal trussing, as used by Sir Robert Seppings, was introduced into some ships as a series of frame-work along the centre of the ship, from pillar to pillar, from the keelson to the decks, and he arranged these on the principle of depending upon struts and not upon ties. Wrought-iron was then much less used than in the present day, and timber forms an excellent material for a strut, weight for weight, in comparison with solid iron-bars, on account of its dimensions giving it stiffness. Struts are also convenient because they require comparatively little attention to the fastening of their ends. They abut against a surface, or into a corner, and their ends are easily prevented from shifting. With ties this is very different; their ends must be made sufficiently secure to resist a strain equal to their whole strength.

Before the introduction of this system, it was no uncommon thing to find ships hogged to the extent of from two to three feet. An instance is quoted in Portsmouth dockyard of an old ship, whose keel was curved upwards to the extent of two feet or more, and which was grounded in dry-dock on a set of blocks laid level. She straightened as she settled upon them, and diagonal trussing being then introduced, it was found to support her in a remarkable degree, when she was again floated. In this case the trussing was applied chiefly in midships, from pillar to pillar, from the keelson to the deck-beams.

not so necessary in iron ships.

In iron-ships diagonals are not so much required on the sides of the ship, because the plating being a connected surface of equal or nearly equal strength in all directions, it is incapable of motion in its parts, and the line of any supposed diagonal is incapable of extension otherwise than by a force sufficient to tear the plating asunder.

Comparison of iron with wooden vessels.

A general consideration of all the strains to which ships are subjected naturally leads to the question of selecting the material which is best adapted to resist them. In treating of the materials used in ship-building, especial reference was had to the various qualities possessed by each, which rendered them more or less valuable individually or collectively. It may perhaps be expected, that before leaving this part of the subject a more direct comparison should be drawn than has yet been done between the relative merits of wood and iron vessels, and that the points in their structure, in which they chiefly differ in strength and safety, should be pointed out. The advocates of either system will, no doubt, discover many errors and omissions in the remarks on this subject, which have been made, or which may now be made; but they are given as the results of close observation and experience for a period of upwards of twenty-five years of practical connection with both classes of vessels. It may at the same time be stated with respect to this treatise, that while the increase of steam-vessels, and the great alterations in the forms of ships since the publication of the previous edition of the *Encyclopædia Britannica*, had to be considered, much of the alteration from the previous very able article on this subject, by the late Mr Crueze, is caused by the necessity of now treating of iron-ships equally with those of wood. An endeavour has been made to introduce as much information respecting iron-vessels, in addition to as full information respecting wooden vessels, as the assigned limits would permit; and the substance of the article by Mr Crueze has been retained in many points, and free use has been made of it wherever desired, so as to form, as far as may be, a concise and consecutive treatise.

Basis of comparison.

If strength alone were to be assumed as the basis of comparison, without reference to weight or cost, it would probably be conceded that a stronger vessel could be built of iron than it would be possible to construct by any combination of wood. It will, however, be more practically useful to compare vessels of about equal weight, or equal cost or strength.

Frames.

An individual frame in an iron-vessel is formed with more continuity of strength throughout its length, than is the case in a wooden vessel, and greater opportunity is given of obtaining strength, no matter what may be the form of the body. By the variety of form into which iron can be rolled by the manufacturer, opportunity is also given to obtain the desired strength with less useless material.

Sheathing.

In the sheathing, whether internal or external, much greater difference exists. In wooden vessels the planks are laid side by side, and with few exceptions are not fastened or connected with each other; indeed they are forced asunder by the caulking required to make the joints between them water-tight. Their only connection therefore is by means of the fastenings which unite them to the frames. The plating of an iron-vessel, on the contrary, is made into one completely connected surface, and even if all the frames were removed, it would remain in shape, and would still form a vessel of great strength and stiffness. The fastenings, also, to the frames will not bear comparison, the power of iron to resist shearing across being so much greater than that of treenails or copper-bolts.

Resistance to bulging force by iron.

The power of iron-plates to resist a force similar to that to which they would be subjected if an iron-vessel took the ground on a hard bottom, with some projecting points of rock or stones, was also experimented on by Mr Fairbairn. The plates were placed upon a frame, leaving a space of 1 foot square, unsupported, and on the centre of this a bar of iron, 3 inches diameter, with its end rounded, was brought to bear. Plate ¼ inch thick was burst with a force of 16,779 lb., and a plate ½ inch thick, bore a strain of 37,723. The plate of double the thickness, therefore, bears more than double the pressure.

by timber.

The power of timber to bear a similar strain was tested at the same time. Oak planks, 3 inches thick, were burst with a force of 17,933 lb., or only a little more than was required to burst the same surface of a plate ¼ inch thick. Oak planks, of 1½ inch thick, were burst with 4406 lb. A plank of double the thickness, therefore, bore much more than double the pressure, the proportion being as the squares nearly.

Beams.

Beams of iron are applicable to both classes of vessels, and their superiority is now becoming so generally acknowledged, that they are being largely used in wooden vessels in the merchant-service and in the French navy.

General strength.

It is, however, to the results of the combination of these materials as a whole that consideration must chiefly be given. Unfortunately there are no want of instances of both species of vessels going to pieces suddenly when cast on shore on rocks; and until iron-vessels are double-plated with an interior water-tight sheathing, wooden vessels, with solid bottoms of floors and futtocks, will probably give greater security in such a position for a short period of time if the sea be rough, and for a greater period if it be smooth; on a flat beach, however, iron-vessels seem undoubtedly to have the advantage. The Great Britain, lying for a whole winter on the coast of Ireland, and the Vanguard, lying ashore for several days on a rocky beach, are two notable instances of iron-vessels having come off comparatively uninjured, after having been exposed to strains which it is believed no wooden vessels could have undergone. There are, at least, no such instances on record with regard to them. As another direct comparison, the Demerara may be mentioned as a wooden vessel which, after being launched, grounded in the river at Bristol while being brought down, and she was so much injured that she was condemned; whereas the Australia, an iron-vessel, on first coming down the Clyde grounded in a similar manner, lying right across the river in one of its narrowest parts, but she came off quite uninjured. Another instance of strength, such as no wooden vessel has ever exhibited, may be quoted in the case of an iron-vessel which, on the occasion of her being launched, stuck on the ways which were upon a high wharf above the water, and more than one-third of the whole length of the vessel was left totally unsupported, overhanging the wharf, and yet she did not break or receive any damage.

The same elements of strength which enabled these vessels, especially the Great Britain and the Vanguard, to withstand the strain to which they were exposed, will also be efficacious in preventing a vessel straining at sea in a heavy sea-way, so as to become leaky and founder at sea from this cause. From a consideration of such facts as the foregoing, the general opinion appears to be, that iron-vessels, as a whole, are not only stronger than wooden vessels, generally speaking, but that they may be made of greater or equal strength, with considerably less weight of hull. The extent to which this saving of weight may be carried, without impairing the strength to an improper or unsafe degree, will always be a subject of inquiry to the iron shipbuilder; but if he err in judgment and produce too weak a ship, the error must be attributed to him, and the material must not be considered to be in fault.

The power of fitting water-tight bulkheads to iron-vessels is also a great advantage, and will be a source of much greater security hereafter, when vessels are better built than they have hitherto been. Their importance, and the great additional safety which they impart, are evident, and the principle may be carried out to any extent, and this longitudinally as well as athwartship. In the after part of screw-ships, the passage alongside of the shaft to the propeller may be made water-tight, and communication with the engine-room may be cut off, if it be desired, and if proper arrangements be made for this purpose. These bulkheads also form a good protection against the very rapid spreading of fire, and in the case of any vessels particularly liable to this danger they might be made double, and water be admitted between them.

The durability of iron-ships has been already referred to, as far as regards ordinary tear and wear; but their superiority in the event of injury by collision, or by being on shore, is still more marked. If a few frames or floors are broken in a wooden vessel, the amount of work required to be entered into to replace them is very great, a large portion of the plank in the neighbourhood requiring to be ripped off. In an iron-vessel, on the contrary, a new piece of frame can be put in to replace the injured part, and the whole made as strong as before, by lapping pieces. And in the sheathing, an injured plate, or a piece of a plate, can be cut out and replaced without disturbing any of the other work.

Iron-vessels for purposes of war.

For purposes of war iron-vessels have been pronounced by some as unfit, the reasons given being, that the iron when struck flies into innumerable small pieces, which would be most destructive to the men on board; and that in the event of a shot passing through the ship and striking the further side, the plates being no longer supported by the frames, but depending upon the rivets only, are apt to be torn off in large pieces. In some experiments made at the Royal Arsenal at Woolwich, in 1844, by the late General Dundas of the Royal Artillery, it was found that the splinters resulted equally whether the plates fired at were of the best Lowmoor iron or of common boiler-plate. A thickness of 12 to 15 inches of wood was found to stop almost the whole of the small splinters; and a less thickness of a material composed of a mixture of saw-dust and India-rubber effected the same object. With a shot fired with no greater velocity than would just enable it to penetrate the $\frac{5}{8}$ plates, the splinters were fewer; and at the edges of the hole through which the shot had passed, the plate was bent back with ragged edges. In some experiments in Portsmouth harbour, an iron target was fired at, with a screen of canvas behind it to show the splinters, and the same results were obtained. In both cases the plates were $\frac{1}{2}$-inch and $\frac{5}{8}$-inch thick. In iron-vessels, therefore, constructed for the purposes of war, if composed of plates of ordinary thickness, it would be judicious to line them with wood to prevent the men being exposed to the risk of such splinters. In ordinary gun-boats, or corvettes, where the men are above the hull of the ship when fighting the guns, this danger is obviated, and a portion of the ship might also be protected to any extent that might be considered desirable. The present changing state of the science of projectiles renders it difficult to provide against all contingencies; but plates of only ordinary thickness will stop all ordinary shells. This is a most important difference, as these, in their various forms, are now the most dangerous to a ship, and iron-vessels may therefore, on this account, lay claim to great consideration as adapted for warlike purposes. If the iron-vessel, then, be so constructed that it can be penetrated by solid shot only, it would become a question of a wooden vessel being burnt or destroyed by shells, or of an iron-vessel being sunk; and it is believed that many would prefer the latter risk. A shell bursting on board, or in the side of a wooden vessel, would cause greater injury and loss of life than the splinters from the shot in an iron-vessel, and these, as has been said, might be lessened in a large vessel, and avoided in the smaller vessels. It was the opinion of many naval officers respecting the effects shown by the experiments at Portsmouth, that if the same number of shots had been fired at targets of wood, the canvas screen would have been swept bodily away, and that such parts of the targets themselves as remained would have been reduced to a mass of fibres, without strength to sustain themselves or resist any strain or pressure whatever. If iron-vessels hereafter show such great superiority in strength and safety at sea, or when cast on shore, or in durability, as to make their introduction into the royal navy important on these accounts, it may then become a question whether a system may not be introduced of constructing the whole of the lower part of the vessel of iron, up to the neighbourhood of the water-line, and that the portion of the vessel above this, where the men would be exposed to the splinters, should be of wood. The iron-frames could be continued up for some distance alongside of the wooden frames, and there are no practical difficulties in such a system that could not be overcome.

PRACTICAL OPERATIONS.

Commencement of practical operations.

After the cursory view which has been taken of the strains to which ships are liable, and the general remarks which have been made on the points to be attended to in their construction, it is now proposed to give a short outline of the proceedings in the actual building of the vessel.

Laying off.

The term "laying off" is applied to the operation of transferring to the mould loft-floor those designs and general proportions of a ship which have been drawn on paper, and which have been previously referred to, and from which all the preliminary calculations have been made and the form decided. The lines of the ship, and exact representations of many of the parts of which it is to be composed, are to be delineated there to their full size, or the actual or real dimensions, in order that moulds or skeleton outlines may be made from them for the guidance of the workmen,

Practical Building.

These working drawings are made by projection, and are not views of the parts as they appear to the eye. In a projected drawing the eye is supposed to move and be directly opposite to each line, as it, in its turn, is represented by the draughtsman. Separate drawings must, therefore, be made for the different faces of any object which are at right angles to each other.

The delineation in this manner of solids of a complicated form is of itself a science, and one which is now attracting much more attention than formerly. It is very ably treated by the Rev. Dr Woolley in a work entitled *Descriptive Geometry*. Before the publication of this work the efforts in this direction in this country had been chiefly made by practical men, each showing the mode of delineating the more difficult objects in his own art. Architectural works showed the mode of delineating the mouldings and details of the columns of the seven orders of architecture. Books on carpentry showed the mode of working and laying off a geometrical or winding staircase, and works on ship-building included, at great length, the modes of laying off complicated and irregularly formed parts. To show the mode of delineating not only the frames, but all the pieces of varying form which are required in the bows or sterns of ships, would be far beyond the limits of this treatise. It is impossible to include either a complete treatise on drawing or a complete set of delineations of the modes of combining the whole of the various minute parts of which all classes of vessels of wood and of iron are composed.

A proper knowledge of the minutiæ of construction and of workmanship can only be obtained by practical experience upon the work itself; and the form and combination of the parts will continually vary with the variations in the form and outline of the bodies and of the heads and sterns of the ships.

Principal plans.

The principal plans of a ship are the sheer plan, the body plan, and the half-breadth plan, and these have been already fully discussed, and their uses explained. In addition to these plans it is customary to furnish the architect with a profile of the inboard works, showing the disposition or distance apart, and the appearance of the timbers which constitute the frame, also the length or the heads and heels, and general arrangement of the floors and futtocks, the midship section, on which is described the moulding or athwartship size of the timbers, the thickness of the exterior and interior planking, the connection of the beams to the side, the dimensions of the waterways and shelf-pieces, and the forms and fastenings of the knees, &c. These, with a scheme of scantlings containing the dimensions and other particulars of the principal pieces which enter into the construction of the fabric, constitute all the preparatory information required by the builder. In private contracts very full information on all these points is generally included in the specification.

Fore and after bodies.

A ship is generally spoken of as divided into fore and after bodies, and these combined constitute the whole of the ship; they are supposed to be separated by an imaginary athwartship section at the widest part of the ship, called the midship section or dead-flat.

Midship body.

The midship body is a term applied to an indefinite length of the middle part of a ship longitudinally, including a portion of the fore-body and of the after-body. It is not necessarily parallel or of the same form for its whole length.

Square and cant bodies.

Those portions of a ship which are termed the square and cant bodies may be considered as subdivisions of the fore and aft bodies. There is a square fore-body and a square after-body towards the middle of the ship, and a cant fore-body and a cant after-body at the two ends. In the square body the sides of the frames are square to the line of the keel, and are athwartship, vertical planes. In the cant bodies the sides of the frames are not square to the line of the keel, but are inclined aft in the fore-body, and forward in the after-body. The reasons for the frames in these portions of a wooden ship being canted, is that, in these parts of the ship, the timber would be too much cut away on account of the fineness of the angle formed between an athwart ship plane and the outline or water-lines of the ship. The timber is therefore turned partially round till the outside face coincides nearly with the desired outline, and it is by this movement that the side of a frame in the cant fore-body is made to point aft, and in the cant aft-body to point forward. This will be best understood by the annexed figure, showing an exaggerated horizontal section of a frame in the fore cant-body, the dotted line representing the extent to which the timber would have been cut away if it had been placed square to the line of keel, and if the side *a b* had not been "canted" aft, turning on the point or edge *a*.

Practica Buildin

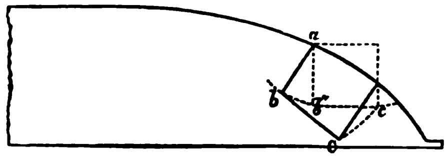

Fig. 31.

In wooden ships the term "timbers" is sometimes applied to the frames only, but more generally to all large pieces of timber used in the construction. Timbers, when combined together to form an athwartship outline of the body of a ship, are technically called frames, and sometimes ribs. In iron-ships the frames are composed of iron-bars of various forms.

Mouldin and sidi

The terms moulding and siding are nearly synonymous with thickness and breadth, observing that the moulding of a piece of timber is the dimension of the side on which the mould is applied for determining its shape or curvature. For instance, the moulding of a beam is its length and thickness; its siding is its fore and aft dimension or breadth.

Room an space.

Room and space is a certain distance determined by the fore and aft dimensions, or the siding of two adjacent timbers, together with the opening between them. It is generally defined as the distance from centre to centre of the frames, or from centre to centre of the spaces between them. The centre line between two adjacent frames is called the joint.

Shift.

Shift in its general sense is applied to a certain arrangement among the component parts of a ship. Thus a shift of deadwood, or a shift of plank, means the disposition of the buts of the timber or plank with reference to the longitudinal distance of one joint from another, and this with respect both to strength and economy.

Bevellin

The bevelling of a timber is the angle contained between two of its adjacent sides. Bevellings are either acute angles, right angles, or obtuse angles. These three separate cases are denominated under bevellings, square bevellings, and standing bevellings.

Sirmark

Sirmarks are certain points or stations marked on the mould of the timbers, at which the bevellings are applied, in order to cut the timber to the bevelling required at that spot. These sirmarks are determined, and their positions denoted in the body plan, by the various diagonal lines.

Water-lines and level-line

Water-lines in the sheer plan, are lines drawn parallel to the surface of the water (Plate III.) Level-lines are similar to water-lines, except that they are drawn parallel to the keel instead of to the water (Plates V. and VI.) In the half-breadth plans, the water-lines or level-lines show the outline of the form of the ship at sections at the corresponding heights in the sheer and body plans.

Diagonal lines.

Diagonal lines, as shown in the body plan and half-breadth plan (Plate III.), and marked 1 D, 2 D, 3 D show the boundaries of various sections which are oblique to the vertical longitudinal plane, and which intersect that plane in straight lines parallel to the keel. In wooden ships, the position of the diagonal lines drawn in the body plan is not arbitrary, because it has reference to the different timbers of which the frame is composed, and also to the station of the ribands and harpins. The number of diagonals is increased in the deeper class of vessels. They are drawn to show the lengths of the floors and futtocks, together with the heights of their heads and heels above the keel, and are marked floor-head, &c. Diagonals, marked as 1st sirmark, 2d sirmark, 3d sirmark, &c., or 1 D, 2 D, 3 D, on the body plan (Plate III.), show the heights and situation of the harpins and ribands which are used to give support to the ship whilst in frame. In wooden ships they are always placed between the heads of the respective timbers.

Diagonals on sheer plan.

The following is the mode of setting off the diagonals in the sheer plan:—Take the perpendicular heights in the body plan, that is, the heights square to the upper edge of the keel of the intersection of the diagonal with each of the transverse sections, and transfer these heights to the corresponding section in the sheer plan. Through the points thus obtained draw a curve, which will be the line required.

Diagonal on half-breadth plan.

To transfer the diagonals to the half-breadth plan: observe the point of intersection of the diagonal on the body plan with each transverse section, and take the horizontal distance of each of these points from the middle line, and transfer it to the corresponding section in the half-breadth plan. Through the points thus obtained draw a curved line, which will represent the horizontal line of the diagonal.

After these lines have been added to the sheer, body, and half-breadth plans on paper, the transference to the floor, where the ship is to be delineated to the full size, is easy. It is the duty of the draughtsman on the mould-loft floor to fair the body, if any of the curves shown by the lines previously drawn on the paper do not appear of easy and good forms, when represented of their full size.

Every form to be drawn on the floor, and its beveling obtained.

On the mould-loft floor it is necessary, in iron-ships, to draw out every frame, so as to be able to give the particulars to the workmen; and it is not only necessary to give them the outline of the frame, but also the beveling or the angle which the outer surface makes with the side at each spot or sirmark. This is obtained from the half-breadth plan at the various points where the different level lines or diagonal lines cross each frame. A variety of modes are practised by different builders of iron-ships to convey this information from the mould-loft to the workmen, instead of using moulds, as almost universally practised by builders of wooden ships. Great accuracy in this respect is required in iron-ships, as in them no dubbing off or pairing the body by the adze is practicable.

Expanding the body.

Expanding the body so as to represent the whole of the planking or outer skin or surface of a ship, is another process connected with laying off; and it is particularly important to the iron ship-builder, as it enables him to obtain the necessary iron-plates from the rolling-mills of the exact widths and lengths that will be required. This is done by drawing a line, to represent the line where the plates meet the keel and stern-posts. On this line the station of any number of frames that may be necessary to give the desired degree of accuracy must be set off, and at these stations lines must be drawn of a length equal to the girt or outline of the frame at that station; this length will be obtained from the body plan. The number of strakes to be used in planking or sheathing the ship must next be determined and be set off accordingly, on the lines representing the different frames; and great art is necessary in this operation, as upon these lines much of the beauty of a ship depends to please the eye of a connoisseur. The shift or the distances between the ends of the different plates may also be determined and marked in this plan, and thus the length, width, and breadth of every plate may be accurately ascertained.

"Sny."

The circumference of the bottom being much larger at the midship part than toward the extremities—that is, at the bow and buttock—the lines for the strakes taper as they recede from midships. They also acquire an upward curve, called "Sny," which renders it difficult to work the plank. When the sny becomes too great, a strake is ended short of the others, and this is termed a "stealer," as it diminishes the sny for the succeeding strakes. Under the buttock it is often necessary to work some of the after-plank wider at the after-end, and this has the same effect of diminishing the sny of the following strakes. "Hang" is the exact reverse of "sny." It mostly occurs in working plank on the inner surface of the timbers, and outside above the main breadth.

With regard to the practical operations in building a ship, nothing more can be attempted here than a few general observations on the principal parts of a ship, and the mode of putting them together, to resist the various strains to which each part will be subjected. The practice in her Majesty's yard will be found very fully explained in Fincham's outlines of shipbuilding, and in a very excellent treatise by Mr Peake, now master-shipwright at Devonport. Some details of wooden ships of the ordinary system of construction will be first described.

The keel

The keel of a ship built in this country is generally composed of elm, on account of its toughness, and from its not being liable to split if the ship should take the ground, though pierced in all directions by the numerous fastenings passing through it. It is generally composed of as long pieces as can be obtained, united to each other by horizontal scarphs. These scarphs are made sloping up from the bottom to the upper surface, on which the floors rest. But the strain to which a keel is subjected has a tendency to curve it up or down, and not sideways. These scarphs should, therefore, be made vertical, in the same manner as scarphs of the beams, as there can be no doubt that the vertical scarph will give the greatest strength to resist a strain in this direction.

Rabbet of the keel.

The rabbet of the keel is an angular recess cut into the side to receive the edge of the planks on each side of it. In the government service this rabbet is made of greater breadth vertically, so that the plank to fill it is required to be of such great thickness that it altogether loses the character of a plank, and becomes a stout massive piece of timber. This arrangement was introduced by Mr Lang, and has been denominated Lang's safety keel. It gives great additional strength to the bottom of a ship, and great lateral support to the keel, when the ship takes the ground and rests on the edge, as the leverage to displace it sideways is thus reduced.

In the merchant service the rabbet is seldom carried so low down on the side, and the garboard strake or strakes are not so thick. The keel forward is connected to the stem by a scarph, sometimes called the boxing scarph, and aft to the stern-post, by mortice and tenon. The apron is fayed or fitted to the after-side of the stem, and is intended to give shift to its scarphs, the lower end scarphs to the deadwood. The keelson is an internal line of timbers fayed upon the inside of the floors directly over the keel, the floors being thus confined between it and the keel. Its use is to secure the frames and to give shift to the scarphs of the keel, and thus give strength to the ship to resist extension lengthways, and to prevent her hogging or sagging. The foremost end of the keelson scarphs to the stemson, which is intended to give shift to the scarphs connecting the stem and keel. The frames or ribs are composed of the strongest and most durable timber obtainable. By Lloyd's rules a durability of twelve years is assigned to frames composed of English, African, and live oak, East India teak, Morning Saul greenheart, morra or iron-bark; of ten years to mahogany of hard texture, Cuba, sabicu, and pencil cedar; of ten years for floors and first futtock, and nine years for second and third futtocks and top timbers, to Adriatic, Spanish, and French oak; of nine years to red cedar, angelly and Venatica; of nine years for floors and first futtocks, and seven years to second and third futtocks and top timbers of other continental white oaks, Spanish chestnut, stringy bark, and blue gum; of eight years and seven years respectively, as before, for North American white oak and American sweet chestnut; of seven years for larch, hackmatac, tamarac and juniper, and pitch-pines.

Floors. The floors in the government service are carried across the keel with a short and long arm on either side alternately, so as to break joint, and between the frames the space is filled in solid.

Shelf-pieces. Longitudinal pieces of timber are worked round the interior of a ship for the purpose of receiving the ends of the beams of the several decks; they are called shelves, and are of the greatest importance, not only for this purpose, but also as longitudinal ties and struts. In any system of diagonal bracing, properly carried out, they should form one side of the parallelogram or of the triangle, and those other timbers, or iron-bars, which form the diagonals or the other sides of the parallelogram or triangle ought to be firmly secured to them. A thick strake of plank used formerly to be worked between the shelf and the timbers or frames, but now it is generally worked home upon them. The shelf is generally supported by some thick strakes of plank worked immediately under it, and formerly it was also sometimes supported by chocks or triangular pieces, like brackets on the ship's side, brought out to be flush with the inner edge of the shelf, and on the face of this an iron-knee. This chock is now generally dispensed with, and the lower side of the shelf is bevelled off towards the ship's side, and the iron-knee is forged to fit under it accordingly. These fastenings will be referred to when treating of the means of securing the ends of the beams. The other fastenings of shelf-pieces are by numerous through-bolts. Timbers which are fayed to the inside of the frame, or upon the inside of the plank, longitudinally or diagonally, solely for the purpose of supporting the frame, are called riders.

The beams. The beams of a ship prevent the sides from collapsing, and at the same time carry the decks. The beams are spaced, and their scantling settled upon, according to the strength required to be given to the decks, and to suit the positions of the masts and hatchways, and other arrangements connected with the economy of the ship. All beams have a curve upwards towards the middle of the ship called the round up. This is for the purpose of strength, and for the convenience of the run of the water to the scuppers. Wooden beams are single piece, two, three, or four piece beams according to the number of pieces of timber of which they are composed. The several pieces are scarphed together, and dowelled and bolted, the scarphs being always vertical. A scarph now very generally adopted was introduced by Mr Edge, late master-shipwright of Devonport dockyard, and is represented in the annexed figure. The beams of ships being supported at both ends, and one of the strains to which they are chiefly subjected being a downward pressure, the upper part of the beams will then be compressed, and the lower parts extended. It is therefore desirable that the lower part of the beams should not be wounded so as to cut the fibres across in that part. An incision above the line of the vertical axis is of less moment, and if an incision be made there for the purpose of introducing a carling, for instance, and if this be well fitted, and be of as hard wood as the beam, the strength of the beam will not be impaired, but may even be increased.

Edge's Beam.

Fig. 32.

Connection of the beams to the sides of the ship. The connection of the ends of the beams to the sides of the ship have been made in various ways. The points to be considered, with reference to this connection, are, that the beam is required to act as a shore or strut, to prevent the sides of the ship from collapsing, and also as a tie to prevent their falling apart; that the beam shall not rise from its seat, and that it shall not work in a fore and aft direction; that the beam may be an effective shore, nothing more is necessary than that the abutment of the end against the ship's side may be perfect.

In order that it may act as a tie between the two sides, it is generally dowelled to the upper surface of the shelf on which it rests; and the under surface of the water-way plank which lies upon it is sometimes dowelled into it. These dowels, therefore, connect it with the shelf and the waterway, and through this means it is thus connected with the sides of the ship. There is, also, in the ships of the royal navy, a plank called a side-binding strake, scored down over and into the beam-ends at some distance from the side, and bolted through the side between the beams. The scoring into the beams connects the in and out fastenings of this strake with the longitudinal tie of the beams, but the advantage does not seem to be commensurate with the labour.

Knees to beams. The beams are also supported by knees below them. Wooden knees are chiefly used in America; and it is argued that they give a better support to the beam from their greater surface, and from their stiffness in the throat, or angle of the knee. The iron-knees used in the royal navy vary in form; they are made not only to support the beam from below, but sometimes with horns to clasp it sideways at a short distance from the side of the ship. The lower arms of these knees are so formed as to fit round the shelf; or sometimes, with a view to prevent the necessity of working the iron into this form, and at the same time afford additional support to the shelf, a chock is fitted under the shelf to receive the face of the knee. While the knee is instrumental in supporting the beam, it is also upon it that dependence is mainly placed to prevent the beam rising, or working in an upward direction. In these fastenings there appears a want of any very efficient means to prevent the beam straining in a fore and aft direction, or working upon the end as upon a pivot.

Strains which a beam must resist. From the short outline previously given of the disturbing forces acting on a ship, it will be seen that the strain on the ends of the beams to destroy their connection with the side and loosen the fastenings, must be very great when the ship is under sail, either on a wind or before it—that is, either inclined or rolling. The principal action of these forces is to alter the vertical angle made by the beam and the ship's side—that is, to raise or depress the beam, and so alter the angle between it and the side of the ship above or below it. On the lee-side the weight of the weather side of the ship and all connected with it, and of the decks and everything upon it, as well as the upward pressure of the water, all tend to diminish the angle made by the beam and the ship's side below it, and consequently increase the angle made between them above it. The contrary effect is produced on the weather side, where the tendency is to close the angle above the beam and open that below it. If the beam when subjected to these strains, be considered as a lever, it will be evident that the fastenings to prevent its rising ought to be as far from the side as is consistent with the convenience or accommodation of the ship; and that while the support should also be extended inwards, the fastening to keep down the beam-end should be as close to the end of the beam, and consequently to the ship-side, as it can be placed.

The annexed section of the side of a three-decked ship of the royal navy shows some of the modes that have been adopted for securing the ends of the beams.

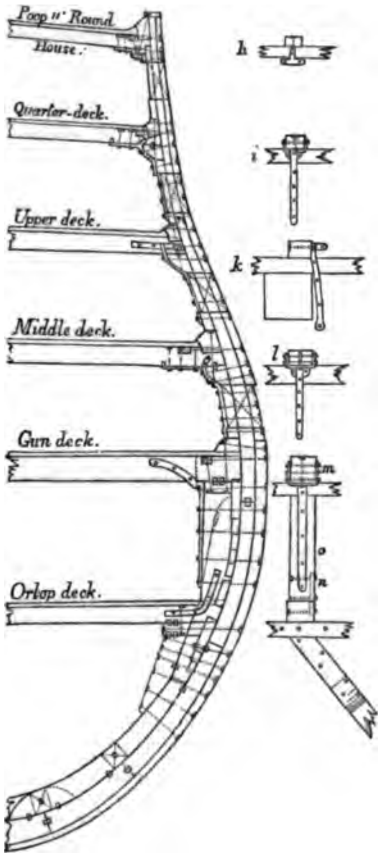

Fig. 33.

Half-beams. Beams which do not extend from one side of the ship to the other are called half-beams. They are introduced whenever the hatches or openings in the middle of the ship are such as to require the whole or unbroken beams to be so wide apart that the deck requires support between them. Their ends, towards the midships, are received by fore and aft pieces called carlings, which go from beam to beam; and any intermediate athwartship pieces between the carlings are called ledges.

Carlings and ledges.

Hooks. The two sides of the ship at the bows are connected by hooks, which are either of timber or of iron. It is important to remember that the hooks above, and those below the surface of the water, are subjected to an opposite strain. The tendency of the pressure of the water on the bow is to make the sides collapse, and therefore the hooks below the water's surface should not only act as ties to the bow while the ship is grounded—as, for instance, when in dock—but should be formed more especially to resist the pressure of the water when she is afloat. Those hooks which are above the surface of the water act principally as ties, the rake of the bow and the weight of its parts tending to separate the two sides of the ship.

Planking. The plank, or skin, or sheathing of a ship, both external and internal, is of various thicknesses. A strake of planking is a range of planks abutting against each other, and generally extending the whole length of the ship. A thick strake, or a combination of several thick strakes are worked wherever it is supposed that the frame requires particular support—for instance, internally over the heads and heels of the timbers; both externally and internally in men-of-war vessels between the ranges of ports; and internally to support the connection of the beams with the sides, and at the same time form a longitudinal tie. The upper strakes of plank, or assemblages of external planks, are called the sheer-strakes. The strakes between the several ranges of ports, beginning from under the upper-deck ports of a three-decked ship in the royal navy, are called the channel wale, the middle wale, and the main wale. The strake immediately above the main wale is called the black strake. The strakes below the main wale diminish from the thickness of the main wale to the thickness of the plank of the bottom, and are therefore called the diminishing strakes. The lowest strake of the plank of the bottom, and whose edge fits into the rabbet of the keel, is called the garboard strake.

Plank is either worked in parallel strakes, when it is called "straight edged," or in combination of two strakes, so that every alternate seam is parallel. There are two methods of working these combinations, one of which is called "anchor stock," and the other "top and butt." The difference will be best shown by the annexed figure. The difference in the intention is, that in the method of working two strakes anchor-stock fashion, the narrowest part of one strake always occurs opposite to the widest part of the other strake, and consequently the least possible sudden interruption of longitudinal fibre, arising from the abutment, is obtained. This description, therefore, of planking is used where strength is especially desirable. In top and butt strakes the intention is, by having a wide end and a narrow end in each plank, to approximate to the growth of the tree, and to diminish the difficulty of procuring the plank. When the planking is looked upon as a longitudinal tie, the advantage of these edges being, as it were, imbedded into each other is apparent, all elongation by one edge sliding upon the other being thus prevented. The shift of plank is the manner of arranging the butts of the several strakes. In the ships of the royal navy the butts are not allowed to occur in the same vertical line, or on the same timber, without the intervention of three whole strakes between them.

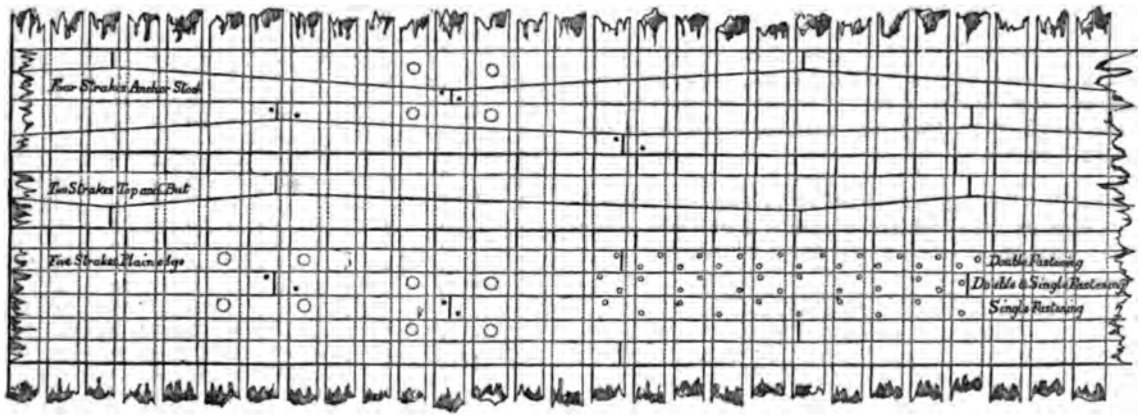

Fig. 34.

Limber-strake. Of the internal planking the lowest strake, or combination of strakes, in the hold, is called the limber-strake. A limber is a passage for water, of which there is one throughout the length of the ship, on each side of the keelson, in order that any leakage may find its way to the pumps.

Ceiling and internal planking. The whole of the plank in the hold is called the ceiling. Those strakes which come over the heads and heels of the timbers are worked thicker than the general thickness of the ceiling, and are distinguished as the thick strakes over the several heads. The strakes under the ends of the beams of the different decks in a man-of-war, and down to the ports of the deck below, if there be any ports, are called the clamps of the particular decks, to the beams of which they are the support, as the gun-deck clamps, the middle-deck clamps, &c. The strakes which work up to the sills of the ports of the several decks are called the spirketting of those decks—as gun-deck spirketting, upper-deck spirketting, &c.

Fastenings of the planks.

The fastening of the plank is either "single," by which is meant one fastening only in each strake, as it passes each timber or frame; or it may be "double," that is, with two fastenings into each frame which it crosses; or, again, the fastenings may be "double and single," meaning that the fastenings are double and single alternately in the frames as they cross them. The fastenings of planks consist generally either of nails or treenails, excepting at the butts, which are secured by bolts. Several other bolts ought to be driven in each shift of plank as additional security. Bolts which are required to pass through the timbers as securities to the shelf, water-way, knees, &c., should be taken advantage of to supply the place of the regular fastening of the plank, not only for the sake of economy, but also for the sake of avoiding unnecessarily wounding the timbers.

The planking in the royal yards is not usually fastened permanently till some time after it is trimmed and brought on to the bottom of a ship. It is thus allowed to season and shrink; and one strake in eight or ten is left out for the purpose of allowing ventilation, and to make good the shrinkage, and also to allow the strakes to be refayed. Without the latter provision there would be such an alteration of edge as would throw the holes made for the temporary securities out of the range of the strakes; but with this precaution it is very seldom that the alteration of edge is such as to require new holes, especially as the iron screw-eye bolts used for this temporary fastening are of much smaller diameter than the permanent treenail fastening, and therefore the holes for them through the plank can still be made good holes for the treenails. This method of securing the planks by a first or temporary fastening, to be afterwards substituted by a treenail, is also of advantage in enabling them to be brought into close contact with the timbers, in the saving of bolt fastenings, and in causing a good and regular seam to be given for the caulking.

The advantages and disadvantages of iron as a fastening for planking have been already discussed. The strength of treenails to resist a cross-sheering strain, as found by Mr Parsons, late of H.M. Dockyard Service, is shown in the following table:—

Experiments on fastenings.

"*Table of the Transverse Strength of Treenails of English Oak used as fastening for Planks of* 3 *and of* 6 *inches in thickness, and subjected to a Cross Strain.*

Number of the Experiment.	Diameter of the Treenails.															
	1 Inch.				1⅛ Inch.				1¼ Inch:				1⅜ Inch.			
	Thickness of the Plank.															
	3 In.		6 In.		3 In.		6 In.		3 In.		6 In.		3 In.		6 In.	
	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.	T.	C.
1	1	8	1	7	1	14	2	8	2	0	3	12	3	0	5	10
2	1	7	1	15	2	2	2	2	2	6	2	10	2	10	3	13
3	1	2	1	8	1	17	2	19	2	15	2	10	4	0	4	0
4	1	5½	1	8	2	2	2	2	2	4	3	12	2	8	3	8
5	2	12	1	3	2	2	1	15	2	18	2	5	3	10	4	0
6	2	2	1	7	2	9	2	10	2	6	2	5	3	10	5	8
7	2	4	1	10	2	8	2	10	3	7	2	5	3	5	3	12
8	1	6	2	3	2	7	2	0	2	5	3	0	3	5	3	13
9	1	8	1	8	2	12	2	10	3	0	4	0	4	6	4	13
10	1	2	2	3	2	10	2	15	3	0	4	10	3	8	4	0
11	2	0	2	0	2	7	2	0	3	9	2	18	4	0	3	8
12	1	8	1	7	2	10	2	0	4	2	3	0	4	10	5	0
13	1	16	2	8	2	17	2	0	3	2	3	18	4	2	5	5
Average	1	11	1	13	2	6	2	6	2	16	3	2	3	10	4	6

"In all these experiments on treenails, when the treenails were evidently good, they gave way gradually. In some of the rejected experiments, however, the treenails certainly did break off suddenly, but then they were evidently, on examination, either of bad or over-seasoned material. It has been asserted that the treenails made from the Sussex oak are much stronger than those made from the New Forest timber, or any other English oak. To ascertain the truth of this assertion, some experiments were made with Sussex and New Forest treenails of all sizes; and the result was, that there was not the least difference in them, the New Forest were, on experiment, quite as strong as the Sussex. In the experiments on treenails, the plank generally moved about half an inch previous to the fracture of the treenail."

The following useful tables were also drawn up by Mr Parsons from a series of valuable experiments carefully made by him, and show the longitudinal holding power of treenails. The first of these tables exhibits the adhesion of iron and copper bolts, driven into sound oak, with the usual drift, not clenched, and subject to a direct tensile strain. By drift is meant the allowance made to insure sufficient tightness in a fastening; it is therefore the quantity by which the diameter of a fastening exceeds the diameter of the hole bored for its reception.

"*Table of the Adhesion of Iron and Copper Bolts driven into sound Oak with the usual Drift, not clenched, and subjected to a direct Tensile Strain.*

Diameter of the Bolt.	Number of the Experiment.	Iron.				Copper.			
		Length of the Bolt driven into the Wood.							
		Four Inches.		Six Inches.		Four Inches.		Six Inches.	
Inches.		Tons.	Cwt.	Tons.	Cwt.	Tons.	Cwt.	Tons.	Cwt.
¼...	1	1	13	...		0	18½	...	
	2	2	0	...		0	18	...	
	3	2	2	...		0	19	...	
	4	1	13	...		0	18	...	
⅜...	1	2	6	2	12	1	7	2	2
	2	2	4	2	11	1	8	2	2
	3	2	4	2	16	1	10	2	2
	4	2	0	2	10	1	13	2	0
½...	1	3	2	8	12	2	10	2	15
	2	3	4	4	0	1	17	3	10
	3	3	0	4	0	2	2	3	1
	4	2	10	4	0	2	5	2	15
⅝...	1	3	2	5	5	3	0	4	5
	2	3	0	4	8	3	6	3	18
	3	3	1	4	8	3	6	3	15
	4	3	1	5	0	2	9	3	5
¾...	1	3	3	6	0	3	10	5	5
	2	3	2	6	0	3	10	5	5
	3	3	10	5	0	3	10	5	8
	4	3	10	6	0	3	18	4	18
⅞...	1	4	10	6	2	4	0	4	13
	2	5	12	5	10	4	0	4	13
	3	3	10	6	11	4	5	4	19
	4	4	10	6	4	4	2	4	19
1...	1	5	0	7	2	4	2	5	19
	2	4	7	8	1	4	8	5	0
	3	4	11	6	5	3	15	6	5
	4	4	0	7	0	4	10	5	0

"In Riga fir the adhesion was, on an average, about one-third of that in oak, and in good sound Canada elm it was about three-fourths of that in oak.

The following table exhibits the strength of clenches and of forelocks as securities to iron and copper bolts, driven six inches, without drift, into sound oak, either clenched or forelocked on rings, and subjected to a direct tensile strain. It gives the diameter of the bolt on which the experiment was made, as well as the number of the experiment:—

Practical Building.

"*Table of the Strength of Clenches and of Forelocks, as securities to Iron and Copper Bolts, driven six inches, without Drift, into sound Oak, either clenched or fore-locked on Rings, and subjected to a direct Tensile Strain.*

Diameter of the Bolt.	Number of the Experiment.	Iron.				Copper.			
		Clench.		Forelock.		Clench.		Forelock.	
Inch.		Tons.	Cwt.	Tons.	Cwt.	Tons.	Cwt.	Tons.	Cwt.
¼...	1	1	16	0	16	1	0	0	8
	2	1	13	0	14	0	19	0	8
	3	1	9	0	20	1	0	0	7
	4	1	9	0	18	1	0	0	6
⅜...	1	3	0	1	15	2	10	1	4
	2	3	0	1	8	2	10	1	0
	3	2	16	1	9	2	5	1	2
	4	2	15	1	14	2	9	1	4
½...	1	4	15	2	11	3	10	1	18
	2	4	10	2	15	3	15	1	18
	3	4	5	2	10	4	0	2	4
	4	4	12	2	12	4	10	1	16
⅝...	1	5	18	3	15	6	0	2	13
	2	6	8	3	6	5	15	2	10
	3	6	8	3	0	6	5	2	16
	4	6	0	3	7	5	10	2	10
¾...	1	7	10	3	10	7	0	...	
	2	7	10	3	15	7	0	...	
	3	8	0	3	10	7	5	...	
	4	8	15	3	15	7	8	...	
⅞...	1	11	11	5	1	7	16	...	
	2	11	15	5	10	7	16	...	
	3	8	11	4	6	7	12	...	
	4	8	6	4	15	7	5	...	
1...	1	12	0	5	18	7	1	...	
	2	12	3	6	18	7	1	...	
	3	11	3	5	12	7	14	...	
	4	11	1	5	2	8	14	...	

"In the experiments on the clenches, the clenches always gave way; but with the forelocks it as frequently occurred that the forelock was cut off as that the bolt broke; and in the cases of the bolt breaking, it was invariably across the forelock hole. According to the tables, the security of a forelock is about half that of a clench.

"It appears an anomaly that the strength of a clench on copper should be equal to that of one on iron. But, in consequence of the greater ductility of copper, a better clench is formed on it than on iron. Generally the thickness of the fractured clench in the copper was double that in the iron. With rings of the usual width for the clenches, the wood will break away under the ring, and the ring be imbedded for two or more inches before the clench will give way.

"With the inch copper-bolts, all the rings under the clenches turned up into the shape of the frustum of a cone, and allowed the clench to slip through at the weights specified.

"Experiments with ring-bolts were made to ascertain the strength of the rings in comparison with the clenches. The rings were of the usual size, viz., the iron of the ring one-eighth inch less in diameter than that of the bolt. It was found that the rings always carried away the clenches, but that they were drawn into the form of a link with perfectly straight sides. The rings bore, before any change of form took place, not quite one-half the weight which tore off the clenches. It appears that the rings are well proportioned to the strength of the clenches."

From these tables it will be seen how much the strength of a clenched or fore-locked bolt falls short of the strength due to the full diameter of the bolt where a tensile strain only is applied to it; and when exposed to a cross strain, it is also well known how much the strength is diminished when the ends are not fastened and held securely in position. An increased use of screw-bolts with nuts and larger plates or rings under the heads and under the nuts would therefore give great additional strength; and if a sufficient length of the bolt were screwed at the end to allow of as much as an inch being cut off when too long, the supply of sizes necessary to be kept in store would not be large. Economy also would be likely to result from the greater accuracy in the length required to be given for the bolt about to be drawn from the store for use.

Practical Building.

Screw-treenails of the annexed form have lately been introduced by Messrs Hall, the well known builders of the Aberdeen clipper-ships, and whose modes of construction will be more particularly referred to hereafter. The increased holding power of such treenails to prevent planks from starting needs no demonstration.

Fig. 35.

Decks.

The decks of a ship, as has before been stated, must not be considered merely as platforms, but must be regarded as performing an important part towards the general strength of the whole fabric. They are generally laid in a longitudinal direction only, and are then useful as a tie to resist extension, or as a strut to resist compression. The outer strakes of decks at the sides of the ship are generally hard wood, and of greater thickness than the deck itself; they are called the water-way planks, and are sometimes dowelled to the upper surface of each beam. Their rigidity and strength is of great importance, and great attention should be paid to them, and care taken that their scarphs are well secured by through bolts, and that there is a proper shift between their scarphs and the scarphs of the shelf.

When the decks are considered as a tie, the importance of keeping as many strakes as possible entire for the whole length of the ship must be evident; and it has already been stated that a continuous strake of wrought-iron plates beneath the decks is of great value in this respect. The straighter the deck, or the less the sheer or upward curvature at the ends that may be given to it, the less liable will it be to any alteration of length, and the stronger will it be. The ends of the different planks forming one strake are made to butt on one beam, and as the fastenings are then driven close to the ends, they do not possess much strength to resist being torn out. The shifts of the butts, therefore, of the differen strakes require great attention, because the transference of the longitudinal strength of the deck from one plank to another is thus made by means of the fastenings to the beams, the strakes not being united to each other sideways.

Strain in caulking to be resisted.

These fastenings have also to withstand the strain during the process of caulking, which has a tendency to force the planks sideways from the seam; and as the edges of planks of hard wood will be less crushed or compressed than those of soft wood when acted on by the caulking-iron, the strain to open the seam between them to receive the caulking will be greater than with planks of softer wood, and will require more secure fastenings to resist it. It may also be remarked that the quantity of fastenings should increase with the thickness of the plank which is to be secured, for the set of the oakum in caulking will have the greater mechanical effect the thicker the edge.

Diagonally laid decks.

A deck, laid in a diagonal direction only, involves a great loss of strength longitudinally, and the advantages are not such as to compensate for this loss, and for the other inconveniences as to wear and tear, which result from such a system. Mackonochie proposed to lay decks in three layers, one diagonally from starboard to port, another from port to starboard, and an upper layer fore and aft. He also proposed a somewhat similar system for the outside planking, and vessels have been built on different modifications of this plan both in this country and in America.

Importance of securing the decks at the extremities.

At the two ends of a ship it is important that the strength of the tie of the deck should be maintained there, and while the continuation and connection of the shelf-pieces and waterway-planks are duly attended to, with any necessary hooks and crutches, additional strength to sustain the projecting bows and raking sterns may be obtained by a judicious connection of several beams to the extreme ends. This may be done by long bolts passed through the beams and secured by nuts and screws at their ends, or by pieces of timber fore and aft, underneath the beams, and bolted to them. These beams should have several ranges of carlings let down between them to diffuse the strain.

Dowelling and scoring down.

In all such connections of wood with wood, dowelling is much to be preferred to scoring down. The latter is objectionable on account of its wounding and weakening the parts in a greater degree, and the joint is subject to become loose or open by the shrinkage of the materials, and it also requires much more care and skill on the part of the workman for its perfect execution. It should therefore be discontinued wherever practicable.

Partners.

The frame-work of timbers which is formed round the mast-holes in each deck is called the mast partners. "Partners" generally are the principal timbers in a framing formed for the support of anything passing through a deck, as the masts and capstands.

Steps.

The pieces of timber to receive the heels of the several masts are called steps, as the main, fore, or mizen steps.

Coamings and head ledges.

Coamings are pieces generally faying on carlings, and rising higher than the flat of the deck, to form the fore and aft sides or boundaries of openings, such as hatch or ladder-ways; head ledges forming the athwartship boundaries to the same openings.

Caulking.

When the planks are fastened, the seams or the intervals between the edges of the strakes are filled with oakum, and this is beaten in or caulked with such care and force that the oakum, while undisburbed, is almost as hard as the plank itself. If the openings of the seam were of equal widths throughout their depth between the planks, it would be impossible to make the caulking sufficiently compact to resist the water. At the bottom edges of the seams the planks should be in contact throughout their length, and from this contact they should gradually open upwards, so that, at the outer edge of a plank 10 inches thick, the space should be about $\frac{10}{16}$th of an inch, that is, about $\frac{1}{16}$th of an inch open for every inch of thickness. It will hence be seen that if the edges of the planks are so prepared that when laid they fit closely for their whole thickness, the force required to compress the outer edge by driving the caulking-iron into the seams, to open them sufficiently, must be very great, and the fastenings of the planks must be such as to be able to resist it. Bad caulking is very injurious in every way, as leading to leakage and to the rotting of the planks themselves at their edges. It frequently happens, however, that the caulking is blamed when the leakage and the attendant evils have been caused by the edges of the planks sliding upon each other through the working of the deck or of the ship.

Marine glue.

Instead of pitch for closing the seams above the oakum, Mr Jeffery introduced a mixture of shellac and caoutchouc, combined with naphtha. This is at first more expensive, but its decided superiority and greater durability, preventing the necessity of so frequently re-caulking, will counterbalance this in due time, so as to be to the advantage of the ship-owner, though this will not make it economical to the ship-builder who builds and completes a vessel by contract. It is insoluble in water, and impervious to it; it is also elastic, and yet of sufficient solidity to fill up the joint and give strength; and it is also powerfully adhesive, so as to connect the planks together at their edges.

The mode of applying diagonal trussing to strengthen the side of a ship constructed in accordance with the foregoing outline, will next be considered.

Diagonal trussing.

In the system of building which was superseded by that termed the diagonal system, the whole of the interior surface of the frame was planked, and a second series of internal frames was worked upon this planking, agreeing in direction with the timbers of the ship. Riders were also introduced in various parts, but not diagonally, and those in the hold were no doubt necessary when it was the custom to "ground" ships on a beach for repair; a large quantity of timber was thus massed together, having the appearance of great strength; but, in fact, from its weight, injudicious combination, disposition and fastening, much of it was, if not injurious, at least useless. The idea of diagonal trussing was not an entire novelty at the time when Sir Robert Seppings introduced it as a system. There is evidence, in the representation of a vessel under repair in the fifteenth century, of some pieces of timber having been used diagonally in her construction, as also in some other isolated instances. The credit, however, of calling the attention of ship-builders to the principles on which the advantages of diagonal trussing depend, is entirely due to Sir Robert Seppings, and no ship is now ever built without the principle being brought into action in a greater or less degree.

He described his system in a paper communicated by him to the Royal Society, and which is printed in their *Transactions* for the year 1814. In that paper, after supposing the frames for a two-decked 74 gun-ship to be in place, and the spaces between the frames filled-in solid, he proceeds as follows:—

"In this state the diagonal timbers are introduced, intersecting the timbers of the frame at about the angle of 45°, and so disposed as that the direction in the fore is contrary to that in the after part of the ship, and their distance asunder from 6 to 7 feet or more; their upper ends abutting against the horizontal hoop or shelf-piece of the gun-deck beams, and the lower ends against the limber strakes, except in the midships, where they come against two pieces of timber placed on each side of the keelson (called additional keelsons), for the purpose of taking off the partial pressure of the main-mast, which always causes a sagging down of the keel, and sometimes to an alarming degree. These pieces of timber are nearly as square as the keelson, and fixed at such a distance from it that the main step may rest upon them. They may be of oak or pitch-pine, and as long as can be conveniently procured. Pieces of timber are next placed in a fore and aft direction over the joints of the frame-timbers, at the floor and first futtock-heads; their ends in close contact with, and coaked or dowelled to, the sides of the diagonal timbers. In this state the frame-work in the hold presents various compartments, each representing the figure of a rhomboid.

"A truss-timber is then introduced into each rhomboid, with an inclination opposite to that of the diagonal timbers, thereby dividing it into two parts. The truss-pieces so introduced into the rhomboid are to the diagonal frame what the key-stone is to the arch; for no weight or pressure on the fabric can alter its position in a longitudinal direction, till compression takes place at the abutments, and extension of the various ties.

"This arch-like property of the diagonal frame not only opposes an alteration of position in a longitudinal direction, but also resists external pressure on the bottom, either from grounding or any other cause, because no impression can be made in its figure in these directions without forcing the several parts of which it is composed into a shorter space."

The trussing here proposed for the hold of the ship was undoubtedly with the intention of introducing the principle of the inverted arch or dome; and it must be remembered, that the general form of the vessels to which Sir Robert

Seppings was accustomed approached that of a hemisphere at their midship section, and was very different from the comparatively flat or plain surfaces now common. Any lower ranges of riders and trusses brought on the floors and first futtocks could have little effect in preventing arching beyond that which arises from the additional resistance they offer to deflexion by their rigidity. In men-of-war with several decks above the lower deck, the object aimed at seems to have been to obtain a firm base on which to ground a new and upper series of diagonal ties and struts. It will be evident from these remarks, that it is not considered that the bottom of a ship, if filled-in solid, and made as little compressible as possible by this means, and by the introduction of additional or sister keelsons, requires any great expenditure of material or labour, in order to adapt a system of diagonal trussing to it. The position for its most beneficial application is undoubtedly the sides of the vessel, but whether struts or ties be used, there must be a proper starting point for their ends. In wooden vessels of ordinary construction, this would, perhaps, be found to be in the sister keelson, nearest the wing, or in the thick strakes or riders brought on at the head and heels of the floors and first futtocks. The importance of these last in resisting any strain, if the ship takes the ground and rests on her bilge, is also evident; and it would therefore be advantageous to increase their strength with this view, even if there existed no other reason. Having determined a base or starting point for the lower ends of the diagonals, the next point to be attended to is to determine a strong line of work to which to attach their upper ends. Where intermediate decks occur the diagonals must either be carried past them in one continued line, or a new system be commenced and carried on from that line. In this case the strain on the parts may become such that the direction of the ties and struts may require to be changed. While diagonals are useful as a means of firmly connecting the adjacent pieces of timber, it must be remembered that this is a small portion of their value, and that full advantage will not be ensured from them without due consideration being given to keep up an unbroken system of sides and of diagonals, with their ends firmly united. It is immaterial whether parallelograms or triangles be used, if the last side of the one be always made the first side of the next. A triangle is a valuable form in structures of this kind, because it is a figure which admits of no alteration in its form; its angles are invariable as long as the sides remain the same, that is, as long as they are neither elongated nor shortened.

These principles are becoming more and more appreciated every day, and the strength of ships is consequently becoming much increased.

Diagonal trussing in Government vessels.

In the government service the diagonals, which extend over the surface of the side of the ship, are of iron-bars, varying according to the size of the ship, and also of wood. The annexed wood-cuts represent and show portions of the side of a two-decked ship, the diagonal riders of iron passing up between the ports (figs. 36 and 37). They commence under the thick strakes over the first and lower futtock-heads, and run up unbroken to the shelf of the upper-deck. On the turn of the bilge, where it is most rounding, and where the ship would rest, if she took the ground, there is a system of wooden trusses introduced to stiffen the vessel at that spot, which has before been stated to be so desirable an object.

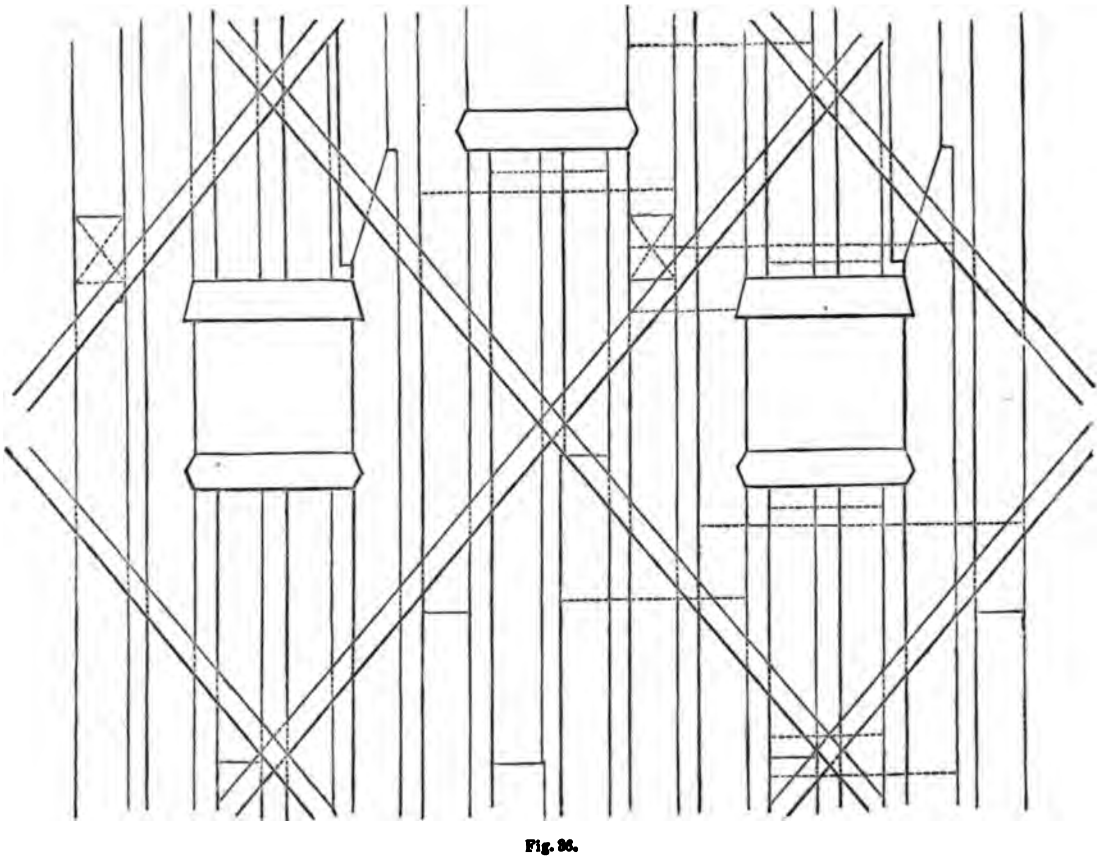

Fig. 36.

In other vessels the iron-bars are laid upon, and sunk into, the frames in one direction, while a series of wooden diagonal riders are placed upon the surface of the internal sheathing, crossing them in the other direction. In the fabric, as a whole, there appears a want, to the eye of an engineer, of a due consideration to the fact, that the strength of a box-girder, or tubular bridge, to which the mind naturally reverts as the simplest form of a long body to sustain

Practical Building. such weights and strains as those to which a ship is liable, lies mainly in the top and bottom, and not in individual portions of the sides. A lattiee, or trellis girder, is nothing without the top and bottom bars uniting the lattice or trellis works. If a weight is to be supported by ties, there must be something to carry their upper ends without yielding; and if it is to be supported by struts, there must be a sound and unyielding foundation for them to rest upon, and from which they may rise.

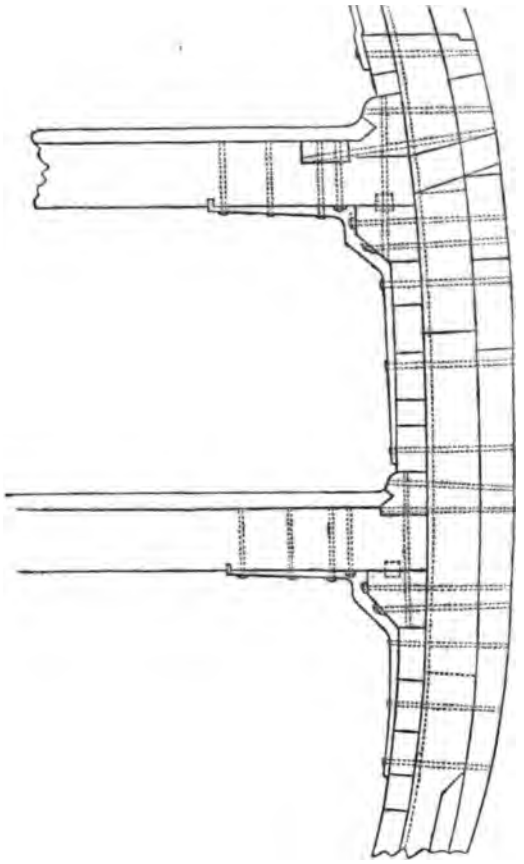

Fig. 37.

Details of ship Schomberg, by Messrs Hall and Co., of Aberdeen. Messrs Hall and Co., of Aberdeen, carry out the principle to a great extent in the vessels built by them.

The following is a general description of the Schomberg (Plate III.), as built by them, in 1854, for James Baines and Co., of Liverpool, and many valuable hints may be gained from the practice of these eminent builders. She was expressly designed for an Australian passenger-ship, and every attention was paid to render her ventilation complete:—

Sheathing. Her register measurement was 2400 tons; her frames were of British oak, 4½ feet from centre to centre, close-jointed and bolted, and her sheathing consisted of four thicknesses of 2½ inch Scotch larch, first two courses worked diagonally at an angle of 45° passing under the bottom of inside keel, and up the opposite side; the third course also passed under the keel, and was laid on transversely, same as the frames; there was a similar course worked inside between the frames, each course having a layer of felt, and a coat of Archangel tar, between them. The outside longitudinal planking averaged 6 inches in thickness, and the whole mass was combined by screw treenails of African oak, 1⅝ inches diameter, put through the whole, there being one treenail at every foot in each strake of plank.

Beams. She had three tiers of malleable iron-beams, there being one attached to each frame on each side of the three decks, as shown in the transverse section (Pl. III.) These beams were laid on pitch pine stringers, which were in two depths, and were attached to the sides by iron staple knees, a piece of plate-iron passing betwixt the beam end and the frame, and these plates being connected with the knees by the throat-bolts passing through them, and thus forming a lodgment for the iron beam ends. There was also a malleable iron-plate, 16 × ⅝ inches, riveted to the top angle-irons on the beams; to this plate the water-ways were secured, besides being bolted horizontally. The sizes of the beams were:—

Upper deck,	7×½ width,	2½×2½	inches in single iron.
Middle deck,	8×⅝	3	inches angle iron.
Lower deck,	do.	do.	do.

The beams were in one length; the lower edge with a bulb, and upper edge with angle-irons, back to back. They were supported by three tiers of iron stanchions, riveted to the beams, and bolted to the keelson and sister-keelsons.

For ventilation, the spaces, 3 feet wide, between the frames, were boarded up, and formed excellent ventilators from the various decks and hold, leading up to a space immediately under the main rail, which was fitted all round with venetians. She was also fitted with large funnels, and with a fanner for forcing the air down to the keel, besides scuttles on every six feet on the middle deck. The saloon was on the upper deck, and was fitted with a double roof for causing a current of air, with orifices all round under the cornice outside.

The vessel having a great rise of floor, it was levelled off inside to the 5 feet water-line, by having a fourth deck laid from end to end, and under this deck tanks were fitted to hold 300 tons of fresh water. Along the upper deck, from saloon forward, there was a range of houses for live stock, cook-house, and accommodation for the crew. This vessel sailed from Liverpool for Australia in 1854, drawing 21′ 6″ forward and 24′ 6″ aft, and on the eighty-fourth day was lost on Cape Otway, on a fine moonlight night. No favourable opportunity occurred during the passage to test her speed for any continued length of time; but she attained, on one occasion, a speed of sixteen knots for a few hours. This ship, complete, cost L.45,000.

The annexed figures are further illustrations of the details of construction adopted by the same builders.

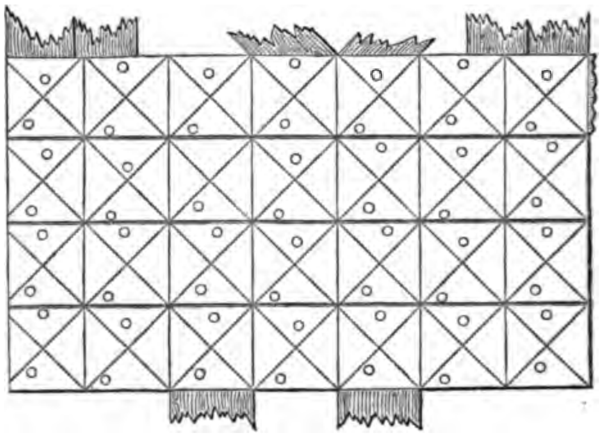

Fig. 38 a.

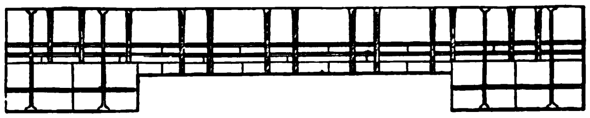

Fig. 38 b.

A section of a clipper ship, of 700 tons burthen, The Vision, of Liverpool, built in 1854, is given in fig. 39. The larboard side represents the bolting in the frames, which are 4½ feet asunder from centre to centre. The starboard side shows the application of the screw-treenails in connecting the various layers of plank, which consist of two thicknesses of 2-inch larch worked diagonally, as shown in figs. 38 *a* and 38 *b*, one thickness of larch worked vertically, and one outside, of an average thickness of 4½ inches, worked longitudinally, the sheer-strakes of East India teak, top sides Dantzic red pine, Wales, and to light water-line of Dantzic imported plank, from thence to the keel-strakes of Dantzic red pine, with two complete layers of hair felt between the planks, which are all coated with vegetable tar.

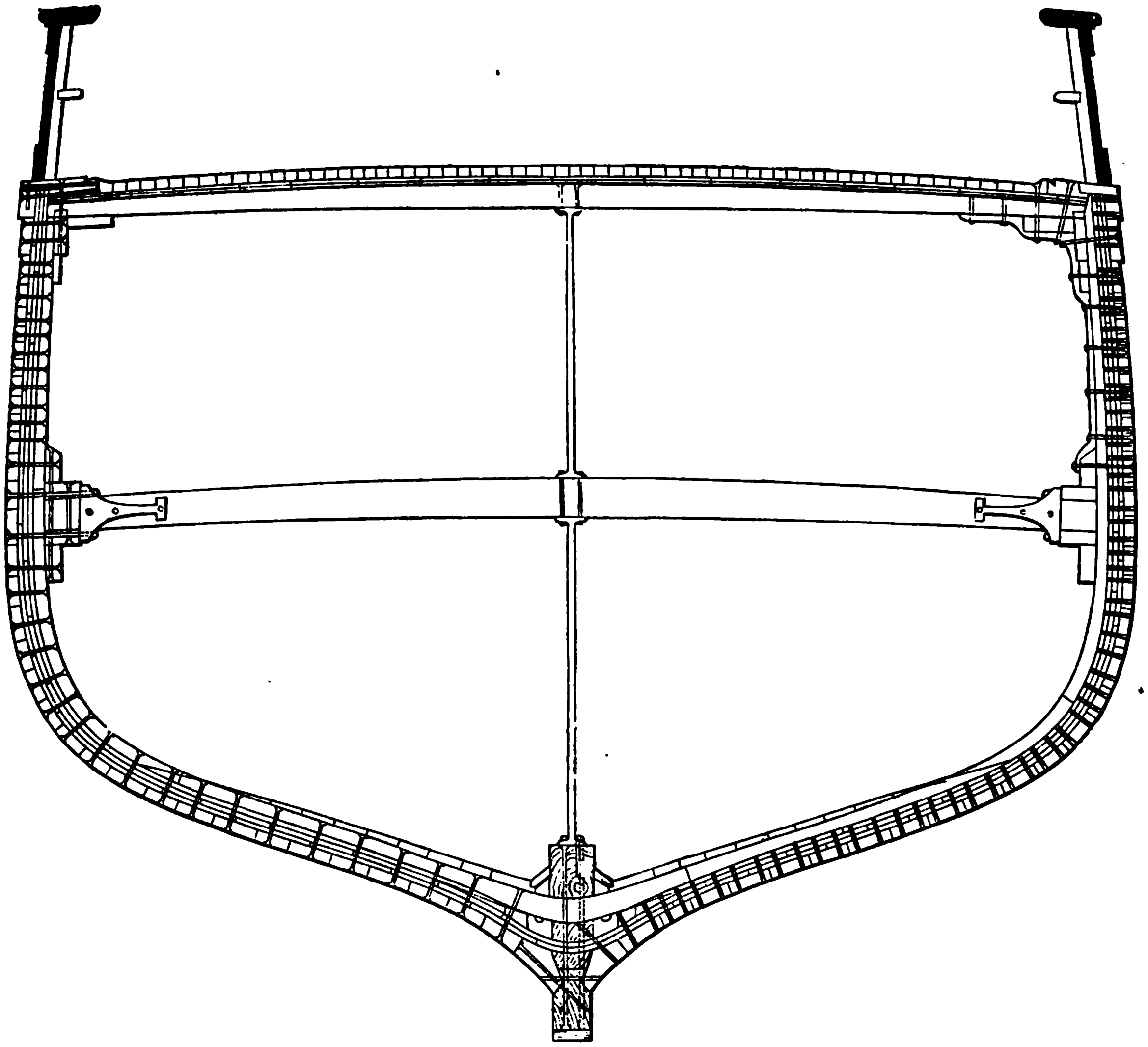

Fig. 39.

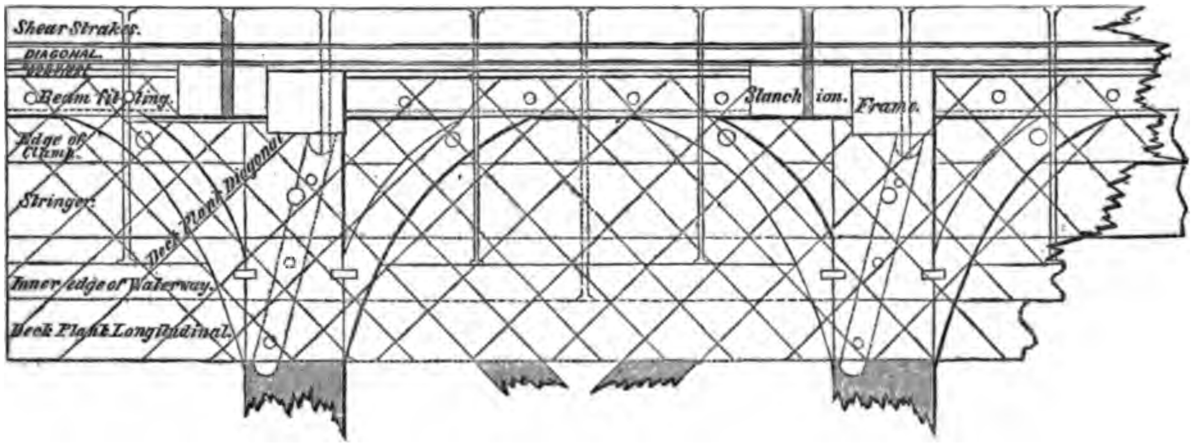

Fig. 40.

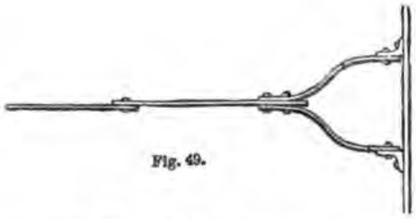

Fig. 49.

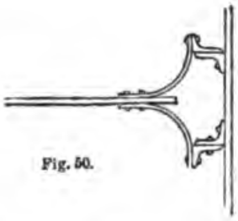

Fig. 50.

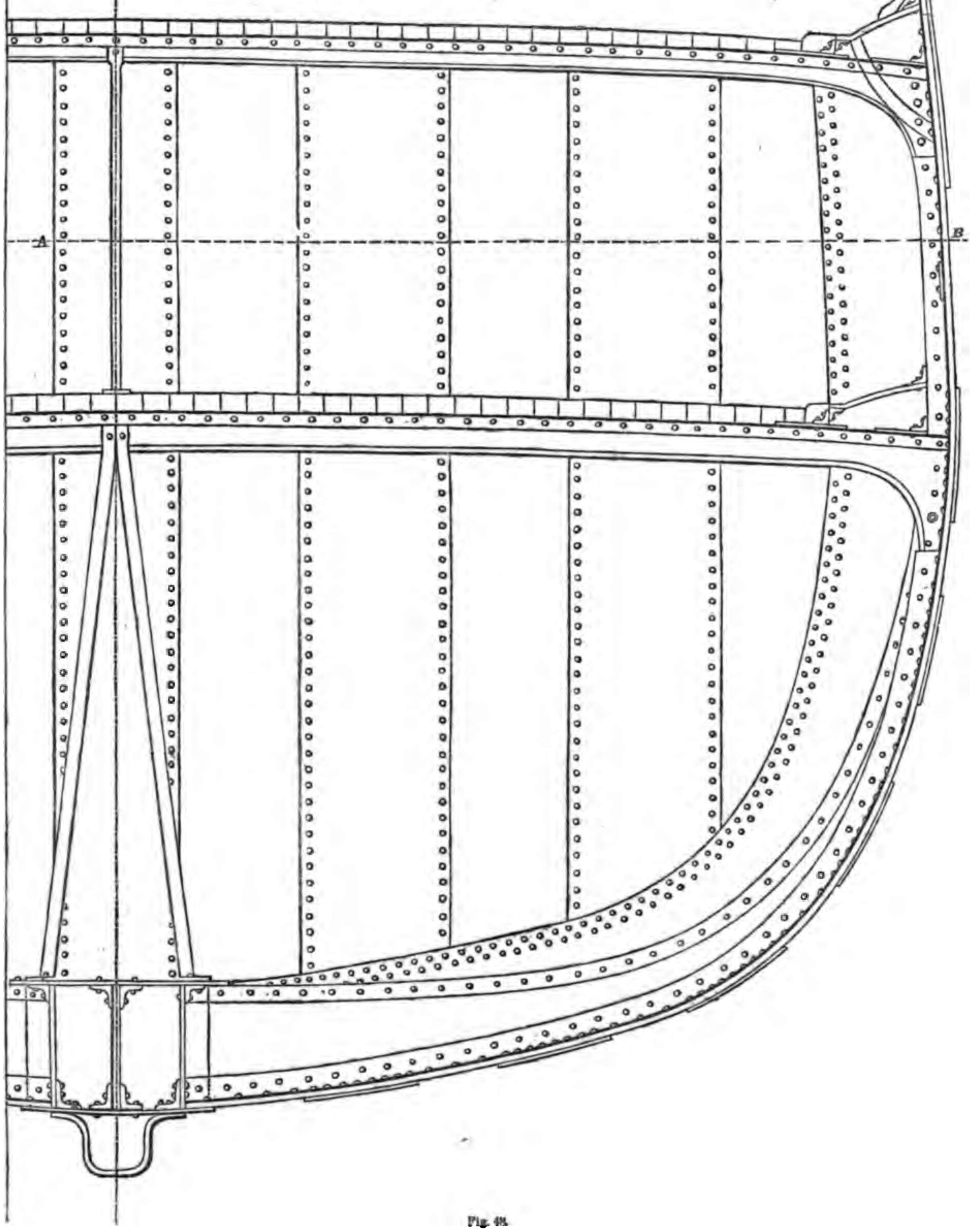

Fig. 48.

Practical Building.

further supposed that the weights are equally distributed over her length, then the strain would require to be the same as for a tubular bridge, or girder, to carry a weight of 750 tons at the middle. Now, if the ordinary rules be applied, it will be found that the sectional area of the bottom flanche of a box-girder of these dimensions, and whose breaking weight is 750 tons, would be 94 square inches; and doubling this for the excess of strength necessary in practice, will give an area of 188, or say 200 square inches of iron. The strength of the deck, therefore, at the middle, should be equal to the strength of iron-bars or plates of this sectional area, and towards the ends it may be diminished to about two-thirds of this strength, on the same principle and in the same manner as the flanches of a beam may be diminished.

An explanation of the theory of the strength of girders is not within the province of this article. It will be found very fully treated in the works of Tredgold, Hodgkinson, Barlow, Fairbairn, Latham and others, as also in some papers in the *Transactions* of the Institution of Civil Engineers, and in a paper in the *Transactions* of the Royal Society, by Mr Barlow, "On the position of the Neutral Axis."

Water-tight bulkheads.

While the advantages of iron water-tight bulkheads are unquestionable, nothing can be worse than that the sheathing should be weakened in one direct transverse line by a series of rivets, placed so close together as to lessen the strength of the plates in an undue degree at that line. The Board of Trade insist upon the bulkheads being attached to two frames (figs. 49 and 50), but it is not apparent how the difficulty is got over by this means alone, because on one or other of these frames the rivets must be sufficiently close to make the joint water-tight. This would be advantageous if the bulkhead were made to run home to the side of the ship, and be made water-tight there by an additional angle-iron, while the two frames on either side are united together through the bulkhead, so as to prevent the vessel separating along the line of weakness between them. In this view the inner line of plates uniting the frames to the bulkhead should be kept as close as possible to the ship's side, and therefore as much as possible in the direct line of the strain to be resisted.

The following is a specification of an iron screw-steamship for the Peninsular and Oriental Steam Navigation Company:—

Principal Dimensions.

Length between the perpendiculars	335 feet.
Length of the keel for tonnage	To be according to the approved design.
Breadth, extreme	39 feet.
Depth amidships (from top of keel)	31 „
Burthen in tons, Nos	2520. $\frac{8}{94}$ O. M.

Keel.—To be formed of plates, as shown in figs. 51 and 52, the centre through-piece to be 3 feet 6 inches deep from bottom of keel to top of floors, and $\frac{14}{16}$ thick right fore and aft. The plate on each side to be 10 inches deep by 1½ inches thick. The fore and aft plate shown on top of floors to be ⅝ in. thick, and 2 feet 6 inches wide, worked so as to fit on top of floors, and connected to centre through-piece by two angle-irons 4 × 4 × $\frac{9}{16}$. The after-end of keel to have an angle-iron 6 × 4 on each side, and a plate ⅞ in. thick on the bottom, to run for 50 feet from the aftermost stern-post.

Stem.—To be made of plate in exactly the same manner as the keel, the plate on each side the centre through-piece to gradually taper to 9½ inches deep at the top, and all the bow-frames to be riveted to it.

Breast-hooks.—As may be required.

Stern-posts.—15 inches broad by 7 inches thick, and a heel left on the after-side to bear the rudder, with eyes for the pintles, and turned so as to form a knee forward on the keel. The screw-port to be forged in one piece to suit the drawing, or as the engineer may require.

Frames.—Of angle-iron, 5½ × 4 × $\frac{10}{16}$, and 20 inches from centre to centre. In engine and boiler spaces, the frames to be doubled in the bottom, and a reverse angle-iron on every frame, 4 × 3 × $\frac{8}{16}$, from floor to gunwale, the whole length of the vessel.

Practical Building.

Plates.—Garboard-strake, $\frac{14}{16}$ plates, as broad as can be procured, or worked; bottom-plates $\frac{13}{16}$, next plates up to the wales $\frac{13}{16}$, from the wales to gunwale $\frac{12}{16}$, except two plates, 2 feet 6 inches wide, $\frac{14}{16}$ thick, or one plate equal to this to form the wales; the sheer strake, $\frac{14}{16}$ thick, to be doubled right fore and aft, and butt-straps inside, as in single plates, all double riveted from keel to gunwale, and all butts to be flush; the upper or sheer-strake to go 12 inches above top of water-way, as per sketch. All spaces formed by the projections of the plates to be fitted with liners, so as to avoid small

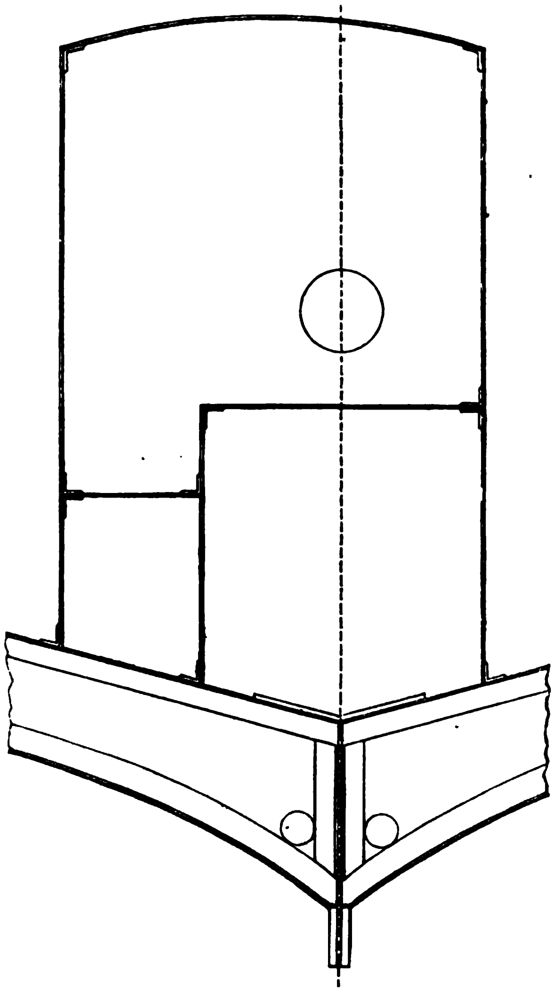

Fig. 51.

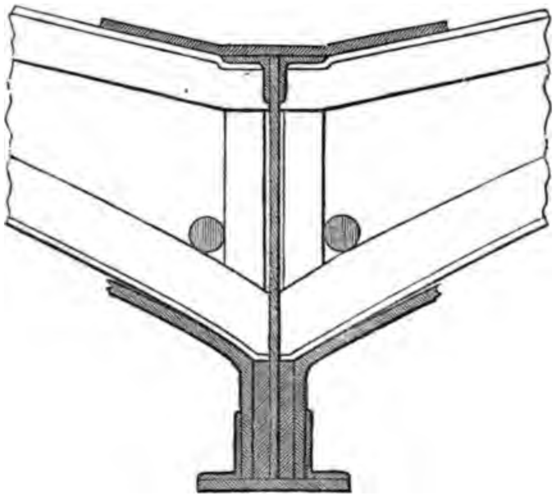

Fig. 52.

pieces and rings being used, except in the case of tne sheer and upper wale-strakes, which will be doubled, and the inner strake will necessarily form the liner. The butts to be perfectly close as well as the seams, as no pieces will be allowed to be put in and caulked over. The counter-sinking to be carefully done and all rivets to be full and smooth outside plates, and to be chipped down while hot. The greatest care to be taken in the punching, to prevent unfair holes.

Floors.—30 inches deep in engine and boiler spaces of $\frac{11}{16}$ plates, with angle-iron, 4½ × 3 × $\frac{7}{16}$, on each side, on top of every floor, to run from 14 to 16 feet up the turn of bilge. The floors in after-hold, 30 inches deep, $\frac{11}{16}$ thick, with single angle-iron on top, 4½ × 3 × $\frac{7}{16}$. The floor-plates to run 6 feet up the turn of bilge on each side of frames in one piece.

Keelsons.—As may be required, and to suit the engineer's drawings, to run right fore and aft as far as the form of vessel will allow.

Pillars.—In holds between keelsons and beams, to be 3½ inches in diameter amidships, tapering to 2½ at the ends. One on every beam, or as may be directed. Pillars on main-deck, one on every other beam, arranged so as to suit the cabin plan.

Bulkheads.—Water-tight; one in fore-peak, two before the engine, one abaft the boilers, and one in after-hold; to be in accordance with the Board of Trade regulations in every respect. To have iron-bulkheads, or floors, on every frame from stern-post for 40 feet, and on every frame from stem for 20 feet, the after ones ⅝ inch thick, the foremost ½ inch. Those abaft the aftermost water-tight bulkhead to run up to the lower-deck water-way plate, and an angle-iron on the top of each, with a water-tight deck, riveted to the same. The lower-deck water-way plate will run through these bulkheads, as well as the water-way forming part of the deck. Proper man-holes, cut through each floor above the shaft, and sufficient water-tight man-hole doors, fitted to the holes in the iron-deck. The floors before the water-tight bulkhead to run up as far above the shaft as may be required. Every other bulkhead, the length of screw-shaft, to have a forged iron-rim, 3 inches wide, 1 inch thick, riveted round shaft-space. The hole for shaft to be drilled from after-end through all these by the engineers. All water-tight bulkheads to be fitted with approved brass sluice-valves. The space below the screw-shaft, abaft the aftermost water-tight bulkhead, to be filled-in solid with bricks and cement. Iron-tie bulkheads to be placed, as directed, between main and spar-decks, about 20 feet apart.

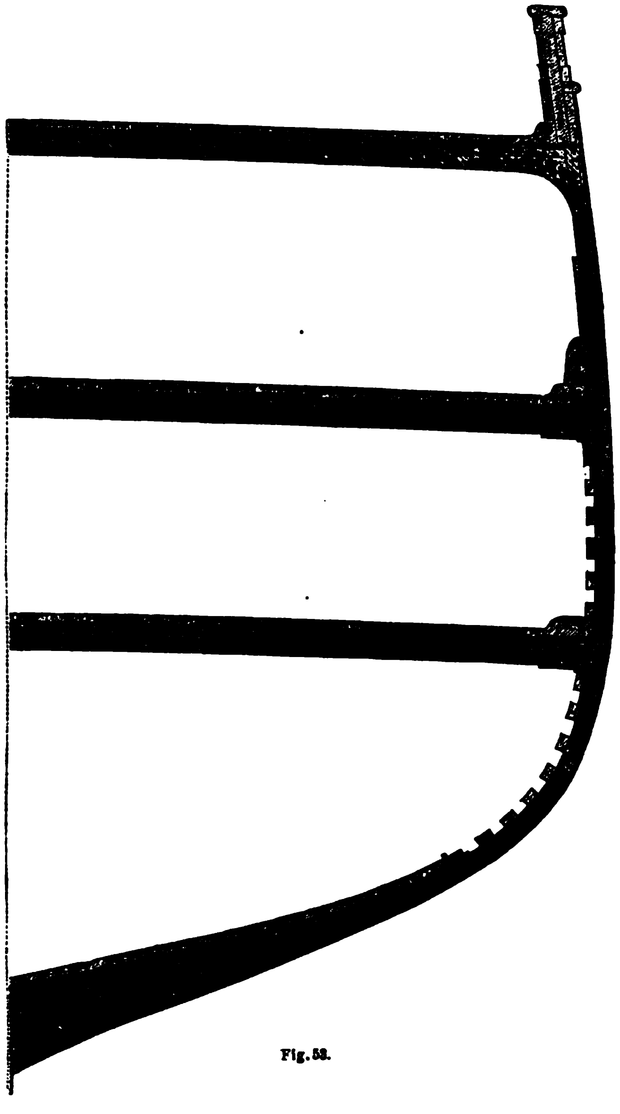
Fig. 53.

Beams.—Of plate, 10 × $\frac{7}{16}$, with two angle-irons on top, 3½ × 2½ × $\frac{7}{16}$. Beams not to be turned at the ends, but to have a vertical and horizontal plate, riveted to under side of beams and side-frames, with an angle-iron in the angle, and to be finished on the lower edge, with half-round iron, as may be required. An angle-iron on each alternate frame, for main and lower decks, with as many in the engine and boiler spaces as the position of the machinery will allow. To have orlop-beams and a deck to allow of such accommodation for stores as may be required (fig. 53). Engine-beams as the engineers may direct. Eight of the foremost beams to be made of an elliptical shape, turned down 2 feet 6 inches to strengthen the bow, and likewise for the hawse-pipes to pass through. The plate to be twice the thickness of the other beams.

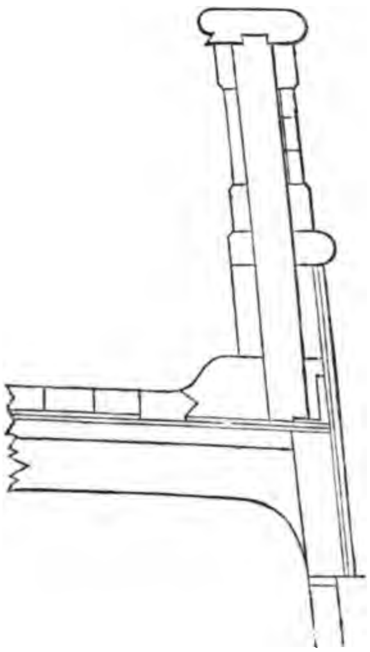
Fig. 54.

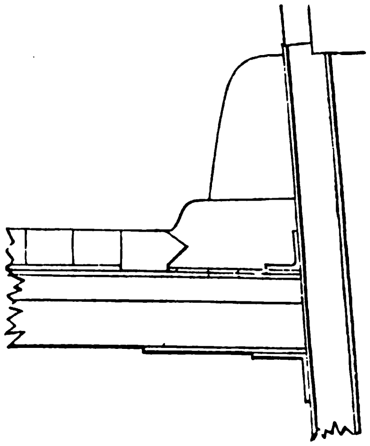
Fig. 55.

Stringers.—An angle-iron, 6 × 4, all round the gunwale, with two covering plates, the outside one 18 × $\frac{11}{16}$, the inside one 24 × $\frac{11}{16}$, riveted to gunwale stringer, and upper side of deck-beams, and 6 inches apart, to allow for pipes or scuppers to pass through the first plank from water-way, which is to be East India teak (figs. 54 and 55). The same on main and lower decks. The lower-deck plates to run right through engine-room and boiler space, and to have in that space an angle-iron top and bottom, and to be from the foremost to the aftermost midship water-tight bulkhead in engine-room $\frac{11}{16}$. Two midship deck-plates, of the same dimensions as the inside gunwale stringer, to run right fore and aft, full length of vessel, on each side of engine-room skylight, and riveted to upper side of deck-beams. To have at least 6 diagonal spar-deck plates, 12 × ½, riveted on top of all these stringers, to tie the sides of the vessel together, to be placed as may be required (fig. 56). The butts of all these fore and aft stringers to be placed so that the whole of them come on beams, and to have a butt-strap to each butt 12 inches in width, and a row of rivets on each side of the edge of the beams. A vertical stringer, 2 feet 2 inches wide, $\frac{11}{16}$ thick, to run round the main-deck at back of spirketting, and to be connected to side deck-plate, or horizontal stringer, by an angle-iron, 6 × 4 × $\frac{11}{16}$. All these fore and aft stringers and deck-plates to run fore and aft, and not to be disconnected or cut through anywhere, and all water-tight bulkheads, beams, or any athwartship work to be cut round them, and all to terminate at each end in plate-breasthooks of $\frac{1}{4}$ in. thicker plate than the stringers, and to run out as far from either end as may be required. A bilge-stringer, formed of two angle-irons, 6 × 4 × $\frac{11}{16}$, with a plate at back 18 × $\frac{9}{16}$, fastened to frames to run right fore and aft the ship. All stringers, vertical and horizontal, water-way plates, &c., to be doubled for 30 feet in way of cargo gangways.

Riveting.—The vessel to be all double riveted with $\frac{7}{8}$ rivets, except in keel and stern-post, which must be $\frac{1}{8}$th inch thicker than the plates they pass through.

Other Iron Work.—Iron casing round boiler space and stoke-hole, between main and upper-decks, likewise all coal-bunker bulk-heads (except what forms part of the engineer's contract). Coal-shoots and deck-plates for them, flat in bunker-bottoms, casing of bunkers, engine-beams, screw-tunnel, iron gratings over stoke-hole on upper deck, ash-bucket pipe from stoke-hole to spar-deck, with revolving cap on top, to be furnished by the contractors. A water-tight slide, at foremost end of screw-tunnel, to be fitted in accordance with the Board of Trade regulations. Preparation to be made for a lifting-screw on the most approved principles. The engineer to furnish all slides and lifting apparatus.

Topgallant Forecastle.—To be in accordance with the drawing given both in length and height, to be plated up from sheer-strake to top with $\frac{3}{8}$ iron-plates, and to be fitted up inside as may be directed. A manger, 3 feet deep, to be fitted forward, with 4 hawse-pipes, bucklers, plates, and all complete, as may be required by the company. The deck to be 3 inches thick, with iron-stancheons, and rails round the top-beams, 8 × $\frac{7}{16}$, bulb-iron, with 2 angle-irons on top, 3 × 3 × $\frac{9}{16}$. A water-closet on each side, the aftermost end outside, with pumps, and all complete for the crew.

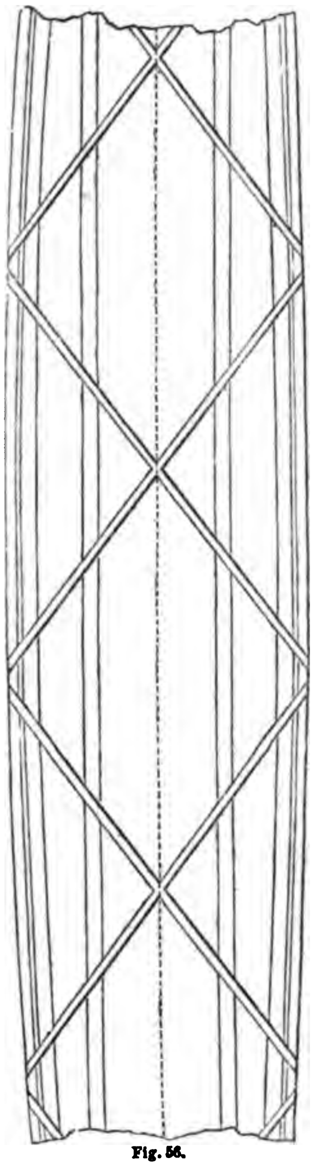

Fig. 56.

Inside Cement.—The vessel to be filled up solid to the limber-holes with Portland cement.

Quality of Iron.—Garboard-strake, sheer-strake, and longitudinal stringers, of Staffordshire B. B., of an approved maker, all the other plates of Staffordshire B., except curves, which are to be the best Lowmoor, or of iron made from best picked scrap equal to this.

Wood Work and General Outfit.

Upper or Spar Deck.—East India teak $3\frac{1}{2}$ inches thick, secured to beams by two $\frac{5}{8}$-inch galvanized iron bolts and nuts, let in $\frac{3}{8}$ths of an inch below the surface, and dowelled with wood. The midship's deck-strakes to be 1 inch thicker, and to run fore and aft, or as may be required.

Main Deck.—Yellow pine 6 × 5, caulked and secured with iron bolts and nuts as upper deck.

Lower Deck.—Yellow pine 9 × $3\frac{1}{2}$, caulked and secured with iron bolts and nuts as above.

Stancheons.—Teak or British oak 6 × 5. Stern timbers of the same 7 × 6, and to run well down, to give strength to the stern. All the other stancheons to run down on top of spar-deck, water-way plate through covering-board, and the space between underside of covering-board, and top of water-way to be filled in solid and caulked, and a piece of teak-spirketting inside of stancheon, bolted through and through, from outside of iron sheer-strake, except in those stancheons which come in way of boats' davits, which will have an angle iron knee to turn under water-way, inside of bulwarks, well riveted to water-way plate. Oak or teak spirketting 18 × 9, to run right round the main-deck inside, on top of water-ways.

Awning Stancheons.—Of iron, all round the vessel.

Water-ways.—Upper or spar deck, and main deck, to be East India teak 18 × 9, and, if required, to be fitted over the angle-iron stancheons.

Ceiling of Hold.—Flat of floor laid with 3-inch American elm, and from that to be ceiled with yellow pine, room and space to the main deck beams. The remainder to be 2-inch close futline, caulked, payed, and beaded over seams, as will be pointed out.

Bulwarks.—Yellow pine 3 × $2\frac{1}{2}$ thick, and to have a panel grooved in the centre.

Main-Rails.—Teak, 12 × $4\frac{1}{2}$; to have copper or yellow metal along the edge outside, fore and aft.

Gangways.—To be where shown on plan—viz. four cargo-gangway ports with all doors, brass scuttles, hanging platform to turn outside or inside as may be required, between main and upper decks, lined in sill and edges, with twenty ounces copper or yellow metal. Two passenger gangways on upper deck, fitted with the most approved accommodation-ladders complete, with all necessary fittings. Four coaling gangways on upper deck, fitted with doors complete; also hanging brackets riveted on ship's side, to carry stage when required. The ends of rough-tree-rail and gangways to be capped with a casting of brass.

Catheads.—British or African oak, 18 × 16, mounted with all stoppers, cleats, &c., as may be required.

Bitts.—Of British or African oak, 22 × 22, stepped on keelson. Towing bitts, topsail-sheet bitts, belaying pin-racks, cleats, eyebolts, timber-heads, &c., to be fitted as and where required.

Bridge.—To be 5 feet 6 inches wide, to be supported with sufficient iron stancheons, and fitted with ladders, lamp-boxes, handrails, and all complete, as may be required.

Masts.—Lower mast and bowsprit of iron or steel as may be approved, and a provision to be made for cutting them away if required, the other masts and spars to be of black spruce or red pine, to be rigged according to plan.

Rigging.—Standing rigging of wire-rope, the rest of best hemp, with all requisite blocks. All blocks to be brass-bushed, or patent leather bushes, as may be preferred; all dead eyes, both upper and lower, to be made of lignum vitæ; if required the vessel to be fitted with Cunningham's patent self-reefing topsails.

Storm-House.—To be built at after-end of upper deck, with two two-berth cabins on each side of wheel, with a water-closet in each, and fitted up inside in every respect as first-class cabins. The top of this house, as well as those of all other cabins and offices on the upper deck, to be double; the upper one teak, the lower one pine, covered with canvass.

Companions and Skylights.—To be built according to plan. The tops of all of them on the upper deck to be made of East India teak.

Boats.—To be in accordance with the Board of Trade regulations, and to be fitted complete, with masts, sails, oars, boat-hooks, breakers, gratings, davits for ship's sides, and all necessary fittings as may be required; brass rowlocks to mail-boat; life-boats to be according to Lamb and White's plan.

Fowl-Coops.—Twelve; 12 feet by 2 feet 4 inches high.

Sheep Pens.—To hold forty sheep.

Scuppers.—Eight on each side on each deck, to be placed where shown.

Fish-Davits.—For fishing anchors to be fitted, as will be shown.

Anchors and Chain Cables.—In proportion to tonnage of vessel, the anchors to be patent, or as required by the Board of Trade regulations.

Winches.—Two; if steam, the difference in price to be paid by the company.

Sails.—One suit of sails complete.

Tarpaulins.—One for each hatch and scuttle.

Awnings.—A complete set, fore and aft.

Pumps.—One copper chambered pump 8 inches in diameter, with brass bucket and lead pipe, fitted in every compartment, and a 7 inch and a 5-inch Downton, fitted as may be directed.

Wheels.—Two of mahogany, brass-mounted, hide-rope, fitted with patent steering gear complete.

Fenders.—With chains, &c., complete.

Ports.—Of East India teak, 21 inches square, with a 5-inch brass scuttle fitted in the centre of each, hung with strong iron hinges, brass-bushed, and copper pins, except where shown round in plan, as in water-closets or other deck-offices, where scuttles must be fitted, 7 inches in diameter, of the best manufacture.

Water-Closets.—Tylor's of Newgate Street to be fitted where shown on plan, with cisterns, pipes, valves, and all necessary fittings.

Baths.—Hot, cold, and shower, to be fitted where shown on plan.

Tanks.—For 12,000 gallons of water, with all requisite cocks, pumps, pipes, and all necessary fittings.

Binnacles.—Two, with adjusted compasses and lamps complete.

Brass Bell.—18 inches in diameter, with vessel's name engraved thereon.

Cook-Houses.—Two of iron, with all necessary fittings complete.

Cooking and Baking Apparatus—With all necessary utensils complete, as may be required to be furnished by the company.

Colours.—A complete set as may be required.

Life-Buoys.—Six of such description as may be required.

Lanterns.—Signal-lanterns and fittings to be fitted where required—viz., 2 bridge, 1 mast-head.

Buckets.—Twelve wash-deck and twelve leather buckets, with the company's crest and ship's name painted thereon.

Hose.—Leather fire-hose and canvass-hose for washing decks, with the necessary couplings complete.

Capstans.—Two; the foremost, or main capstan, to be one of Brown's patent double-headed capstans, to work on top of topgallant forecastle, with all the bitts, stoppers, &c., fitted complete on spar-deck. The after one to be Brown's patent double-power capstan for warping the ship, and to be fitted complete.

Meat-Safe and Vegetable Locker.—One of each to be made and fitted, as will be shown.

Butcher's Shop.—To be where shown on plan, slate-tanks, and all complete.

Cabins.—To be fitted according to plans furnished by the company, arranged generally as the "Pera" and "Candia." The contractors to find everything complete, except saloon and fore-cabin tables, seats, chairs, sideboards, sofas, bed and sofa mattresses, curtains, camp-stools, glass, earthenware, plated goods and cutlery; cabin-lamps and looking-glasses; pantry, steward's and store-keeper's utensils; but the contractor will find all the furniture and fittings for all the cabins and offices in the ship, including first and second class passengers, officer's, engineer's, steward's, and any other cabin in the ship, such as chests of drawers, washstands with marble tops, tables, toilet-shelves, or any other fittings that may be required; likewise all the different offices on deck, as shown in plan, to be fitted complete, such as surgery, lamp-room, baker's shops, scullery, or any other office not named here, but shown on plan. All the cabins in the ship to be fitted with Robinson's patent ventilating bulkheads, as per elevation.

Painting.—All the wood-work to have four coats. The main-deck cabins, from the main hatch forward, to be grained oak in the very best style. The main saloon to have at least six coats of paint and two of best varnish, and the whole of the gilding to be of the very best quality.

Mail-Room.—To be where shown on plan. Space for sixty tons of mail, and to be lined with zinc all over. The bottom to have ledges of wood, 3 × 2½, 12 inches apart, secured to deck.

Sail-Room.—To be where shown on plan, and to be covered over with zinc.

Purser's Store-Rooms.—To be where shown on plan, and to be fitted up inside as may be directed.

Boatswain and Carpenter's Store.—To be where shown on plan, and to be fitted up as shall be directed.

Finally.—The whole of the material and workmanship to be of the very best quality, and the vessel (with the foregoing exceptions) to be entirely fitted and ready for sea at the cost of the contractors, notwithstanding any omission in this specification, and subject to the approval of the managing directors, or of such surveyor or surveyors as they may appoint to inspect the work.

The following is a copy of the specification of an iron screw-steamship, built for the European and Australian Royal Mail Company. The Australasian was built in 1857, by Messrs J. and G. Thompson, of Glasgow, under the inspection of Mr Bowman, of London, who has kindly permitted its publication here. The strength of this vessel, and the soundness of the principles on which she is constructed, were well proved by her grounding in the Clyde, on her first passing down the river after being launched, when she came off, as before stated, quite uninjured.

Specification of an Iron Screw-steamship to be built for the European and Australian Royal Mail Company.

Principal Dimensions.

	Ft.	In.
Length of keel	310	0
Breadth of beam	42	0
Depth of hold to spar-deck	29	9
To have three decks, with full poop and full topgallant-forecastle		
Height of poop	8	0
„ topgallant-forecastle	6	3
„ from main to spar-deck	8	6

Keel and Keelson.—The keel to be formed of three thicknesses of plate; the centre plate to be 1 inch thick, and 45 inches deep; forming, at same time, the main keelson and centre of keel; these plates to be in as long lengths as possible, to be put together, butt-jointed, with straps of same thickness, and double-riveted above that part which forms a portion of the keel; the plates to run the entire length of the vessel, and for 10 feet up the stem. The keel side-plates to be 12 inches × 1⅛ inch; to be in as long lengths as can possibly be obtained; to be all scarphed on to each other, scarphs 6 inches long; these three thicknesses of plate, to be partially riveted together before the garboard-strake is fitted on; the garboard-strakes to be double-riveted to the keel with 1¼th inch rivets; all the holes to be runneled out perfectly true before riveting; the butt of the keel-plates and garboard-strakes to be carefully shifted and caulked, and made water-tight. (Section AB, fig. 59.)

Stern-post.—To be of best hammered scrap-iron in one piece, the after-post to be 12 × 5 inches, the inner-post to be 12 × 7 inches; the lower portion, uniting the two posts, to be 12 × 8 inches; and to have about 8 feet of keel attached to it, and with corresponding scarph for riveting to keel. The keel portion to be planed out into a groove, 1 inch wide and 6 inches deep, into which the keelson plate is to be worked, and double-riveted through and through. The end of the keelson-plate to be secured to the inner post by two vertical bars of angle-iron secured to it by rivets, and to the post by tapped bolts (fig. 57). The inner post, at the line of the lower deck-stringer, to have a palm welded to it, which is to be firmly riveted to the stringer, so as to give security to the post (fig. 58). To be formed in the same way as the keel, from iron of the same dimensions, and riveted together in the same way; the keel, keelson, floors, stem, and stern-post to be according to sketch to be furnished.

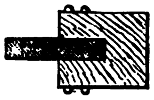

Fig. 57.

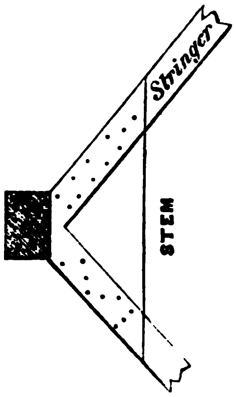

Fig. 58.

Frames.—To be spaced throughout the vessel 18 inches apart from centre to centre, of angle-iron, 4 × 3½ × ⅝th inch, to have a reverse angle-iron on every frame, 4½ × 3½ × ½ inch, riveted along the top of the floor-plates, and up the frames, to the height of the upper deck-beams, by ⅞th inch rivets, 6 inches apart (every alternate frame from main-deck may be left without reverse iron, a piece being put in underneath the clamp-plate). Where desired, in wake of boilers and engines, the frames and reverse bars to be worked double.

Floors.—The floor-plates at keelson or amidships to be 33 inches deep × ⅝th inch thick; to be carried up past the turn of bilge, say to the 6 feet water-line, and riveted to the frames and reverse angle-irons. The end of each floor, which butts against the keelson, to have a vertical angle-iron, 5 × 3 × ½ inch, riveted to the floors and to the centre keelson, (section CD, fig. 59). Along each side of the top of keelson-plate there will be angle-iron 5 × 5 × ⅝ths. riveted on a level with the top edge of keelson-plate and floors. A

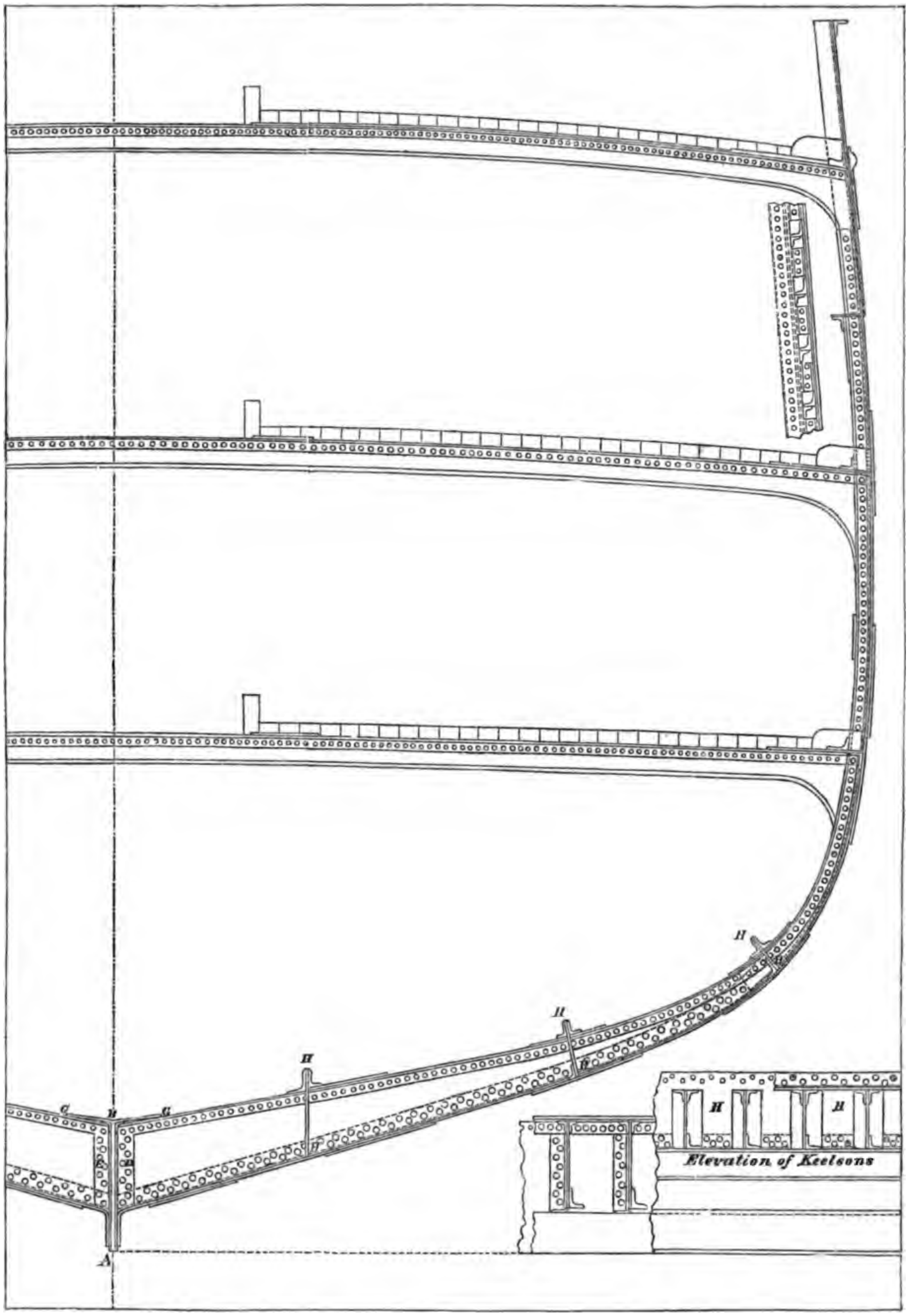

Fig. 59.

plate 36 × ⅞th inch in engine-room, and 36 × 11/16ths at ends of vessel, in long lengths, will run the whole length of the vessel, and be riveted to the angle-iron on top of keelson, and to the reverse angle-irons of the floors; these plates to be built jointed, and double riveted, section GG.

Keelsons—To have two side and two bilge keelsons, to be formed of plates 30 inches broad × ⅝th inch, riveted to the reverse frames. On the centre of these plates there will be double angle-iron 6 × 3½ × ⅝th, riveted back to back, and to the plates. From betwixt these angle-irons there will pass down to the skin-plate ⅝th inch thick, the breadth regulated by the distance apart of the frames and reverse angle-irons; these plates to be riveted at the foot to short pieces of angle-iron, secured to the skin, and at the top, betwixt the floor angle-irons, section H. H., &c., &c.; to have intermediate keelsons for about 150 feet amidships, to be double angle-iron 6 × 3½ × ⅝th inch, riveted back to back, and to the reverse angle-irons on the floors, and to be connected to the outer skin, same as the other keelsons, section H. H. The whole of the stringers, main, bilge, and other keelsons, to pass unbroken through the bulkheads, and to be made water-tight by strong brackets, riveted to them, and to the bulkheads.

	Fd.	200 feet Mid.	Aft.
Plating.—Garboard-strake to be fitted close up to the frames………	⅞	1 in.	1 in.
Next strake to garboard (to garboard)………………………………	¾	⅞	⅞
Thence to bilge………………………	11/16	¾	11/16
Bilge-strake………………………	11/16	¾	11/16
Thence to wales………………………	9/16	⅝ & 9/16	½
Wales in two strakes………………	⅞	⅞	⅞
Thence to sheer-strake……………	7/16	½	7/16
Sheer-strake at least 36 in. broad	⅞	1	⅞

The plating from keel to gunwale to be lap-jointed horizontally with vertical flush-butts, with an internal strap of corresponding thickness to the respective plates, 8 inches wide. The butt-straps of the sheer, wale, or garboard-strakes to be cut across the thread of the iron from plates, and to be 1/16th thicker than the plates to which they are respectively fitted. All the plates which end on screw-frames, and the next adjoining them on every strake, to be not less than 11/16ths thick, and double riveted, with very great care, to the stern-frame.

Riveting.—The keel, stem, stern-post, and all the longitudinal seams of the plates, up to the spar-deck, to be double riveted. All the butts throughout the ship to be double riveted. Double riveting to have about eight rivets to the foot. The bar-rivets, through frames and plates, to be spaced 6 inches apart, and the plating to be wrought out and in fashion; the space between each alternate strake, and the frame being filled with a solid sliver-piece closely fitted; all the rivets of keel, stem, and stern-post, to be 1⅛th inch diameter; those passing through inch plates to be 1 inch; through ⅞th plates, to be 13/16ths; through ¾th plates, ⅞th inch; remainder, ⅝th inch.

Caulking.—The whole of the seams and butts to be caulked in the most careful manner, and made perfectly water-tight; and on no account is any canvass, or red-lead, or like substance, to be inserted in the seams, but all to be caulked throughout, metal to metal.

Beams.—Main-deck beams, of patent bulb-iron, 10 × ⅝th inch; upper and lower deck-beams, of patent bulb-iron, 9 × ½ inch, all to be spaced on alternate frames; the upper, main, and lower deck-beams to have double, 3 × 3 × ½ inch angle-iron, securely riveted on top edge, with rivets 8 inches apart; all the beams to have suitable knees, solid, 18 inches deep, for securing them to the frames, formed by bending round the ends of the beams.

Stringers.—On the upper-deck, of plate, 42 × ⅝ths amidships, and 9/16ths at end, with angle-iron 8 × 3½ × ⅝th inch riveted to it, and to the deck-beams, and double riveted to the sheer-strake on the main and lower deck, of plate 36 × ⅝ths amidships, and 7/16ths at end with angle-iron, 5 × 3 × ⅝th inch, firmly riveted to the main and lower deck-beams, and reversed angle-irons, 2 feet below the main and upper deck-beams, to have a clamp-plate 18 × ⅝th inch, running the whole length of the vessel, and securely riveted to the reverse angle-irons on the frames, by rivets spaced 4 inches apart. All the butts to be double riveted.

Deck Trussing.—On the upper and main deck, on each side of the hatches, to have a plate 24½ inches, carried right fore and aft, worked in lengths of 15 feet, with double-riveted butts, the whole riveted to the beam angle-irons with ten rivets in each; the whole space from the outside edge of this to the inside edge of gunwale stringer on the upper-deck to be filled in with plate, wrought in long lengths, not less than 18 inches broad and a ½-inch thick (these plates may be ⅜-inch, and cover a space equal in weight to those plates specified).

All butt-jointed longitudinal straps single riveted, thwart straps double riveted; the whole riveted to the beam angle-irons with rivets spaced 4 inches apart.

Hold Stancheons.—From keelson to lower deck beams to have 3½ inches round iron stancheons, riveted securely to the keelson-plate and the beams; above these from lower deck to main deck to have 3 inches round iron stancheons, firmly secured to both tiers of beams where necessary

Bulkheads.—To have the number of water-tight bulkheads that may be required by the company, fitted between double frames and over keelson and stringers, supported by suitable bars of angle-iron 4 × 3 × ½, spaced 30 inches apart.

Bulkheads to be carried to main deck, and to be fitted in every respect in accordance with the Board of Trade regulations. Between the aftermost bulkhead, to which screw-propeller pipe is attached, and the stern-post, to have fitted on every frame, up to the height of lower-deck beams, a series of bulkheads formed of ½-inch plate, and firmly riveted to the frames, and secured on the top with double angle-iron; at this line breast-hooks, specified afterwards, are to be worked forwards to the pipe bulkhead, so as to form an iron deck above these bulkheads specified, and to be riveted to the double angle-iron on them. The hole for passing stern-pipe through to be carefully arranged, so that no more than necessary space is cut.

Rudder.—The stock to be 7½ inches diameter, with turned pintles, of best hammered scrap-iron, in one piece with the frames, and plated with ⅝ths plate.

Breasthooks and Crutches.—To be fitted at each deck, fore and aft the ship, at the junction of the stringer plates; bilge and side keelson formed by riveting triangular plates about 9 feet long to these fore and aft ties, so as to firmly unite the two sides of the ship.

Mast-Partners.—On the various decks to be formed of materials similar to the beams, and to be securely riveted to them.

Gunwale Moulding.—To be formed of 6-inch half-round iron in length, securely riveted to the upper edge of wale strake by rivets about 8 inches apart.

Water-ways.—On main and lower deck of red pine 4½ inches thick, and on the upper deck of East India teak 18 inches broad by 9 inches thick, both securely bolted to the stringer plates by two rows of bolts and nuts.

Decks.—To have three decks. Upper deck throughout where exposed to be of best East India teak 3½ inches thick, to be secured to the beams by bolts and nuts at every third beam, and with a wood screw of best form on both sides of the alternate beams, the whole to be planed true on the edges, top, and bottom before being laid, and thoroughly caulked and payed with resin or pitch, as may be directed by the company, and made perfectly water-tight; main-deck to be of best seasoned Quebec yellow pine 3½ inches thick, thoroughly secured to the beams by wood screws with bolts in the butts, thoroughly caulked, payed and made water-tight; lower-deck of 3 inches yellow pine to be similarly fitted.

Rails.—The rails to be of best East India teak of suitable breadth, firmly bolted to stancheons, to be covered on the outside and inside edge with 18 oz. yellow metal, firmly nailed; to have a netting all round of best cordage, firmly secured to galvanised iron rods on rail and water-way.

Bulwark Stancheons.—To be of East India teak, and to be fitted into sockets formed of angle-iron, 7 × 3 × ½; these to be riveted to the stringer plates at proper intervals for the stancheons, one bolt through each socket and stancheon.

Hatch Coamings.—On main, upper, and lower decks, of East India teak, of dimensions to suit the size of the hatches, and securely bolted to the iron carlines; to be protected by iron plates on sides and top, and fitted with iron battens, cleats, and cutbands; on upper decks to have teak skylights on the hatches.

Ceiling.—In flat of floor in holds of 2½-inch elm, thence to hold beams of 2-inch red pine from hold beams to main-deck beams, and cabins and store-rooms of 1-inch yellow pine close seamed; the ceilings to be bolted to reverse angle-irons with galvanised screw-bolts.

Ports.—To have four gun-ports on each side, with flaps properly arranged in netting, and fitted with ring-and-eye bolts as required.

Capstands.—To have one of Brown's patent capstands of suitable size, placed forward, with patent chain-stoppers, and four riding bitts complete for working cable; in addition, to have a cast-iron working capstand, with brass top on quarter-deck poop, both complete, with all necessary bars.

Catheads.—Of British oak, with anchor stoppers, and all usual fittings.

Bitts.—To have at least five cast-iron mooring timber-heads on each side, of suitable strength, properly bolted through water-ways and stringer plates, with heavy chocks of hard wood timber below.

Hawse-pipes.—To have a strong cast-iron hawse-pipe on each bow, of size to suit chains, firmly secured to the skin of the ship; also stern and side mooring pipes of cast-iron where required, and firmly secured.

Chain-Lockers.—To be built of wood where required.

Anchors and Chains.—To have anchors and chains; the chain cables of best best iron, and to be tested to the government test. Hemp-warps according to Lloyd's rules.

Anchor-Davits.—To have two strong anchor-davits, with blocks and falls complete for lifting anchors.

Pumps.—To have a pair of 6-inch Redpath's patent pumps in each compartment, with lead-pipes and roses, and all the necessary iron gearing for working.

Scuppers.—To have sufficient lead scuppers on upper and main deck, well secured to ship's side and water-ways.

Tanks.—To have suitable iron tanks made of quarter plates, capable of containing 10,000 gallons of water, with two fixed copper pumps with brass boxes, lead pipes, and iron gearing complete for working, and placed where required.

Masts and Spars.—To be rigged as a ship, with one complete set of masts and spars according to plan; lower masts and bowsprit of yellow, red, or pitch pine in one stick, or built and hooped if necessary; topmasts, lower and topsail yards, and jibboom to be of red or pitch pine, the remainder of black spruce; to be all according to plan, and complete with all usual iron work of best quality.

Rigging.—All the standing rigging to be of galvanised wire, the running rigging to be of the best St Petersburg or Manilla hemp and chain where required, chain of best best iron.

Blocks.—To have a complete set of iron and rope stropped blocks of suitable sizes, the lower and topsail yards brace blocks, topsail peak and throat haulyards, catblocks, &c.; to have Dalton's patent roller bushes in the sheaves, the standing rigging to be set upon lignum vitæ dead eyes of proper size; to have all necessary snatchblocks, catblocks, watch-tackles, and belaying-pins of greenheart.

Sails.—To have one complete suit of sails, the topsails to be fitted with Cunningham's patent reefing apparatus according to plan, of Gonvock extra canvass, with suitable Nos. complete, ready for bending with sail covers as required.

Iron Work.—All the small iron work of the hull to be furnished complete of the best quality.

Boats.—To have at least six boats, according to Act of Parliament, complete with strong iron davits, tackle falls, &c., as usual. The boats to be supplied with ash oars, rudders, tillers, and boathooks, and the four largest to have masts and sails.

All the boats to be supplied with canvass covers and gripes as required; the four midship boats to be carried inboard on beams of proper strength, and properly supported on iron stancheons from the rail, and to be fitted with patent lowering apparatus to a plan to be furnished.

Gangways.—To have properly-fitted gangways opposite to each hatch for receiving cargo; to have on each side a passenger-gangway, with suitable accommodation-ladders, davits for lifting, iron railings, and man-ropes.

Coaling-Ports.—To have fitted along ship's side, between upper and main-decks, the number of coaling-ports that may be afterwards found necessary, properly hinged, so as to be perfectly watertight when closed, and fitted with strong iron shoots inside, communicating, by grated openings, with the upper-decks and with coal-boxes.

Painting.—The outside of the ship to receive three coats of the best oil paint, the inside two coats, except the bottom, which is to be coated with patent cement. The woodwork on deck to receive three coats, and to be grained in imitation oak. Masts and spars to receive two coats of paint or varnish. Cabins and internal fittings to be painted in the best manner, as may be afterwards directed.

Winches.—To have three double-power cargo winches, with derricks and chains complete, for working cargo.

Side Lights.—To have two brass side lights in each state-room on main-deck and spar-deck, all securely riveted to ship's side, and made water-tight.

Bells.—To have a ship's bell and belfry, with name engraved on it, and binnacle-bell.

Binnacles.—To have two brass and one mahogany binnacle, with lamps.

Figurehead.—To have a handsome full-length figurehead, with trail-boards, stern and quarter carving, as may be required to suit name, all handsomely relieved with gilding.

Flags.—To have one ensign, one burgee, one union-jack, one blue-peter, one private signal, and one set of Marryatt's signals with chest and book.

Signal Lanterns.—To have complete set of Admiralty signal lanterns (brass, of large size).

Guns.—To have two brass 4-pounder, and four iron 9-pounder guns, with breechings, rammers, and sponge complete, with all the usual complement of muskets, pistols, and cutlasses.

Steering Apparatus.—To have a handsome double-steering wheel of E. I. teak, fitted with right and left handed screw-steering gear, brass nuts, malleable iron crosshead, connecting-rods, and screw. To have two portable tillers fitted to rudder-stock; wheel to be covered by a substantial house, with glass front.

Cook-House.—To have a spacious galley of iron fitted on main or spar-deck, near funnel, with the most improved form of cooking apparatus and baking ovens for crew and passengers; the woodwork of the galley to be lined with 5lb. lead and felt, and the floor to be covered with fire-tiles, and to have proper ventilators on sides and top.

Poop.—To have a poop to extend from after-part of vessel to after-part of after-hatch, about 90 feet long; in forming the poop, every alternate frame of the vessel to be carried up, to which are to be joined the beams of the poop, same size of iron as the frames. The sides and after-end of the poop to be rounded over and plated with ⅝ plates, the poop-deck to have teak water-ways, 12 × 5; teak decks, 3″ × 5″. The whole fastened to the beams with bolts and screws, every butt to have a screw-bolt. Stancheons of galvanised iron to be carried round the poop, with a teak rail on top. The poop to be fitted with suitable skylights, made of teak, fitted in the best style for light and ventilation; also to have round or square side lights in state-rooms, as may be required; to have side stairs, with brass rails, from the upper deck. The inside of poop to be fitted up in first style for passenger accommodation, and in accordance with a plan to be approved; to have two bath-rooms; also a water-closet for every eight passengers, side state-rooms, ladies' sitting cabin, captain's cabin and steward's pantry, with all the necessary furniture and fittings; the whole of the very best description of workmanship and material, as usual in large passenger steamers of the first-class.

Main-Deck.—On the main-deck a dining-room, to be entered by a spacious stair, either from inside of poop or from upper-deck, to be fitted with all the necessary furniture; a full set of dining-tables, sofas, settees, and chairs covered with morocco; to have mirrors, carpets, sideboards, stoves, lamps, swinging trays, &c., &c., and to have side state-rooms for first-class passengers, with carpets, curtains, sofas, wash-stands, &c., the whole arranged to a plan to be approved of.

Second-Class Accommodation.—To be fitted on main-deck forward for 100 passengers, with a water-closet for every 12 passengers, bath-room, &c. Saloon under spar-deck, of polished E. I. teak, with tables, settees, &c. The steward's bar and other conveniences all in the best manner.

Deck-House.—To have a strongly-fitted deck-house, as large as possible, consistent with other deck arrangements; to be constructed with iron-frames and beams, made fast to strong teak coamings, bolted to the deck-beams. The deck of the house to be of 2½ inches yellow pine, with a side covering board to form moulding, of E. I. teak; the sides and ends to be of 1½ inch yellow pine, half checked or feathered, and grooved; the house to be fitted according to a plan to be arranged and approved.

Officers' Accommodation.—To have accommodation for the officers, engineers, stokers, and stewards, with a sufficient number of water-closets and other conveniences, fitted on main-deck, between the first and second-class cabins, with separate ladder-ways, all as may be afterwards arranged.

Topgallant Forecastle.—To extend from the back of the figurehead of vessel to the fore side of the fore-hatch, being about 68 feet in length, and in height about 6 feet to 6 feet 6 inches; every alternate frame of the vessel at forecastle to be carried up to deck of forecastle, with reverse angle-irons, 4 × 3 × ½ inches, by piecing the present frames; to have an angle-iron stringer, 4 × 4 × ½ inches, with plates 18 × ½ inches. The beams to be of bulb-iron, 7 × ½, placed on every frame; these beams to be turned down at ends, to form knees, same as the other beams of the vessel; the beams to have an angle-iron, 2½ × 2½ × ⅜ inches, riveted on each side, for fastening down decks; to have two beam-ties riveted on top of plates, 12 × ½; and that part of the forecastle deck where capstan comes through, to be all plated between the beam-ties; same to extend a sufficient length for strengthening that part of capstan; plating to be $\frac{7}{16}$ths thick, and to extend from gunwale of vessel to top of forecastle, and the whole length of forecastle with double riveted butt-joints. The decks to be of teak, 5½ × 3 inches, with teak water-ways, 12 × 4½, well fastened down, caulked, and made water-tight; the part of deck at capstands to be well fastened and strengthened with teak planks, of increased thickness to those on deck; the top of forecastle to be fitted with all the necessary chocks, &c., required for a vessel of this class. The capstand for anchors to be double, and wrought on topgallant forecastle; but the stopper and riding-bitts to remain on spar-deck, as originally intended. The front of forecastle to be neatly closed in and panelled, equal to bulwarks of vessel. The interior to be fitted up for crew, as may be directed by owners, with suitable brass aide lights for ventilation.

Forecastle.—The crew to be accommodated in forecastle, under spar-deck, with berths, mess tables, &c., as may be required.

Lower-Deck Fittings.—The lower-deck, forward and aft, to be fitted with bullion-room, mail-room, wine-cellar, store-rooms, &c., as may be directed, all in the most approved manner.

On the main-deck, forward of second-class cabin, the remaining space to be fitted with butcher's shop, cabin for petty officers, and other necessary fittings, as may be directed.

Skylights.—The second-class cabin to be lighted and ventilated by skylights, fitted on cargo hatches, with suitable gratings, and other particulars as required.

Sundries.—All the locks, hinges, hat-hooks, &c., to be of brass, and fitted as required, and of the best description; to have complete sets of lamps for all the cabins, locks and bars for all the hatches and store-rooms; hen-coops, sheepfold, pig-sty, sets of capstand bars for both capstands; four 60-gallon water-casks four harness-casks, twenty-four buckets, twenty-four mess kids; four water-funnels, six breakers, four deck-tubs, and four tar-buckets; awnings for quarter-deck, with iron stancheons, binnacles, and bell-covers; skylight-covers and tarpaulines as required; iron bell-mouthed ventilators, and windsails for engine-rooms where required.

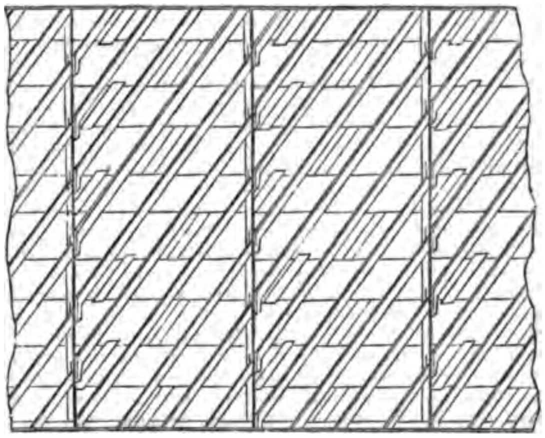
Fig. 60.

Taylerson's diagonal framing.

Messrs Taylerson and Company, of Port-Glasgow, have patented a diagonal arrangement of the frames of iron vessels. They substitute diagonal framing in the place of the ordinary vertical framing, or intersperse diagonal with vertical frames. The annexed figure shows the latter system of arrangement. No addition of strength, however, to the side of a ship will obviate the necessity for strength in the bottom and in the deck. If rupture were to take place at the top edge of the side, it may be doubted whether the diagonal frame would do more than divert the line of rupture into the sloping line between itself and the next frame. The same builders use a remarkably strong form of keel and keelson (fig. 61); and a representation of this is annexed, showing at the same time their mode of attaching the water-tight bulkheads; they introduce a piece of timber at each bulkhead, where it is attached to the ship's side, and fasten this by screws from the outside, with a view of lessening the number of rivet-holes. This most desirable object is no doubt attained, but great care must be taken that corrosion of the fastenings does not take place.

Arman's mixed system of wood and iron.

Mr L. Arman, of Bourdeaux, has constructed ships with diagonal iron framing inside a framing of wood of very light scantling, the sheathing of the ship being of wood. Inside the vessel, and attached to the iron frames, he introduced a series of horizontal stringers of plate-iron at intervals from the deck to the keelson, which is also of iron. This system imparts great strength to the framework of the vessel, and it is believed that it has, upon the whole, been very successful. Altogether the combination of wood with iron has been carried much further in France than in this country. Iron beams are being much used in their vessels, and iron rudder-pieces, the latter being very advantageous in men-of-war, from their smaller size.

Effects of Lloyd's register in ship-building.

Before closing these remarks, the influence or effects exercised upon the practical construction of ships by the rules of Lloyd's register require to be noticed, as they form a code of instructions to which all merchant-builders of this country are compelled to adhere. These rules are stated to be compulsory, because if a builder deviates from them, or ventures to differ in any point from the opinions of the surveyor, his vessel loses caste, either by being excluded altogether from the first class, or by being put on it for a less term of years. This does not suit the purchaser, and as there is no appeal from the decision of the surveyor, the builders must submit. In the first place, it may be remarked, that there is but one table of scantlings, &c., for ships of the same tonnage, while it is evident that the same rules as to scantling, &c., cannot be correct for the sharp long ship intended for carrying light cargoes, such as tea, wool, &c., and also for those which are intended for heavy dead-weights. Nor is any difference permitted in the scantlings of the timbers at the bow and at the stern of full or sharp ships. The rules do not directly interfere with the forms of ships, but in some respects they have undoubtedly indirectly militated against the production of fast-sailing vessels.

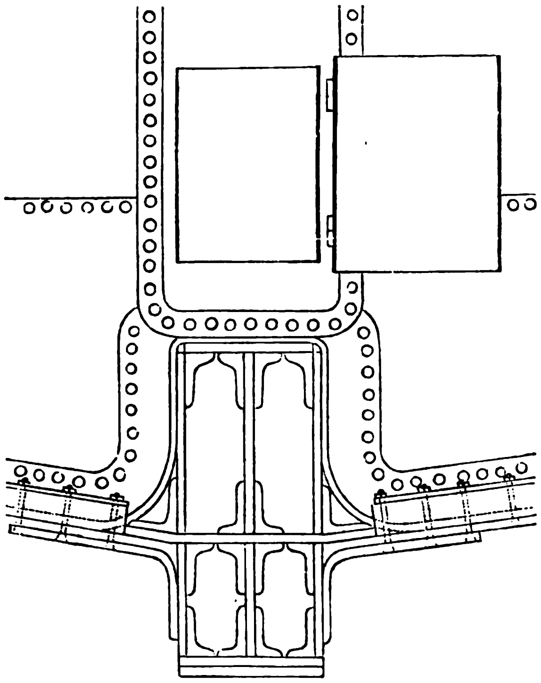
Fig. 61.

The supporters of Lloyd's register claim to themselves the credit of having improved the British mercantile marine; but, in the opinion of many experienced persons, its effect has been to produce a dead and spiritless mediocrity. That the construction of many very bad ships is greatly prevented is true, but there is no actually compulsory law to force every ship to be inspected and classed at Lloyd's, and many ships are sailed independent of any such inspection: its action in this respect, therefore, is not complete. On the other hand, it is equally true, that men of skill and talent are restrained from introducing improvements in the combination of materials. That this is the effect produced is well known; and as an instance, it may be mentioned, that on the first proposal being made to introduce iron beams into a wooden vessel, leave was refused unless the vessel was put into a lower class; and this improvement, which is now fully admitted by Lloyd's, was kept back for many years. It is natural that the general feeling of servants of the government, or of large public or joint-stock companies, should be against taking responsibility upon themselves by introducing or permitting changes; but it is much to be deplored if this spirit is brought into such a position as to be a drag upon the talent and energies of the whole nation. Shipowners who are not themselves practically acquainted with ship-building, take the natural course of adopting Lloyd's register as their standard. They contract for a ship to be built in such a manner that she may be put into the first class at Lloyd's, and they thus declare themselves ready to pay the cost of the builder's adherence to Lloyd's rules.

The ship-builder knows, perhaps, that he could introduce improvements, but he is unwilling to subject himself to the risk of a refusal by Lloyd's surveyors, and as the purchaser for whom he is working is satisfied, he builds accordingly. The want of encouragement by Lloyd's rules to increase the durability of ships has been before noticed. Under the existing rules, then, there seems to be reason to fear that the tendency of Lloyd's register has been to some extent to cause increased expenditure, to restrain improvement, and to uphold a dead and stagnant mediocrity. It is to be hoped that care will be taken to guard against the possible existence of such evils for the future.

On Launching.

Launching.

Ships are generally built on blocks which are laid at a declivity of about $\frac{5}{8}$ths of an inch to a foot. This is for the facility of launching them. The inclined plane or sliding plank on which they are launched has rather more inclination, or about $\frac{7}{8}$ths of an inch to the foot for large ships, and a slight increase on this for smaller vessels. This inclination will, however, in some measure, depend upon the depth of water into which the ship is to be launched.

While a ship is in progress of being built, her weight is partly supported by her keel on the blocks, and partly by shores. In order to launch her, the weight must be taken off these supports, and transferred to a movable base; and a platform must be erected for the movable base to slide on. This platform must not only be laid at the necessary inclination, but must be of sufficient height to enable the ship to be water-borne, and to preserve her from striking the ground when she arrives at the end of the ways.

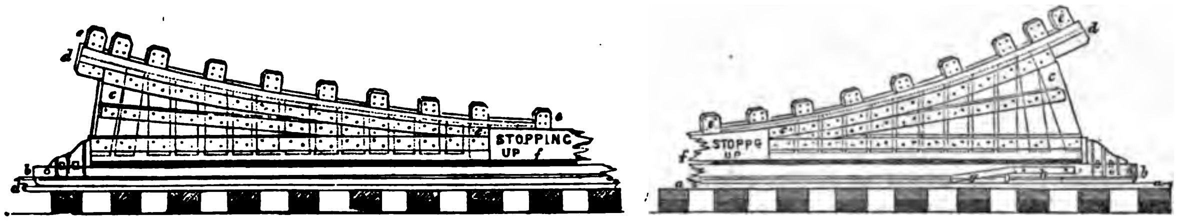

Fig. 62.

For this purpose, an inclined plane, *a*, *a* (figs. 62 and 63), purposely left unplaned to diminish the adhesion, is laid on each side the keel, and at about one-sixth the breadth of the vessel distant from it, and firmly secured on blocks fastened in the slipway. This inclined plane is called the sliding-plank. A long timber, called a bilgeway, *b*, *b*, with a smooth under surface, is laid upon this plane; and upon this timber, as a base, a temporory frame-work of shores, *c*, *c*, called "poppets," is erected to reach from the bilgeway to the ship. The upper part of this frame-work abuts against a plank, *d*, temporarily fastened to the bottom of the ship, and firmly cleated by cleats, *e*, *e*, also temporarily secured to the bottom. When it is all in place, and the sliding-plank and under side of the bilgeway finally greased with tallow, soft soap, and oil, the whole framing is set close up to the bottom, and down on the sliding-plank, by wedges, *f*, *f*, technically called slivers or slices, by which means the ship's weight is brought upon the "launch" or cradle.

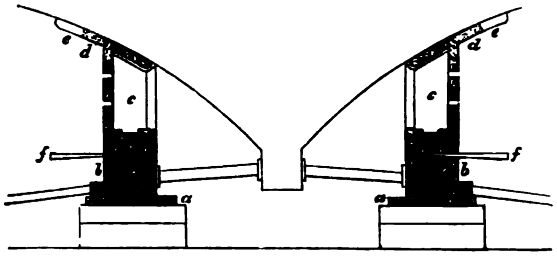

Fig. 63.

When the launch is thus fitted, the ship may be said to have three keels, two of which are temporary, and are secured under her bilge. In consequence of this width of support, all the shores may be safely taken away. This being done, the blocks on which the ship was built, excepting a few, according to the size of the ship, under the foremost end of the keel, are gradually taken from under her as the tide rises, and her weight is then transferred to the two temporary keels, or the launch; the bottom of which launch is formed by the bilgeways, resting on the well greased inclined planes. The only preventive now to the launching of the ship is a short shore, called a dog-shore (*g*), on each side, with its heel firmly cleated on the immovable platform or sliding-plank, and its head abutting against a cleat (*h*), secured to the bilgeway, or base of the movable part of the launch. Consequently, when this shore is removed, the ship is free to move, and her weight forces her down the inclined plane to the water. To prevent her running out of her straight course, two ribands are secured on the sliding-plank, and strongly shored. Should the ship not move when the dog-shore is knocked down, the blocks remaining under the fore part of her keel must be consecutively removed, until her weight overcomes the adhesion, or until the action of a screw against her forefoot forces her off.

Launching on the keel.

A much less expensive mode of launching is now much practised in the merchant-yards of this country, and has been long in use in the French dockyards, allowing the keel to take the entire weight of the vessel. The annexed figure represents this method (fig. 64). The two pieces (*a a*), which are shown in the figure as being secured to the ship's bottom, are the only pieces which need be pre-

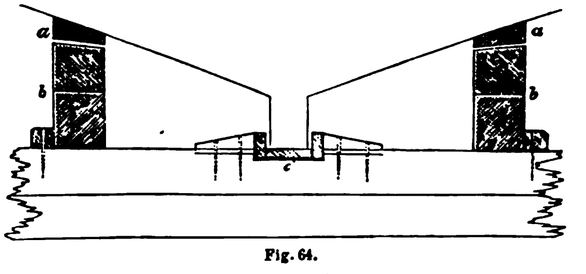

Fig. 64.

pared according to this system for each ship, the whole of the remainder being available for every launch. A space of about half an inch is left between them and the balk timber placed beneath them, as it is not intended that the ship should bear on these balk timbers in launching, but merely be supported by them in the event of her heeling over. The ship, therefore, is launched wholly on the sliding-plank (*e*), fitted under the keel. Messrs Hall of Aberdeen launched a vessel of 2600 tons in this manner without a single cleat upon her bottom or riband of any kind, and avoided all the making-up of the side-ways, except for about 60 feet in midships for keeping the ship upright. The centre-way was hollowed, and a round sliding-way fitted in it, and the keel was thus supported from end to end. This may therefore be considered to be the safest, cheapest, and easiest mode of launching long sharp ships.

If a ship is coppered before launching, so that putting her into a dry-dock for that purpose becomes unnecessary, it is then desirable that she should be launched without any cleats attached to her bottom. This method of fitting the launch, as represented in figure 65, is then adopted for this purpose. The two sides of the cradle are prevented being forced apart when the weight of the ship is brought upon them by chains passing under the keel. Each portion of framework composing the launch has two or more of these chains attached to it, and each chain is brought under the keel, to a bolt *a*, which passes slackly through one of the poppets, and is secured by a long forelock *b*, with an iron handle (*c*), reaching above the water-line, so that when the ship is afloat it may be drawn out of the bolt. The chain then draws the bolt *a*, and in falling trips the cradle from under the bottom. There should be at least two chains on each side secured to the fore-poppets, two on each side secured to the after-poppets, and two on each side to the stopping up, and this only for the launch of a small ship: in larger ships the number will necessarily be increased according to the weight of the vessel and the tendency that she may have, according to her form, to separate the bilge-ways. This tendency on the part of a sharp ship by a rising floor, or by her wedge-shaped form in the fore and after bodies, is great, but there is not much probability of a ship heeling over to one side or the other.

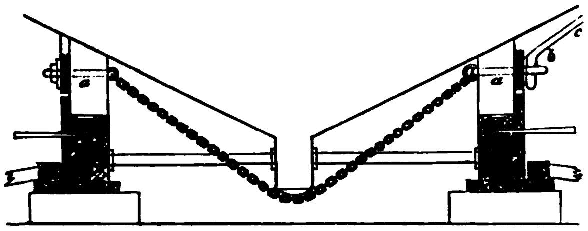

Fig. 65.

It is recorded that upon one occasion of our sailors having taken possession of an enemy's arsenal, and finding a vessel on the stocks nearly completed, they removed the shores from one side, and tried to upset her by wedging up the shores on the other side, but were unable to do so. There appears, therefore, to be no valid objection to the cheaper and more ready method of launching on the keel. (A. M—Y.)

STEAM SHIPS.

Of the various triumphs of man's ingenuity for which this age is so remarkable, none, perhaps, has conduced more to the wellbeing and happiness of the human race than the art of Steam Navigation. This is apparent when we consider the vastly extended means of communication which we now enjoy with the most distant parts of the globe; the fresh impulse given to commercial undertakings by the rapidity, the safety, and the certainty of steamships, as compared with sailing-vessels; and the increasing spread of civilization and Christianity attendant upon our intercourse with distant and semi-barbarous nations. It is not wonderful, therefore, that the merit of having invented an art so pregnant with interest to mankind should be claimed for many different individuals; and we accordingly find the names of ingenious men of all countries associated, more or less, with its origin.[1]

Paddle-wheels used by the ancients.

Blasco de Garay, 1543.

The use of paddle-wheels, propelled by manual or animal power, dates back to a very remote period, these having been employed by the Romans, and other nations of antiquity, for propelling their war-galleys; but it is doubtful whether any advantage was thus obtained in economy of labour, as compared with the use of oars. It is not, therefore, until the gradual development of the steam-engine, and its introduction as a motive power, that we can hope to find any advancement in the long-sought-for art of navigating ships against adverse winds and currents. The first historical notice we meet with of such a combination—a steam-engine placed on board a vessel to act as the propelling agent—occurs in the year 1543, when we are informed that Blasco de Garay, a sea-captain in the service of Charles V. of Spain, succeeded in propelling a ship of 200 tons burthen in the harbour of Barcelona, at the rate of a league (or three miles) an hour. No information is afforded us of the nature of his apparatus, except that it comprehended a boiler, which, it is stated, was liable to burst; that the power was transmitted through paddle-wheels, and that the vessel could be turned with much facility by means of the apparatus. We can only speculate as to the nature of this mysterious engine, but it seems probable that it owed its efficacy to the reaction of a jet of high-pressure steam, on the same principle as that famous classical toy, the Æolipile of Hero, invented B.C. 120. Notwithstanding that the scheme was commended by the emperor and his ministry, and its author promoted, we do not read of any second experiment being made, or of any further notice being taken of the invention. We may assume, therefore, that in this case the propelling power was found to be insufficient and unsatisfactory, and the experiment was worthless in its result.

Dr Papin, 1681.

In the year 1630, David Ramsey, "page of the king's bed-chamber," obtained a patent "*To make boats, ships, and barges goe against the wind and tyde,*" but we do not hear of any experiments having been made by him. The patent office contains records of various similar suggestions made between the years 1630 and 1681, but nothing of any practical value appears to have been effected. At the latter date the ingenious Dr Papin, a Frenchman, described a method of propelling a vessel by steam. The only engine then known, however, being itself very crude and imperfect, the doctor experienced so much difficulty in reducing his scheme to practice, that it is believed no actual trial of it ever took place. His principal difficulty lay in obtaining the required rotatory motion from the reciprocating one of the piston, for which purpose he proposed to employ two cylinders, the piston of one of which should be ascending, while that of the other should be descending, the continuous rotative motion being obtained by means of racks attached to the extremities of the piston-rods, working *alternately* into a pinion on the paddle shaft. Although Dr Papin's schemes can only be viewed in the light of theoretical suggestions, he still deserves much credit both for his idea of the atmospheric engine, and for his proposal to employ it for working the paddles of a boat. Savery, on the other hand (who published his *Miner's Friend* in the year 1698), although a great actual improver of the steam-engine, and famous in his day as a clever mechanician, appears to have doubted the applicability of his engine to the propulsion of ships, since he only alludes cursorily to the possibility of such a thing.

Newcomen, 1705.

In the year 1705 Newcomen, having adopted Papin's suggestions of the cylinder and piston, and Savery's method of condensation, first completed the atmospheric engine, and made it *capable* of becoming, in practical hands, an efficient propelling power; and it is worthy of remark, that even at the present day, we have several excellent paddle-wheel steamers which are most satisfactorily propelled by modern atmospheric engines, constructed by the late Mr Seaward. The great engineering difficulty at this period was how to convert the reciprocating motion of the piston into the rotary motion of the shaft; for although, to our eyes, the *crank* may appear a very simple and almost self-evident expedient for this purpose, it was not till long afterwards that we find it introduced.

Jonathan Hulls, 1736.

In the year 1730, Dr John Allen proposed to propel a vessel by the re-action of a jet of water forcibly expelled from the stern—a scheme which has been repeatedly revived since his time, and which has recently been attended with a considerable amount of success in the hands of Mr Ruthven of Leith. Six years after Dr Allen's proposal, Jonathan Hulls obtained a patent for his "*Invention of a machine for carrying ships and vessels out of or into any harbour or river against wind and tide, or in a calm.*" His idea of a steam-boat was as follows; and however we may now be inclined to smile at his rude mechanism, in comparison with the beautiful machinery of a steamship of our own times, Jonathan Hulls undoubtedly deserves much credit for his ingenuity. In his boat two paddle-wheels were suspended in a frame projecting from the stern. In the body of the boat were two steam cylinders, whose pistons acted on the atmospheric principle; that is to say, they were impelled in one direction only, by the pressure of the atmosphere acting against a vacuum. To each piston one end of a rope was fastened; the rope was then carried round a grooved wheel or pulley on the corresponding paddle-wheel, the other end of the rope being allowed to hang free, with a weight attached to it. When one of the pistons descended in its cylinder by the pressure of the atmosphere, it pulled its rope, and consequently moved the paddle-wheel round in a degree due to the length of the stroke and the diameter of the pulley. While the piston was ascending in the cylinder, on the re-admission of the steam, the counter-balance weight at the end of the rope dragged the pulley round in the contrary direction; but the pulley being attached to the paddle-wheel by

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[1] The historical portion of this article is indebted to Professor B. Woodcroft's *Sketch of the Origin and Progress of Steam Navigation* for some valuable facts.

ratchet-work, it was so arranged that the paddle-wheel remained stationary during the retrograde motion of the pulley. There being two cylinders and two paddle-wheels in the boat, one would be in motion whilst the other was stationary, and thus a continuous progressive movement was given to the boat. It is uncertain whether this plan was ever put in practice.

James Watt, 1780.

We now arrive at the era of James Watt, whose inventive genius removed most of the obstacles which had hitherto prevented the steam-engine from being effectively employed for propelling vessels. His main improvement, after his invention of the separate condenser, was the substitution of the double-acting in place of the single-acting or atmospheric engine, by which means the power of an engine of given size and weight was at once doubled, while the motion was at the same time rendered more uniform. About this time also (1780) the crank and fly-wheel were first patented by James Pickard. Although Watt's improvements rapidly paved the way for the successful adaptation of the steam-engine to the purposes of navigation, we do not find that he himself devoted much attention at first to this subject, confining his views to perfecting the rotatory-engine, and increasing its economy. Accordingly, we find that it was not till after the expiry of their patent in 1800 that Boulton and Watt's engines were applied to this use.

In the year 1781, the Marquis de Jouffroy constructed a steamboat at Lyons of the following dimensions:—140 feet long, 15 feet beam, and 3·2 feet draught of water. His experiments, which were made in the river Soane, were probably unsuccessful, as the subject was allowed to drop.

Miller of Dalswinton, Taylor, and Symington. 1788.

Leaving undescribed some abortive schemes of Ramsay and Fitch in America, and Serrati in Italy, which were attended with no practical result, we pass on to the first really successful attempts at steam navigation, which were made in 1788 by a Scottish gentleman, Patrick Miller of Dalswinston, in Dumfriesshire. Having previously experimented with boats propelled by the power of men and horses applied to paddle-wheels, he resolved to make the steam-engine do this work; but neither he nor Mr James Taylor, who resided in his family as tutor, and assisted him in his experiments, could devise a plan for applying the engine. In this dilemma Taylor suggested that they should call to their assistance an old schoolfellow of his, Mr William Symington, an engineer, at that time employed in endeavouring to adapt the steam-engine to wheeled carriages. Mr Miller accordingly saw Symington in Edinburgh, and, after examining the model of his locomotive carriage, was convinced of the perfect applicability of a similar engine to drive the paddle-wheels of a boat, and gave orders for one to be made under the direction of Symington and Taylor. This engine was accordingly made in Edinburgh, sent to Dalswinton, and put together by them in October 1788. The engine, in a strong oak frame, was placed on one side of a twin, or double pleasure-boat, on Dalswinton loch; the boiler was placed on the opposite side, and the paddle-wheels in the middle. In the same month of October the machine was put in motion, and the inventors had the gratification of witnessing the perfect success of their efforts. Although the cylinders of their engine were but 4 inches in diameter, this first steamboat attained a speed of 5 miles an hour on the waters of the lake.

Mr Miller, being now desirous of trying the experiment on a larger scale, commissioned Mr Symington to purchase one of the canal-boats employed on the Forth and Clyde Canal, and to have suitable engines constructed for her at Carron Ironworks. When this new machinery was ready, a trial took place on a straight reach of the canal of about 4 miles in length, on the 26th of December 1789, when the vessel moved at the rate of about 7 miles an hour. Many other experiments followed with a similar result, as will be seen by the following notice of them sent (by Lord Cullen) to several of the Edinburgh newspapers:—

> "It is with great pleasure I inform you that the experiment which some time ago was made upon the great canal here by Mr Miller of Dalswinton, for ascertaining the powers of the steam-engine when applied to sailing, has lately been repeated with great success. Although these experiments have been repeated under a variety of disadvantages, and with a vessel built formerly for a different purpose, yet the velocity acquired was no less than from 6½ to 7 miles an hour. This sufficiently shows that, with vessels properly constructed, a velocity of even 8, 9, or even 10 miles an hour, may be easily accomplished, and the advantages of so great a velocity in rivers, straits, &c., and in cases of emergency, will be sufficiently evident, as there can be few winds, tides, or currents, which can easily impede or resist it; and it must be evident that, even with slower motion, the utmost advantages must result to inland navigation."

The Charlotte Dundas, 1801.

Although these experiments were thus partially successful, and their value well understood and appreciated, we find that Mr Miller's boat was soon afterwards dismantled and laid up at Carron, and nothing further was at that time attempted. This apparent apathy can only be accounted for by the fact (which was afterwards acknowledged by Mr Miller himself), that Symington's machinery was not equal to the task of propelling a boat with the degree of certainty and regularity necessary to ensure commercial success. Hence, although the great principle of the possibility of steam navigation was thus apparently settled by Mr Miller's experiments in 1788 and 1789, it was not till the year 1801 that a really practical steamboat was first produced in Scotland. In this year Thomas Lord Dundas, who was well acquainted with Miller's experiments, and who was a large proprietor in the Forth and Clyde Canal, engaged Mr Symington to undertake a fresh series of experiments on this subject, with the view of employing steamboats for towing on the canal in place of horses. The result was the production of the Charlotte Dundas, named after his lordship's daughter, and which, from the simplicity and practical nature of its machinery, may be justly considered as the "first practical steamboat." The superiority of this boat over its predecessors lay in Symington's more judicious arrangement of the machinery, which consisted of Watt's double-acting engine, working a connecting-rod and crank, which turned a single paddle-wheel, revolving in a well-hole near the stern of the vessel. This engine had one horizontal cylinder, 22 inches in diameter and 4 feet stroke. In March 1802 Lord Dundas, Mr Speirs of Elderslie, and several other gentlemen, being on board, the Charlotte Dundas "took in drag," says Mr Symington, "two loaded vessels, each upwards of 70 tons burthen, and with great ease carried them through the Long Reach of the Forth and Clyde Canal to Port-Dundas, a distance of 19½ miles, in six hours (being at the rate of 3¼ miles per hour), although it blew so strong a gale right ahead that no other vessel on the canal that day attempted to move to windward." Notwithstanding this favourable result, the scheme was doomed a second time to disappointment, in consequence of some of the proprietors of the canal becoming alarmed at the destructive effects of the wash of the steamboat upon the banks. The boat was therefore laid up in a creek of the canal, where it remained as an object of curiosity for several years. It may be remarked, that this production of Symington's possessed every necessary qualification which is considered requisite, even at the present day, to make a good and useful steamer; and in proof of the confidence it inspired in its own time, we may observe that the Duke of Bridgewater actually ordered eight steamers from Symington for use on the Bridgewater Canal, to be built on the model of the Charlotte Dundas. His grace dying, however, shortly afterwards, this order was never executed.

Steam Navigation.

Fulton, 1803.

We now arrive at the period when American enterprise stepped in to avail itself of the painful and laborious results of these costly experiments, which although made and perfected in this country, had not yet been turned to good account. About a year after Symington's experiment with the Charlotte Dundas, Fulton, the American engineer, made a similar though less successful experiment on the Seine, for the weight of his engine broke the vessel in two, and the whole went to the bottom. He persevered, however, and in August 1803 completed another vessel with its machinery. This boat was 66 feet long and 8 feet wide, but moved so slowly that his experiment is described as having been a failure. He afterwards came to Scotland, and saw Symington's steamboat on the Forth and Clyde Canal, his visit being thus recorded by Mr Symington:—

> "When engaged in these experiments I was called upon by Mr Fulton, who told me he was lately from North America, and intended returning thither in a few months, but having heard of our steamboat operations, could not think of leaving this country without first waiting upon me, in expectation of seeing the boat, and procuring such information regarding it as I might be pleased to communicate, observing that, however advantageous such an invention might be to Great Britain, it would be still more valuable in America, where there were so many great navigable rivers. In compliance with his earnest request, therefore, I caused the engine-fire to be lighted up, and, in a short time thereafter, put the steamboat in motion, and carried him 4 miles west on the canal, returning again to the point from which we started in one hour and twenty minutes (being at the rate of 6 miles an hour), to the great astonishment of Mr Fulton and several gentlemen, who, at our outset, chanced to come on board. During the trip Mr Fulton asked if I had any objection to his taking notes regarding the steamboat, to which I made no objection, as I considered the more publicity that was given to any discovery, intended for general good, so much the better; and, having the privilege secured by letters-patent, I was not afraid of his making any encroachment upon my right in the British dominions, though in the United States I was well aware I had no power of control. In consequence, he pulled out a memorandum-book, and, after putting several pointed questions respecting the general construction and effect of the machine, which I answered in a most explicit manner, he jotted down particularly every thing then described, with his own observations upon the boat during the trip."

Fulton having thus obtained what information he could, returned shortly afterwards to America, and, in conjunction with Mr Livingstone, obtained a patent securing to them the prospective advantages of steam navigation in America, by what they were pleased to call "their invention of steamboats." They very wisely got all their machinery from England; so that in the year 1807 the first steamboat in America was launched, and fitted with a pair of engines constructed by Boulton and Watt.

The Clermont, 1807.

This vessel, called the Clermont, though probably fitted with superior machinery to that in Symington's boat, was barely so fast, making less than five miles an hour. Her dimensions were 130 feet long, 16½ feet beam, and 7 feet deep; the boiler 20 feet long, 7 feet deep, and 8 feet broad; the steam-cylinder (one only) was 24 inches in diameter, and 4 feet stroke; burthen 160 tons. Her paddle shaft was of cast-iron, with no outer support beyond the sides of the ship. The diameter of the paddle-wheels was 15 feet, the boards being 4 feet long, and dipping two feet in the water. She was subsequently lengthened to the extent of 140 feet keel. In the beginning of the year 1808 the Clermont was placed for regular work on the Hudson River, between New York and Albany, a distance of 125 geographical miles, and was crowded with passengers, her speed after the alteration being at the rate of 5 miles an hour. This was, therefore, the first steamboat that ever ran continuously for the accommodation of passengers, and the first that ever remunerated her owners, and to this the Americans may justly lay claim; but that Fulton was the "inventor" of the present system of steam navigation, as asserted by some American authors, cannot be admitted; nor, indeed, did he "invent" any single improvement in the construction either of the machinery or the vessel. The success of their first steamer induced Messrs Fulton and Livingstone to build two other vessels, the Car of Neptune, of 300 tons, and the Paragon, of 350 tons, also supplied with Boulton and Watt's engines.

Steam Navigation.

Stevens, 1808.

The first person who ever took a steamer to sea was also an American, R. L. Stevens of Hoboken, who had been associated with Livingstone previously to the connection of the latter with Fulton, and had brought his experiments to a successful issue nearly as soon. As Fulton, however, had secured to himself the exclusive privilege of navigating by steam in the state of New York, Stevens boldly took his vessel round by sea from the Hudson to the Delaware. To him are due many of the present peculiarities of American steamers. He it was who first adopted the long stroke; the upright guides for the piston-rod; the beam overhead, raised on a high framework of wood, working above the deck; and the connecting-rod, descending thence to the paddle-shaft, all characteristic of American steamers to the present time. He also improved the form of the American boats, by substituting a fine entrance and run for the old bluff bow and stern, as well as by increasing their relative length to eight or ten times the beam. Stevens is believed to have been the first engineer who constructed a "tubular" boiler, though these did not come into general use till long after his time.

Comet, 1812.

Although steam navigation had been thus early introduced on the American waters, it was not till the year 1812 that the first regular passenger-steamer made its appearance in this country, on the Clyde. This was the Comet, built for Mr Henry Bell, the proprietor of the Helensburgh Baths on the Clyde, and who had long been a most zealous advocate of steam propulsion. This little vessel was 40 feet long on the keel, and 10 feet 6 inches beam, propelled by a steam-engine of three or four horse-power, with a vertical cylinder, and working on the bell-crank principle—the engine being placed on one side of the vessel, and the boiler (of wrought iron) on the other. The Comet made her first voyage in January 1812, and continued to ply regularly between Glasgow and Greenock, at a speed of about 5 miles an hour. She was propelled by two small paddle-wheels on each side, each wheel having four boards only. She was afterwards transferred to the Forth, where she ran for many years between the extremity of the Forth and Clyde Canal and Newhaven, near Edinburgh. The distance is 27 miles, which is stated by Mr Bell to have been performed, on the average, in 3½ hours, being at the rate of above 7½ miles an hour.

Henry Bell.

Mr Bell had on several occasions brought his projects for steam navigation under the notice of the British government, but always without success; and it was not till the year 1819 that the admiralty of the day became impressed with the importance of steam-power for towing men-of-war, chiefly through the representations of Lord Melville and Sir George Cockburn. The first steam-vessel in the royal navy was then built, and was also named the Comet. She is still in existence, and measures 115 feet in length, 21 feet in breadth, and draws 9 feet water, being propelled by a pair of engines, by Boulton and Watt, of 40 horse-power each.

But to return to Mr Bell's steamers on the Clyde. The Comet was so successful, that two other steamers, of increased size and power, were constructed; and, in 1814, Mr Cook, of Glasgow, built a fourth, called the "Glasgow," which, in point of power and efficiency, became the standard at that time for river-steamers. The marine engines hitherto constructed had all been applied *singly* in the vessel; but in 1814 Messrs Boulton and Watt first applied *two* condensing engines, connected by cranks set at right-angles on the shaft, to propel a steamer on the Clyde. This was found to be a great improvement, and thenceforward almost all steamers have been fitted with two engines.

In the year 1815 a small vessel, with a side lever-engine of 14 horse-power, by Cook of Glasgow, made a voyage from Glasgow to Dublin, and thence round the Land's End to London. It then ran with passengers between London and Margate with some success, though encountering great opposition from the Thames watermen.

David Napier, 1818.

In 1818 Mr David Napier, to whom we owe the introduction of British coasting steamers, as well as of steam-packets for our post-office service, first established between Greenock and Belfast a regular steam communication by means of the Rob Roy, a vessel of about 90 tons burthen and 30 horse-power, built by Mr William Denny of Dumbarton. For two winters she plied with great regularity and success between these ports, and was afterwards transferred to the English Channel, to serve as a packet-boat between Dover and Calais. Soon after this Mr Napier had the Talbot built for him by Messrs Wood. She was 120 tons burthen; and when fitted with two of Mr Napier's engines, of 30 horse-power each, this vessel was in all respects the most perfect of her day. She was the first steamer that ran between Holyhead and Dublin. About the same time, also, he established the line of steamships between Liverpool, Greenock, and Glasgow, for which traffic he built the Robert Bruce, of 150 tons, with two engines, of 30 horse-power each; the Superb, of 240 tons, with two engines of 35 horse-power each; and the Eclipse, of 240 tons, with two engines of 30 horse-power each. All these were established as regular coasting traders before the year 1822.

The James Watt, &c., 1822.

In the latter year the steamer James Watt was built by Messrs Wood, to ply between Leith and London. She was the largest steamer that had yet been built, being 448 tons' measurement, and fitted with two engines of 50 horse-power each, by Messrs Boulton and Watt. The Soho followed on the same line, and was equally successful. The next great advance made was in 1826, when the United Kingdom was constructed, this vessel having been regarded in her day with as much wonder and interest, from her (so-called) gigantic proportions, as were afterwards the Great Western, the Great Britain, and, more recently, the Great Eastern. The United Kingdom was 160 feet long, 26½ feet beam, and 200 horse-power; the ship being built by Mr Steele of Greenock, and the machinery by Mr David Napier. Prior to this time many improvements had been made in the arrangement and construction of the marine engine by Boulton and Watt, Maudslay and Field, Penn, and others of our eminent mechanical engineers; the expansive action of steam in the cylinder having already been taken advantage of by Messrs Maudslay and Field in their engines, which were also fitted with escape-valves on the cylinders, and other improvements.

The Savannah, 1819.

The first steamer which crossed the Atlantic was the "Savannah," an American vessel of 300 tons burthen, which arrived at Liverpool in the year 1819, direct from the United States, in 26 days, partly steaming and partly sailing. Being fitted with engines of small power, and the vessel being otherwise unsuited for ocean navigation, this must be regarded rather as a bold experiment (and not a very successful one) than as establishing the practicability of a rapid and regular steam communication between this country and America; for it is only in the combination of these two qualities of speed and regularity that the steamship excels the sailing vessel. In 1829 the Curaçoa, an English built vessel, of 350 tons and 100 horse-power, made several successful runs between Holland and the Dutch West Indies. In the mean time Dr Lardner and other theorists attempted to demonstrate, that the navigation of the Atlantic by steam-power alone was impracticable; and it was not till the Sirius and the Great Western had shown the fallacy of their reasoning, that the public mind was disabused of this idea. The Sirius was not built expressly for transatlantic navigation; she belonged to the St George Steam-Packet Company, and had run with a good reputation between London and Cork. Her tonnage was about 700 tons, and her horse-power 320. She started from London on the morning of the 4th of April 1838, with 94 passengers. Though first in the race, she was only three days in advance; for on the 7th of the same month the Great Western, built and fitted at Bristol expressly for the purpose, followed her. The Sirius arrived at New York on the 22d, being 17 days clear on the passage, and the Great Western (sailing from Bristol) on the 23d, being 15 days. The Sirius again sailed on her homeward passage on the 1st of May, and the Great Western on the 7th of May, and they arrived, the first on the 18th, and the second on the 22d, being 16 and 13½ days respectively. The average speed of the Great Western on this voyage was thus 8·2 knots on her outward passage, and nearly 9 knots on her homeward, reckoning the distance at 3125 knots for the one, and 3192 for the other. She consumed 655 tons of coal going out, having still 205 tons remaining in her coal-boxes upon her arrival at New York. Coming home her consumption was 392, having 178 tons remaining on her arrival at Bristol. Her average daily consumption varied from 27 tons, with expansive gear in action, to 32 tons without it. As the Great Western possesses considerable historical interest, some of her principal dimensions are here subjoined. She was designed and built by Mr Paterson of Bristol, and fitted with machinery by Messrs Maudslay, Sons, and Field of London. She is 212 feet long between the perpendiculars, 35 feet 6 inches beam, and 23 feet 3 inches depth of hold, drawing from 16 to 18 feet of water. Her tonnage is 1340 (builders' O.M.), and her engines (on the side-lever construction) are 440 horse-power. Her cylinders are 73½ inches in diameter, and 7 feet stroke, making 12 to 15 revolutions per minute. Her complete success was doubtless mainly attributable to the fact, that she was especially fortunate both in her designer and in her engineers, who are still, perhaps, the most eminent of the present day in their respective departments.

The Sirius and Great Western. 1838.

The practicability of transatlantic steam navigation being thus triumphantly established, the British Queen, the President, and other large steamships, were built in rapid succession, as well as many steam-vessels of war.

The screw-propeller introduced, 1837.

Up to this time the paddle-wheel was the only propelling agent employed; but in 1837 the rival system of propelling ships by means of the screw-propeller first came prominently into notice, through the successful experiments of Captain Ericsson and Mr F. P. Smith. Captain Ericsson's small vessel, of 45 feet in length, 8 feet beam, and but 2 feet 3 inches draught of water, towed the American ship Toronto, of 630 tons, on the Thames, on the 25th of May 1837, at the rate of 4½ knots an hour, against the tide, as authenticated by the pilot; and also towed the admiralty barge, with their lordships on board, from Somerset House to Blackwall and back, at the rate of about 10 miles an hour. Later in the same year Mr Smith made some very successful trips with his small boat and screw-propeller between Margate and Ramsgate. The next screw-vessel was the Robert Stockton, built in 1839 by Messrs Laird for an American gentleman, who had witnessed Captain Ericsson's experiments. This boat was also perfectly successful; but the Board of Admiralty still failed to recognise the peculiar applicability of this means of propulsion for vessels of war. The next year, however, in 1840, Mr F. P. Smith, having obtained the support of some influential mercantile men, brought out the Archimedes, a screw-vessel of 232 tons burthen and 80 horse-power. The success of this vessel was so complete, that the Admiralty were at length induced

The Archimedes, 1840

The Rattler, 1842.

to make a trial of the screw in the royal navy, and the Rattler was ordered to be built on the same lines as the Alecto paddle-wheel steamer, and to be fitted with engines of the same nominal power. The next screw-steamer worthy of notice was the Dove, an iron boat, constructed under Mr Smith's direction. Her speed, however, proved so unsatisfactory to her owners, that they ordered her to be changed into a paddle-wheel boat; and as it happened that she had been built with very fine after-lines, her constructor, Mr Smith, unfortunately charged her deficiency of speed to this circumstance, and adopted the theory that full stern-lines were the most advantageous for the action of the screw. The Rattler was now tried; and her trials having fully satisfied the Board of Admiralty, they ordered the construction of several screw-vessels, which were all built with full sterns. This idea having at length been proved, by further experiment, to be erroneous, and that, on the contrary, fine after-lines were absolutely required for the proper efficiency of the screw-propeller, so as to allow of a ready access and escape of the water, the whole of these vessels were deficient in speed, and some of them were altered at great cost.

The screw had meanwhile advanced rapidly into favour as an auxiliary power for fast sailing vessels in the merchant service; and more recently it has been extensively employed for full powered steamers of the very largest class (in preference to the paddle-wheel) by several of our great mail-packet companies, the Peninsular and Oriental Company taking the lead in this respect.

The requirements of the great navigable rivers of America have naturally led to the supremacy of that nation in the art of *river* navigation. The description of the large American river-steamer, The New World, given in another part of this article, as a type of her class, will be found both novel and interesting.

This rapid sketch of the rise and progress of steam navigation would not be complete without referring specially to the wonderful development it has lately received in the construction of the Great Eastern, which, notwithstanding a few minor defects, has undoubtedly proved herself to be a most efficient steamship. In addition to the interest naturally excited by the immense size of this vessel (whose proportions and performance will be given hereafter), she is destined to solve another problem in marine engineering, namely, the desirability of combining screw-propeller and paddle-wheels in the same steamship.

A statistical table is subjoined, showing the progress of steam navigation in the British Empire, from its first introduction in 1814, down to the most recent times for which returns have been received.

Table showing the progress of Steam Navigation in the British Empire, by the Registrar-General of the Board of Trade.

British Merchant-Steamers built and registered each year.			Total number of Merchant-Steamers belonging to the British Empire in each year.	
Year.	Steamers.	Reg. Tons.	Steamers.	Reg. Tons.
1814	6	672	2	456
1815	10	1,394	10	1,633
1816	9	1,238	15	2,612
1817	10	2,054	19	3,950
1818	9	2,538	27	6,441
1819	4	342	32	6,657
1820	9	771	43	7,243
1821	23	3,266	69	10,534
1822	28	2,634	96	13,125
1823	20	2,521	111	14,153
1824	17	2,234	126	15,739
1825	29	4,192	168	20,287
1826	76	9,042	248	28,958
1827	30	3,784	275	32,490
1828	31	2,285	293	32,032
1829	16	1,751	304	32,283
1830	19	2,226	315	33,444
1831	36	4,436	447	37,445
1832	38	4,090	380	41,669
1833	36	3,9 5	415	45,017
1834	39	5,756	462	50,735
1835	88	11,281	538	60,520
1836	69	9,700	600	67,9 9
1837	82	12,147	668	78,288
1838	87	9,857	722	82,716
1839	65	6,522	770	86,731
1840	77	10,639	824	95,807
1841	54	12,391	856	104,845
1842	67	14,931	906	118,930
1843	53	6,739	942	121,455
1844	73	6,930	988	125,675
1845	73	11,950	1012	131,202
1846	88	17,172	1070	144,784
1847	115	17,333	1154	146,557
1848	128	16,476	1253	158,078
1849	80	13,480	1296	167,310
1850	81	15,527	1350	187,631
1851	88	23,527	1386	204,654
1852	112	31,792	1414	223,616
1853	162	49,008	1534	264,336
1854	189	66,446	1708	326,452
1855	263	84,862	1910	408,290
1856	245	58,621	1950	417,717

Explanation of statistical table.

It should be observed that the "register" tonnage here given is exclusive of the tonnage of the engine-room, which in a well-powered steamer generally amounts to one-half, or more of the registered tonnage. An addition of one-half should therefore be added for the gross tonnage of this table. To take an example. The Shannon, West India mail packet, has

Register tonnage .... 2187·24
Engine-room do. .... 1284·57 } H. 775.
Gross do. .... 3471·81

The horse-power (nominal) averages about one-third of the register tonnage; so it may be fairly assumed that this country now possesses (in 1860) a fleet of 2150 merchant-steamers, having an aggregate gross tonnage of 670,000 tons, and a nominal horse-power of 165,000 horses.

The steam navy of this country consists at present of about 468 vessels, having an aggregate tonnage of 470,000 tons, and a nominal horse-power of 110,000 horses.

	Steamships afloat (1859).		Building or Converting.	Total.
	Screw.	Paddle.	Screw.	
Ships of the Line......	33	—	16	49
Frigates	19	9	6	34
Block Ships	9	—	—	9
Mortar Ships	4	—	—	4
Corvettes and Sloops ..	38	35	9	82
Small Vessels	3	24	—	27
Gun Vessels	26	—	—	26
Gunboats	161	—	1	162
Floating Batteries	8	—	—	8
Tenders, &c.	4	38	—	42
Troops & Store Ships .	13	2	—	15
Yachts	1	4	—	5
Total	319	112	32	463

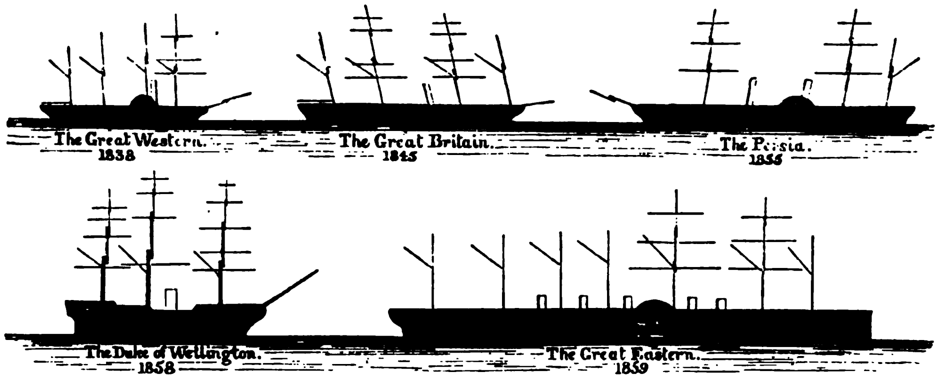

Fig. 1.—Comparative sizes of the above Steamers.

In constructing a steam-vessel three things require to be specially considered, each of which is a sufficiently complex study in itself; namely, the ship, the engines and boilers, and the propeller. To combine these in such a manner as to produce a perfect whole is one of the most difficult problems of modern engineering, demanding at once the theoretical attainments of the natural philosopher, and the laboriously acquired knowledge and shrewd sagacity of the practical mechanician. As the limits of this article must preclude the pursuit of theoretical investigation, it is proposed to confine it almost exclusively to the practical part of the subject, and to a record of the results of actual and approved performance.

The marine engine.

The marine steam-engine, although acting on the very same principles as the ordinary land condensing-engine, and provided with the same integral parts, differs from it essentially in the particulars of weight and form, being necessarily made as light, and as compact, as possible. These requirements throw many obstacles in the way of the marine engineer which are not encountered on shore, both as regards the engines and boilers; and his difficulties are increased by the stern necessity which exists on board ship for the utmost economy in the consumption of fuel, the value of which is there immensely enhanced.

Side-lever engines.

The oldest type of the marine-engine is the side-lever variety, which, till within the last ten or twelve years, was almost universally employed in steamers; and which is, indeed, still preferred for paddle-wheel steamers by at least two large mail-packet companies—viz: Cunard's and the West India Mail Company (fig. 2). There are several good reasons why this form of engine should be thus favoured. In the first place, the working parts are well balanced on either side of the main centre (*c*, fig. 2), so that the engine will stand in any position without the piston having a tendency to fall by its own weight, thus enabling the crank to be kept in the most advantageous position for giving prompt motion to the shaft immediately that the engine is started. Direct-acting engines are often very troublesome in this respect. Another advantage of the parts being nicely balanced is, that the engine works with little friction, and consequently less strain, and wear and tear of the brasses and moving parts of the machinery. Hence the side-lever engine is very economical in maintenance and repairs, as well as in the quantity of oil and tallow required for lubrication, no mean item in the expenditure of some engines. Again, this form of engine admits of a good long stroke and connecting-rod, by which means the steam may be used to best advantage in the cylinder, while, at the same time, the thrust of the piston is transmitted to the crank in the most equable and effective manner. Many pairs of side-lever engines are still doing their work well, after more than twenty years' service, and have cost less for repairs than most direct-acting varieties in half that time.

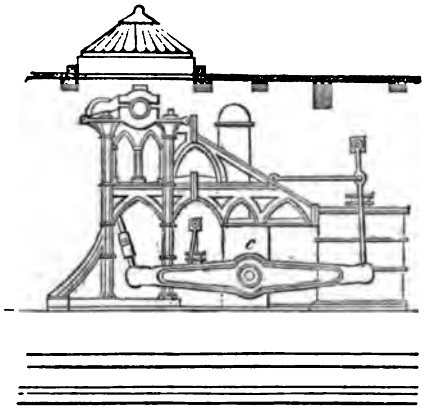

Fig. 2.
Side-lever Engine.

Direct-acting engines.

But although it may be quite true that side-lever engines are thus economical in their working, it does not necessarily follow that they are the best form of engine for passenger-steamers. On the contrary, when we consider the value of space and weight in a first-class merchant-steamer, it appears probable that they are really more expensive

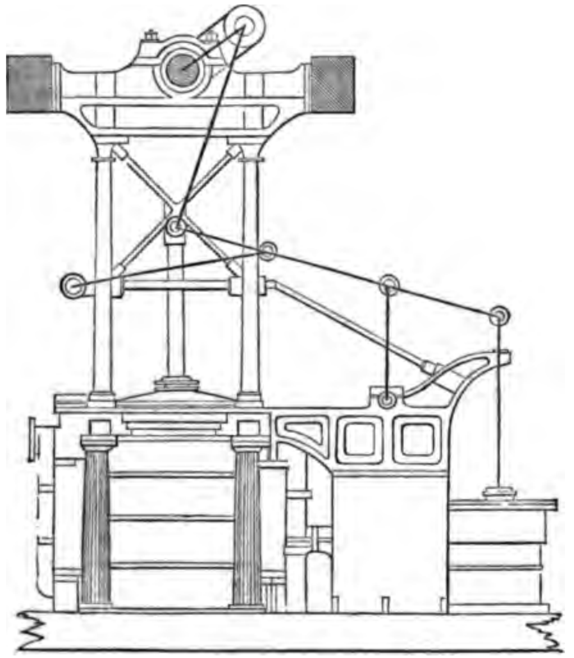

Fig. 3.
Direct-acting Engines in Gorgon, &c. (Seaward.)

Steam Navigation.

than the lighter and more compact forms of direct acting-

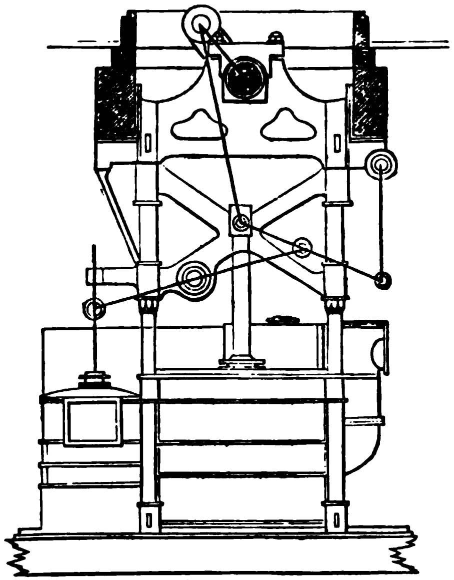

Fig. 4.
Direct-acting Engines in Vulture, &c. (Fairbairn.)

engines which have now so generally come into use, and by

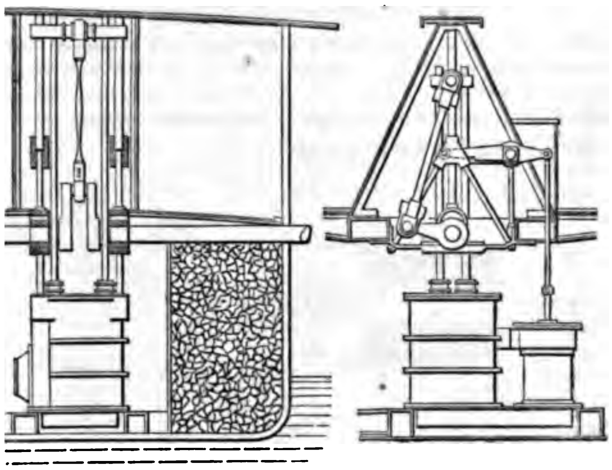

Fig. 5.
Direct-acting Engines for shallow draught. (Maudslay and Field.)

employing which we may save at least 20 feet in the length of the engine-room, and 100 tons of displacement, in engines of 500 nominal horse-power. Direct-acting engines, being susceptible of great variety of form, have assumed as many different shapes as there are manufacturing engineers ready to invent, adapt, or distort them, as the case may be; and the now very general use of the screw-propeller has, of course, varied and modified these forms still more. In the merchant service, the height of the machinery is not of much moment, provided only that it does not raise the centre of gravity of the vessel too high; but in the steam-navy it is considered essential that the whole of the engines and boilers should (if possible) be kept under the water-line of the ship, as a protection from shot; which, in the case of screw-vessels, is now generally accomplished (see fig. 15).

Steam Navigation.

Varieties.

Direct-acting paddle-wheel engines may be classed under four heads; namely, those which preserve the parallelism of the piston-rod by means of the system of jointed rods called a parallel motion (figs. 3 and 4); those which use guides or sliding surfaces for this purpose (figs. 5 and 7); oscillating engines (fig. 6), in which the cylinders are hung upon pivots, and follow the oscillations of the crank; and those denominated "trunk-engines" (fig. 8), in which a hollow cylindrical trunk is attached to the piston, and passes, steam-tight, through the cylinder cover. Several of these varieties have their distinctive appellations, being known as the "steeple-engine" (which is a favourite form on the Clyde); Maudslay's double-cylinder engine (fig. 7); the annular-piston engine (with two piston-rods); the atmospheric engine; the combined-cylinder engine (Plates XXI. and XXII.); and several others. As verbal description is of little value in making these forms intelligible to the reader, sketches of the more characteristic of them are subjoined, as well as detailed plates of approved examples (see Plates). These engines are generally made with two cylinders, but in the case of screw-engines there are sometimes three, and sometimes four cylinders

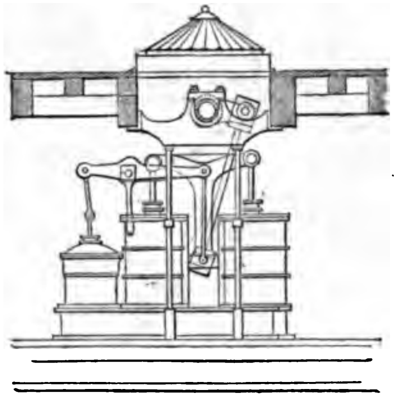

Fig. 7.
Direct Double-cylinder Engines, suitable for large power. (Maudslay.)

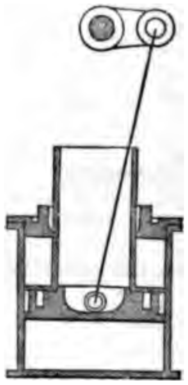

Fig. 8.

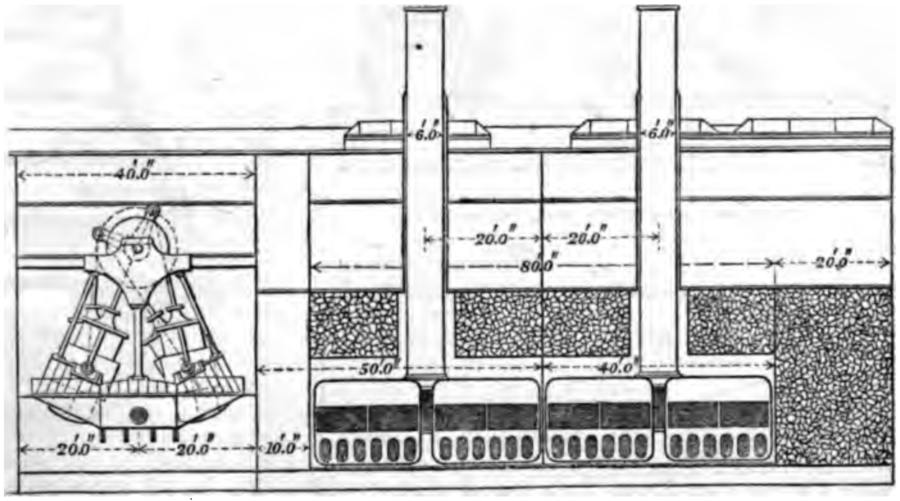

Fig. 6.—Oscillating Paddle-wheel Engines in the Great Eastern. (J. Scott Russell.)

placed in all possible positions; being found upright, inverted, horizontal, and inclined.

Screw-engines.

Screw-engines are made either with or without gearing. The use of geared wheels intervening between the engine and the propeller admits of a slow speed of piston with a high velocity of screw, and is so far beneficial, but in practice there are several disadvantages attending it.

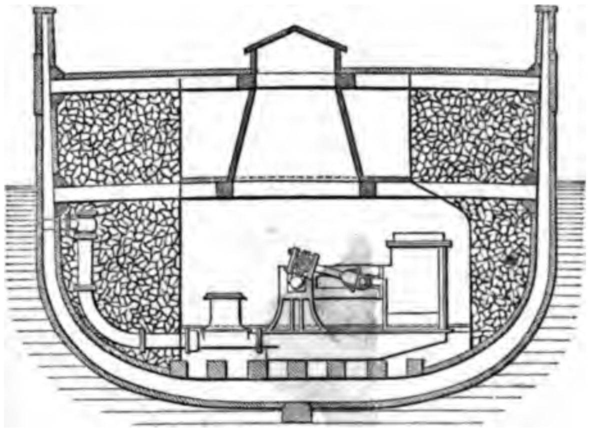

Fig. 9.

Horizontal Screw-engine (Direct), adapted for the Royal Navy, &c.

The driving-wheel is necessarily very large and cumbrous, while the wooden teeth with which it is fitted are subject to unequal wear, and are liable to be "stripped," or broken off, by a sudden stroke of the sea upon the screw. Their revolution is also attended with a loud rumbling noise, from which there is no escape on board-ship. In steam-vessels of war it is difficult to keep the top of the large wheel sufficiently low, while at the same time their draught of water admits of the use of a screw of great diameter and pitch, by which means the necessary speed may be obtained for the ship without unduly increasing the velocity of the piston. Hence there are comparatively few geared screw-engines in the Royal Navy. In the case of full-powered screw-engines in the merchant service, the use of gearing is generally found to be necessary (fig. 10), but it may be advantageously dispensed with wherever the power of the engines is not calculated to give a very high speed to the ship. The velocity of piston in actual use in different classes of steamers will be hereafter noted.

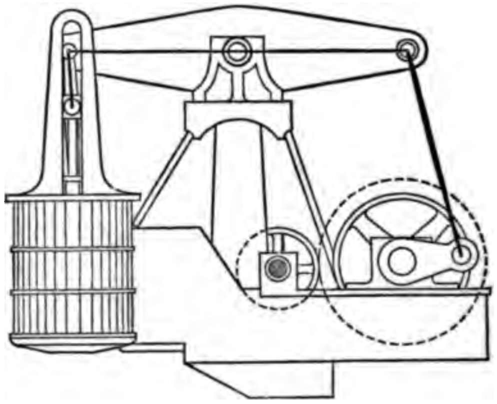

Fig. 10.

Vertical Screw-engine (Geared), adapted for the Merchant Service.

The following (Figs. 11 to 16) are other examples of Screw-engines:—

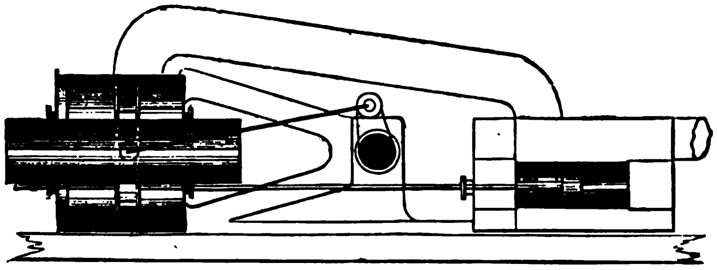

Fig. 11.—"Trunk" Screw-engine, Direct.

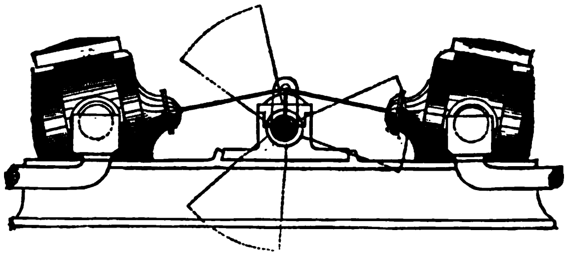

Fig. 12.—Oscillating-Cylinder Screw-engine, Direct.

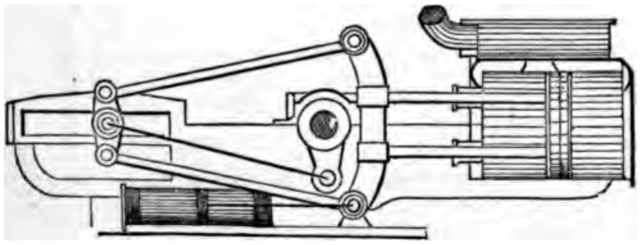

Fig. 13.—Double Piston-rod Screw-engine, Direct.

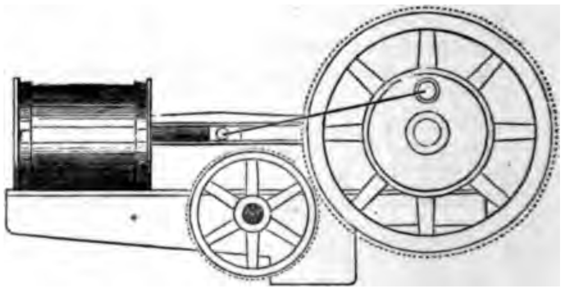

Fig. 14.—Horizontal Cylinder Screw-engine, Geared.

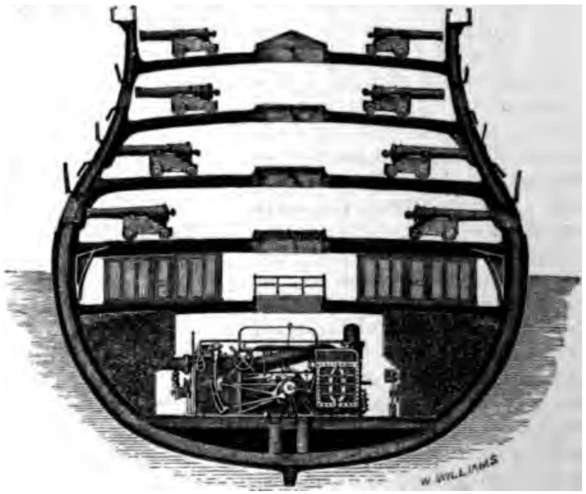

Fig. 15.—Screw-engines in the Royal Navy, Direct.

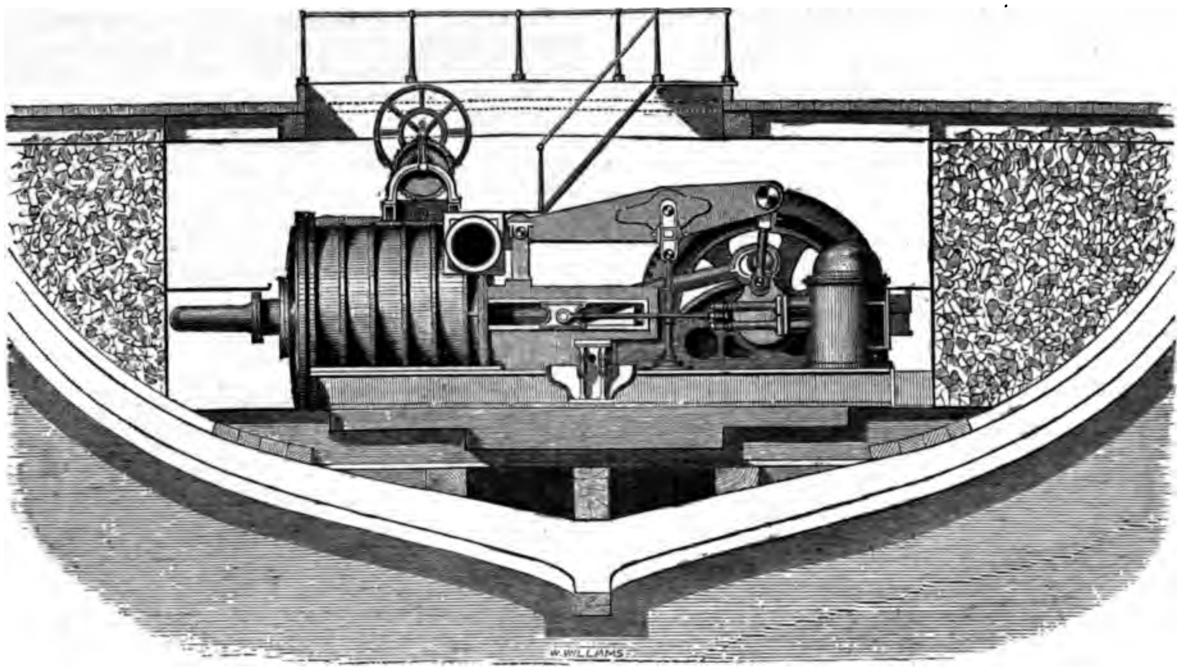

Fig. 16.—Screw-engines in the Royal Navy, Geared.

Nominal horse-power.

The cylinder of the steam-engine, being that portion of the machine in which the power is developed, must be considered as its principal member. Upon its dimensions depend, in some degree, the size of all the other parts of the engine, as well as its reputed powers, being called an engine of 100 or of 200 horse-power according to the diameter of the cylinder, modified to a small extent by the length of the stroke. This, called the nominal horse-power, is obtained by the formula—

$$\text{H.P.} = \frac{\text{Area of cylinder} \times \text{effective pressure} \times \text{speed of piston}}{33{,}000}.$$

In this formula the area of the cylinder is taken in square inches; the "effective pressure" is assumed at 7 lb. (by some makers at 7½ lb.) to the square inch; and the speed of the piston (according to the arbitrary rule adopted by the admiralty), is presumed to vary with the length of stroke, as shown in the following table:—

Stroke.		Speed of piston.	Stroke.		Speed of piston.
Ft.	In.	Ft. per min.	Ft.	In.	Ft. per min.
3	0	180	6	0	221
3	6	188	6	6	226
4	0	196	7	0	231
4	6	204	7	6	236
5	0	210	8	0	240
5	6	216	9	0	248

It is at once apparent that the power thus calculated cannot be the real power of the engine, since it is wholly irrespective of the pressure of steam in the boiler, the perfection of the vacuum in the condenser, the actual number of reciprocations of the piston, and the varying loss by friction depending upon good or bad workmanship, and the general plan of the engine. For the sake of convenience, however, the nominal horse-power is still retained, since it defines, with tolerable accuracy, the actual *size* of the engine, and its commercial value, in so far as the latter is dependent upon the dimensions of the cylinder. To remedy, in some degree, the uncertainty attending the use of this term, it is now becoming usual for the purchaser of a steam-engine to insert a clause in his contract, binding the manufacturer to show a certain specified amount of indicated horse-power.

Indicated horse-power.

The indicated horse-power of an engine is obtained by the aid of a valuable little instrument called an indicator, consisting mainly of a small cylinder placed in connection with the cylinder of the engine, both above and below the piston. This little cylinder is open at the top, and is fitted with a piston which presses against a spiral spring. The cock which connects the indicator with the cylinder of the engine being opened, steam is admitted under the piston of the indicator during the one stroke, and vacuum during the other, precisely as in the large cylinders; thus causing the little piston to push and pull alternately against the spiral spring. If the pressure were uniform throughout the stroke, the indicator-piston would start at once from top to bottom, and *vice versâ*, remaining stationary until acted upon by the opposite pressure; but since the pressure within the cylinder of a steam-engine is constantly varying during every portion of the stroke, it follows that the pressure on the spiral spring of the indicator, and the corresponding movement of the indicator-piston, must be variable too. If a pencil be fixed to the piston-rod of the instrument, it will register the fluctuations of pressure upon a piece of paper held close to it; but unless some provision be made for allowing the pencil a clear space on the paper at each successive instant of time, it will only move up and down in the same vertical line, and the markings due to fluctuation of pressure will be undistinguishable. To obviate this, the paper receives a circular motion in one direction during the down-stroke of the piston, and a reversed circular motion during the return-stroke, the result being that, as the pencil moves vertically up and down, a continuous curved or sloping line is traced on the paper. By this line an oblong space is inclosed, called the indicator-figure, card, or diagram, the vertical ordinates of which will then represent the effective pressures at the corresponding portions of the stroke, and their mean length will therefore indicate the average pressure in the cylinder during the whole period of the stroke.

Description of the indicator

Indicated and effective horse-power.

To find the indicated horse-power, therefore, we must take the area of the cylinder in square inches, multiply it by the average pressure as found from the indicator-figure, and again by the actual number of feet through which the piston is travelling per minute; when the product, divided by 33,000, is the indicator or gross horse-power of the engine. This must not be confounded, however, with the *effective* power of the engine, or that actually available for the purpose for which the engine is used. To obtain this, a considerable deduction (about 25 per cent., it is believed) must be made for the friction of the moving parts, and for the power required to work the valves, air-pump, feed and bilge pump, &c.; but as this would be nearly alike for all well-constructed engines of equal power, and no ready means exist for testing it, the gross or indicated horse-power is taken as the measure of the power in all ordinary cases.

An example of a set of indicator-diagrams (fig. 17) is subjoined, to show the manner in which they are usually worked out; and it will be seen that, in this instance, a pair of engines of 500 *nominal* horse-power were actually exerting an *indicated* horse-power of more than 2000 horses, or four times the nominal. This may be taken as the usual proportion now existing between nominal and indicated horse-power in modern engines by the best makers, while using steam of from 15 to 20 lb. pressure; but the average performance of existing engines is still very much below this, not exceeding from 2 to 2·5 times the nominal horse-power.

Proportion of indicated to nominal horse-power.

Indicator-Diagrams taken from Screw-engines of 500 horse-power, by Ravenhill, Salkeld, and Company.

(Steam in Boilers 20 lb.)

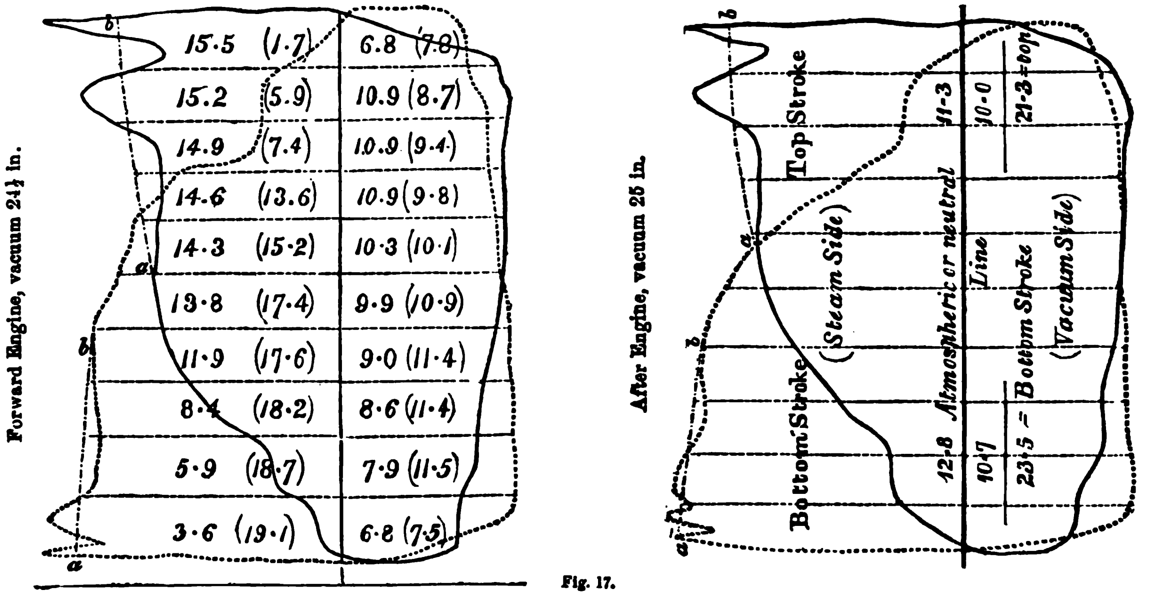

Fig. 17.

Calculation for finding Ind. H. P.

Steam ....11·7 (13·5) 9·2 (9·8)
Vacuum .... 9·2 (13·5)
Top stroke ......20·9 Bottom......(23·3)

Diameter of Cylinder..................................71 inches.
Length of stroke...................................... 3 feet.
Indicated pressure (mean of 6 experiments).....21·904 lb.
Mean number of revolutions per minute ....63½.

$$\frac{3959{\cdot}2014 \times 381 \times 21{\cdot}904}{33{,}000} = 1001{\cdot}248 \text{ H. P.} \times 2 = 2002{\cdot}496.$$

Ind. H. P. of both engines.

Speed of the vessel at a mean draught of 24 ft. 9½ in....10·897 knots.

Mean of forward engine.....................................22·1 lb.
„ after engine..22·4 „
Mean of both engines..................22½ lb.

Indicated horse-power depends mainly on the boiler.

The size of the boiler is obviously a very important element in determining the indicated horse-power of an engine, inasmuch as the speed of the piston (or the number of revolutions per minute) depends mainly upon the supply of steam from the boiler. The power of an engine may thus always be increased by adding to the size of the boiler, provided the steam-passages are large enough to admit of the increased flow of steam without its becoming throttled or "wire-drawn." A large boiler, however, implies a large consumption of coal as a necessary attendant upon any increase of power in the engines, or velocity in the ship; so that in practice it is generally found inconvenient for sea-going steamers to urge their engines to the utmost duty of which they are capable, as tending to limit the distance which it is possible to run with a definite weight of coals. Hence it follows, that while vessels making short runs (such as the Holyhead packets) will show an indicated horse-power of four, or even five times their nominal, a transatlantic steamer cannot afford to do so, although her engines may be equally efficient.

The dynamometer is an instrument used to measure the force actually expended in propelling the vessel; or, in other words, for showing the effective horse-power of the engines. It is fitted occasionally on board of a screw-steamer, the thrust of the propeller being transmitted through a series of levers to a Salter's spring-balance; but it is difficult to obtain true indications from this instrument, which is liable to many disturbing influences. There is a fixed dynamometer at some of H.M. dockyards, by means of which the pull of any steamer, whether paddle or screw, may be obtained in tons.

Velocity of piston.

It will be understood, from what has been already said, that the speed at which marine engines are driven is very various, and also that it is liable to vary (even in the same vessel) according to circumstances; such as the steaming capacity of the boilers, the necessity for economizing fuel, and the dimensions of the paddles or screw. Apart from the proper or "calculated" speed, there is of course the additional consideration of the variable trim of the vessel, and the undulations of the sea, which affect the speed of the engines by throwing more or less work upon them, in proportion as the propelling agent is deeply or lightly immersed. The subjoined tables will convey some idea of the velocity at which pistons are driven (under the most favourable circumstances of *trim*) by some of the principal marine engineers of the day:—

Speed of Pistons in Merchant-Steamers (Paddle and Screw).

Name of Vessel.	Makers of the Machinery.	Diameter of cylinder.	Length of stroke.		Revolutions per minute.	Speed of piston in ft. per min.	How propelled.
		Inches.	ft.	in.	Revols.	Feet.	
Great Eastern	Watt	84	4	0	50	400	Screw, direct.
Delta	Penn	72	7	0	25	350	Paddle, feathering floats.
Great Eastern	Scott Russell	74	14	0	12	336	Do. common.
Shannon	R. Napier	97	9	0	18	326	Do. „
Mersey	Maudslay and Field	60	5	0	30	300	Do. „
Ceylon	Humphrys	72	3	0	50	300	Screw, direct.
Colombo	R. Napier	72	5	6	26½	291·5	Do. geared.
Atrato	Caird	96	9	0	15	270	Paddle, feathering.
Pera	Rennie	75	4	0	32	256	Screw, geared.
Oneida	Inglis	82	4	6	26	234	Do. do.
Tamar	Penn	72	7	0	16½	231	Paddle, feathering.
Prince Consort	Scott Russell	30	2	6	45	225	Do. do.
Speed of Pistons in Government Screw-Steamers.							
Agamemnon	Penn	70⅜	3	6	60	420	Trunk, direct.
Mohawk	Humphrys	42¼	2	2	88	381	Horizontal, direct.
Esk	Scott Russell	50	2	9	68	374	Oscillating, direct.
Arrogant	Penn	55	3	0	61	366	Trunk, direct.
Princess-Royal	Maudslay and Field	64	3	0	58	348	Horizontal, direct.
Simoom	Watt	43⅜	3	0	55	330	Oscillating, direct.
Conflict	Seaward	46½	2	0	70	280	Horizontal, direct.
Duke of Wellington	R. Napier	94	4	6	30	270	Horizontal, geared.
Highflyer	Maudslay and Field	55½	2	6	53	265	Horizontal, direct.
Dauntless	R. Napier	84	4	0	31	248	Horizontal, geared.
Fairy	Penn	42	3	0	40	240	Oscillating, geared.
Sharpshooter	Miller and Ravenhill	46	3	0	38	228	Horizontal, geared.
Rifleman	Ravenhill	34	2	9	36	198	Oscillating, geared.
Rattler	Maudslay and Field	40½	4	0	25½	204	Double cylinder, geared.

All the merchant-steamers in this table have a speed of above 13 knots, and the government steamers of 10 knots.

Some of these speeds are nearly twice as great as would be sanctioned by the table previously quoted as embodying the practice of James Watt; and although, theoretically speaking, there may be no objection to such high velocities, they are inconvenient in practice, from the tendency of the working parts to heat by the friction, from the rapid wear of the parts, and their increased liability to accident or derangement.

Long and short stroke engines.

Although engineers are perfectly agreed as to the superior advantages of a long stroke for their engines, it will be seen by the preceding table how rarely in the case of screw-engines this desirable object can be accomplished. The cause of this is, that the *pitch* of the screw-propeller (by which term is implied the linear advance made by the screw during one complete revolution, supposing it to be working in a solid), cannot be effectively increased beyond a certain proportion, depending upon the diameter of the screw; and as the latter is necessarily limited by the draught of water, it follows that the only available means for augmenting the linear advance of the screw is by increasing the number of revolutions. For each revolution of the screw two journeys of the piston (in a direct engine) are required, and to enable this to be done within the required time, the strokes must be short. The chief disadvantages attending a short stroke are the more frequent recurrence of the "dead points" of the crank (when the piston arrives at the top and bottom of the cylinder), at which times much of the momentum of the moving parts is destroyed, and a jerk ensues in the engine; and the loss of a certain quantity of steam contained within the cylinder ports or passages at each stroke, which does not exert a direct pressure on the piston. It is natural to suppose, also, that short-stroke engines do not derive so much benefit from expanding in the cylinders as those having longer strokes.

Long and short connecting-rods.

Another desideratum for all kinds of steam-engines is a long connecting-rod, as tending to diminish the angular strain thrown upon the main crank, and thus avoid the loss of power arising from unnecessary friction. This action is made apparent by the accompanying sketch (fig. 18), in which *a b* represents a long connecting-rod, and *a′ b* a short one, their relative efficiency varying as the angles *a*, *b*, *c*, and *a′*, *b*, *c*. The defects of a short connecting-rod become sensible in practice by greater liability of the bearings to heat, by an increased wear of "brasses" and packings, and a larger consumption of oil for lubricating.

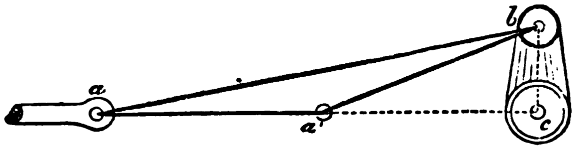

Fig. 18.

Cutting off the steam in the cylinder.

The cylinder of a steam-engine is never allowed a full measure of steam from the boiler, this being shut off at some part of the stroke according to the power it may be desirable to exert. A certain quantity of steam, varying generally from ⅙ to ⅕ of the contents of the cylinder, is always excluded by the slide valve, which is made to close the steam-port before the end of the stroke. In most engines a further amount of steam is excluded by means of a separate valve, called the expansion-valve, which is so arranged that it may "cut off" the steam, or prevent a further supply, at any desired point, according as it may be wished to economize fuel, more or less, at the expense of velocity. Thus, some engines are worked with ¾ of a cylinder full of steam to each stroke, some with ½, and others with only ¼; or the same engine may be worked successively at the different "grades of expansion" corresponding to these quantities. This is called "working expansively," because the portion of steam thus shut in continues to expand in volume, and to give out elastic force, to the end of the stroke.

Advantages of expanding steam in the cylinders.

Two advantages arise from cutting off the steam in this way. Firstly, it allows the stroke to be completed under a diminished pressure, so that the piston comes gently to rest at the top and bottom of the cylinder, without imparting a destructive jar to the machinery; and, secondly, it is economical of power (or, which is the same thing, of *fuel*), since it is found that the force actually exerted upon the piston by the isolated steam, during its expansion into the increased volume as the piston descends in the cylinder, is considerably greater than that due to the simple pressure of the same weight of steam acting at a uniform density.

It is found by calculation that when the steam is cut off at ½ stroke, seven-tenths of the power already exerted in the cylinder is added by the subsequent expansion of the steam; when cut off at ⅓, 2·1 times the power is added; and when cut off at ¼, 2·4 times nearly. According to the usually-received natural law regulating the pressure and elasticity of steam, it is assumed that the pressure is inversely proportional to the volume of the steam after it has expanded into the increased bulk, or, in other words, that when the steam has expanded to twice its original volume its pressure will be reduced one-half; when it has expanded four times its volume, the pressure will be ¼th, and so on. The pumping-engines in Cornwall, which do their work so very economically, use steam of about 40 lb. pressure, cutting it off in the cylinder after ⅙th or even ⅛th part of the stroke has been made, the remaining ⅞ths being performed wholly by expansion.

Expansion can be rarely pushed to its extreme limits.

It is very seldom, however, and that only when special means are provided for this purpose, that the principle of expansion can be beneficially carried out in marine engines to an extent nearly approaching that just mentioned. It is a well-known property of all gaseous fluids, steam included, that any expansion of volume is necessarily accompanied with the loss of sensible heat, which is taken up in the latent form by the expanded gas or vapour. Hence, when the steam expands under ordinary circumstances within the cylinder of a steam-engine, a portion of it is compelled to part with its latent heat, to enable the rest to retain the gaseous form. This portion of steam, therefore, condenses into water of the same temperature, which forms a thin film over the interior surface of the cylinder. When the return stroke begins, and the watery lining of the cylinder is brought into connection with the condenser, it rapidly evaporates into steam of low tension. This steam, besides vitiating the vacuum, acts still more injuriously by robbing the cylinder of the heat which it required for evaporation; when the metal of the cylinder, being thus lowered in temperature, condenses the steam, upon its re-admission, to a serious extent. Thus it happens that the principle of expansion, when carried out to any great extent in cylinders which are only "clothed" in the usual way, has so frequently failed to realize the expected economy of fuel; and this has been most unjustly charged to a defect in the principle of expansion.

Advantage of a steam-jacket.

In the case of the Cornish engines already mentioned, where the steam is expanded to eight times its volume with known advantage, the cylinder is invariably surrounded with a "jacket" kept well supplied with dense hot steam from the boiler, by which means it is retained at a high and nearly uniform temperature during the entire stroke; and to this steam-jacket it is mainly due that so remarkable an economy attends the use of expansion in Cornwall. The cylinders of a marine engine, on the other hand, are protected from radiation by a clothing of felt and wood only; but in the few instances where a steam-jacket has been applied, the most beneficial results have followed.

Advantage of super-heating the steam.

Another mode by which the expanded steam may be protected from condensation in the cylinder is by previously imparting to it an extra dose of heat beyond that due to its pressure, or, in other words, by "superheating" it. It is apparent that this extra heat becomes available for the supply of the latent heat demanded by the expanding steam, which is thus saved from premature condensation.

Conditions under which the full benefit of expansion may be obtained.

In order to derive the utmost benefit of which the principle of expansion is capable, it is necessary that the initial pressure of the steam should be considerable, that it should have plenty of space to expand into, and that the cylinder should be maintained at a high temperature. These conditions would seem to imply the use of a large jacketed cylinder of sufficient strength to bear the high initial pressure. As such a cylinder, however, would be very heavy and cumbrous, the plan has been occasionally adopted of using *two* cylinders in which to utilize the steam, namely, a large and a small one. In this case the high-pressed steam from the boiler is admitted into the small cylinder only, and after expanding in that to twice or three times its volume (by which its pressure is reduced to one-half, or one-third), it is then admitted from the small cylinder into the large one, where the expansive process is finally completed under the most favourable circumstances.

Combined-cylinder engines.

This combination, called the combined-cylinder engine, has of late been brought prominently forward by the engineering firm of Randolph Elder and Co., of Glasgow. Plates XXI. and XXII. represent the engines of the steamers Callao, Lima, and Bogotâ, made on this principle, and which have attracted much notice by their remarkable economy of fuel. Their principle dimensions will be afterwards given with the description of the plates. They were thus described by Mr Elder at the late meetings of the British Association—"These engines are constructed with the view of getting the greatest amount of power from a given quantity of steam at a given pressure, with less total weight of engines, boilers, and water, and occupying less total space than is found in the ordinary class of steam-engines on board of steamships. To accomplish these objects the following construction of engine has been adopted:—The cylinder capacity is so great as to admit of the steam being expanded to within 2 lb. of the pressure in the condenser at the end of the stroke, while the engines are working full power. In order to reduce the violent shock of steam at 42 lb. pressure on such a large piston, a cylinder with a piston one-third of the size is placed beside it. This small cylinder receives the steam direct from the boiler during one-third of its stroke, after which it is cut off. This steam is consequently reduced to one-third of its original pressure, or to 14 lb., at the end of the stroke, and it then enters the second or larger cylinder. Here it is expanded three times more, or down to 4⅔ lb. Thus, the steam at 42 lb. is expanded to 14 lb. in the first cylinder, at which pressure it enters the second cylinder, and is further expanded down to 4⅔ lb.; but as the second piston has three times the area of the first, the load will be the same on both pistons, and the piston-rods, cross-heads, and connecting-rods may be the duplicates of each other." The steam is superheated in the boilers to about 400°, and the cylinders are steam-jacketed and clothed with felt and wood. The feed-water is heated before entering the boilers. It is stated that, although the engines worked with superheated steam, this was found inadequate to prevent condensation in the cylinders without the use of the steam-jackets in addition, the indicator diagrams taken from these engines showing a marked increase of power resulting from a free use of the steam-jackets, the supply of steam to which may be modified at pleasure.

Economy of fuel in Lima, Bogota, &c.

These vessels have all shown a minimum consumption of from 2 to 2½ lb. of best Welsh coal per indicated horse-power per hour, their speed being at the same time 12½ to 13 knots, which must be considered a very satisfactory result. Their consumption of coal at their usual working trim is about 3 lb. per indicated horse-power, the vessel making 11 knots; whereas the more usual consumption of modern marine engines varies from 4 to 5 lb. per indicated horse-power per hour, and the average consumption of all classes cannot be less than 6 lb.

Two cylinders not considered requisite.

It is not contended, however, that the system of expanding in two cylinders is essentially requisite towards the attainment of a great economy in the consumption of fuel, and there are many instances of single-cylinder engines in which the same beneficial results have followed a like judicious combination of means and appliances for this purpose. A case in point is supplied by the recent performances of the steamship Thunder, a vessel fitted with machinery of much the usual kind, by Messrs Dudgeon of London. Although supplied with steam of only 14 lb. pressure, her engines do not consume more than 2¼ lb. of coal per indicated horse-power per hour, the vessel making 13 knots. Her machinery is represented by Plates XIX. and XX., and will be found fully described at page 140. An indicator-diagram from her engines is here subjoined (fig. 19).

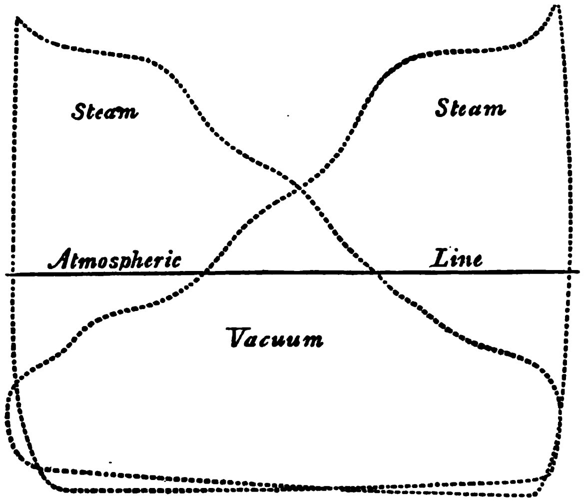

Fig. 19.

Screw-steamer Thunder.—3d Nov. 1859.

Forward Engine.—With super-heated steam and expansion.

Steam in boiler	13 lb.
Pyrometer on superheater	330 deg.
Number of revolutions	50
Diameter of cylinder	55 inches.
Stroke	36 „
Indicated horse-power, each cylinder, with expansion	= 348

Economy of fuel in steamer Thunder.

It may be stated that a consumption of 2¼ lb. of coal per indicated horse-power per hour would represent in Cornwall a "duty" of about 90,000,000 of pounds raised 1 foot high in an hour by a bushel (or 94 lb.) of coal, which is considered economical working even for a Cornish engine. The success achieved in the case of the Thunder appears to be due to the conjunction of the following good qualities in the machinery—viz., a perfect command of steam in the boilers, the superheating and expanding the steam in "belted" or jacketed cylinders, and the allowance of an unusually large inlet and outlet for the steam by the main valves.

Economy of fuel in Omeo.

Another example of unusual economy in the consumption of fuel has been recently shown in the auxiliary screw-steamer Omeo, fitted with engines of 100 nominal horse-power, by Messrs Morrison of Newcastle. These engines use steam at 60 lb. pressure, which is expanded to a large extent in single cylinders, and afterwards condensed in the usual way, the cylinders being surrounded with steam-jackets. The engines work up to 426 indicated horse-power, while driving the ship at 9 knots, and burning only 2·4 lb. of coal per indicated horse-power per hour. As the use of high pressure steam necessarily implies a boiler of corresponding strength, the Omeo's boilers are cylindrical, with "coned" furnaces and upright "coned flues," fitted with a superheating chamber on the top. The employment of steam of this high tension, however, is not to be recommended for passenger-steamers.

Importance of the question of economy of fuel.

The question of economy of fuel is of vital importance even in a national point of view, as affecting the maintenance and extension of some of our great postal lines of ocean steamers, and it is now receiving a large share of attention both from steamship owners and engineers. The subject naturally divides itself into two heads—the production of steam in the boiler, and its subsequent employment in the engine.

The boiler.

1st, *The Boiler.*—It is a material point towards economical working that the boiler should be large enough to ensure a constant command of steam without the necessity for "forcing" the fires, or continually stirring them up. This acts prejudicially in more ways than one. In the first place, each time that the fire-door is opened the cold air rushes in through it, and mixing with the hot gases in the furnace, checks their perfect combustion, at the same time that it robs the interior of the boiler of much valuable heat. Again, if the boiler be deficient in heating surface, the fires must be kept *thin*, to promote rapid combustion; and as these fires are specially liable to "burn into holes," a quantity of cold air enters the furnace through them, and the same cooling effect is produced in the flues and passages. It may be also remarked that, however desirable it may be to "burn smoke" by admitting air into the furnace above the bars, it is seldom an *economical* process, and if not managed with great caution, is apt to become very much the reverse. The best practice seems to be to admit a definite small quantity of air to the fires through perforated fire-doors of the common construction; those complicated doors fitted with Venetians, or other contrivances, for opening and closing the apertures, requiring too much attention from the firemen to be practically useful, besides adding to the weight and expense of the doors. Again, the natural consequence of stirring the fire too much is, that a large quantity of small coal and cinder falls through the bars into the ash-pit, and as the boilers cannot supply the constant demand for steam unless the fires are kept bright and active, these cinders cannot be re-burned, for fear of checking the formation of steam. They are thrown overboard, therefore, with the ashes, and a heavy expense is incurred.

Forcing the fires is expensive of fuel.

Smoke-burning not economical.

Stoking is not a mere mechanical operation.

It may be thought by some persons that stoking is a mere mechanical operation, easily acquired by the commonest labourer; but this is a great and vital error, which generally costs steamship owners many thousand pounds before they find it out. The stokers, in fact, may be wasting coals by the ton at the furnaces of the boilers for want of proper supervision, while the engineer is straining every nerve to save a few pounds weight by economizing steam in the engines, and possibly congratulating himself, at the same time, upon his able management. It is no unusual case for a difference of 20 per cent. in the consumption of fuel to arise simply from good or bad stoking, by which is meant the whole management of the fires and the draught. The *quality* of the coals is another important item in estimating the consumption per horse-power, and some remarks on this subject will be made hereafter. In large ships the mere labour of passing the coals along to the front of the fires is very severe, and some contrivance of slides or rails to enable the buckets to be easily run down the firing stage is recommended. The stoker's duty is, at the best, a most irksome one, and it is found in practice that any contrivance which adds to his comfort or convenience, whether it be by reducing the heat of the stoke-place, supplying him with a tap of cold distilled water, &c., is amply repaid by the increased attention bestowed on the fires.

The comfort of the stokers should be consulted.

Draught to the fires.

Rapidity of combustion.

A marked reduction in the heat of the stoke-place in many of her Majesty's ships has attended the use of the double smoke-box doors, shown in the subjoined sketch (fig. 20), which are kept cool by a current of air passing between the double linings. It is very important, both as regards the coolness of the stoke place and the steaming power of the boilers, that the draught of air to the fires should be encouraged as much as possible by means of large hatches, wind-sails, and air-tubes. It is found preferable, where rapid combustion is required, to allow two or more funnels to the boilers, if by this means the draught may be made more direct; for the question here is not merely how to generate steam with the least possible consumption of fuel, but how to do this in the least possible time, and with a boiler of the least possible weight and capacity. It is comparatively an easy matter to evaporate water economically in a Cornish boiler, for instance, but a very difficult and complex one under the conditions imposed upon the marine engineeer. The ordinary rate of combustion in the furnaces of marine boilers is about 15 lb. of coal burned on each square foot of grate-bar surface per hour; and the ratio existing between the absorbent or "heating surface" of the boiler and the grate-bar surface varies from 15 to 25 of the former to 1 of the latter. The furnace-bars are frequently made so thick as unnecessarily to impede the admission of air to the fires. They should not exceed ¾ of an inch for wrought-iron, or 1 inch for cast iron, on the upper edge, and should have an air-space of from 7/16ths to ½ inch between them, while burning Welsh coal.

Fig. 20.

Heating surface.

The nature and arrangement of the heating surface in a boiler is very material, the chief points to be considered being, that the steam may have a ready escape from every part of the heated surface, that every portion of the interior of the boiler should be accessible for "scaling," or removing the crust of insoluble matter which forms upon the plates and tubes, and that soot and ashes should not collect in any of the flues or passages. A large and high furnace is very desirable for facilitating the proper admixture of the combustible gases with the oxygen of the air. Brass tubes are much preferable to iron for rapidity of evaporation, as might be expected from their relative powers of conducting heat. Some recent experiments have shown, that the evaporative power of clean brass tubes is, to that of iron, as 125 : 100; and copper tubes as 150 : 100, nearly.

Use of salt water in marine boilers.

Salt-water being necessarily used in the boilers of sea-going steamers, this is liable to become more and more saturated with salt and earthy impurities in proportion as the steam passes off to the engines. A twofold evil thus arises. The super-salted water, as it increases in density, demands more heat before it will part with its steam; and the insoluble ingredients it contains (chiefly the carbonates of lime and magnesia, and the sulphate of lime), gaining strength with the abstraction of the steam, are deposited inside the boiler, thus forming a non-conducting skin, which greatly impairs its efficacy, and subjects the plates to risk of injury from the fire. To remedy this, a certain portion of the water in the boiler is "blown off" into the sea, its place being supplied by the feed-pumps with a corresponding portion of the hot water, which results from the condensation of the steam by a jet of sea-water. As the temperature of the "feed," however, does not exceed 100°, while that of the brine it replaces is probably about 230°, it is evident that much heat is thus lost, more especially as a good deal of steam is believed to escape with the water that is blown off. Notwithstanding this, however, it is more economical of heat to keep the water in the boiler tolerably fresh by a copious admission of feed, which prevents in a great measure the formation of scale, and conduces to the longevity of the boiler at the same time.

Constituents of sea-water.

According to Dr Ure's experiments, the largest proportion of salt held in solution in the open sea is 38 parts in 1000 by weight, and the smallest 32. In a specimen brought from the Red Sea, 43 parts were found, the specific gravity of the water being 1·035. The Mediterranean contains about 38 parts in 1000, the British Channel 35·5, the Arctic Ocean 28·5, the Black Sea about 21, and the Baltic only 6·6.

The same authority states, that deep sea-water from the ocean (from whatever locality) holds nearly the same ingredients in solution, containing, on an average, in 1000 parts—

25·0	Chloride of sodium or common salt.
5·3	Sulphate of magnesia.
3·5	Chloride of magnesium.
0·2	Carbonates of lime and magnesia.
0·1	Sulphate of lime.
34·1	

Also a little sulphate and muriate of potash, iodide of sodium, and bromide of magnesium.

"Blowing off."

Surface blow-off.

Proper degree of saturation of water in boiler.

It is now a common practice to "blow off" the requisite quantity of brine continuously, in the proper proportion to the amount of feed admitted, so as to keep the water in the boiler at a certain regular degree of saturation, at which it is found by experience that little or no deposition of "scale" will take place. Till within the last few years, boilers were always blown-off from the *bottom* only, it being not unnaturally supposed that the heaviest and most saturated water would be found there; but experience has now proved that the greater portion of the impurities from which the scale is formed are to be found on the *surface* of the water of the boiler (being carried upwards by the steam), and should be abstracted from thence. Mr Lamb, the superintending engineer of the Peninsular and Oriental Steam Navigation Company, was the first to introduce "surface blow-off," which is now very generally used in addition to blowing-off from the bottom, and is attended with a considerable improvement in the condition of the boiler surfaces. The rule adopted by this company is, that the feed and blow-off shall be so regulated, the one to the other, that the water in the boiler may be always at the degree of saturation marked 17 on the scale of their hydrometer, which represents a saturation of between 3/32 and 4/32 parts of salt, pure water being represented by zero, common sea-water by 1/32, and fully saturated sea-water by 12/32.

The following table shows the boiling point and specific gravity of sea-water (at 60° Fahr.) of different degrees of saturation, expressed in parts of salt contained therein, the barometer indicating 30 inches of mercury:—

	Saltness.	Boils.	Sp. gr.
Pure water..............	0	212°	1·
Common sea-water....	1/32	213·2°	1·029
Up to this point but	2/32	214·4°	1·058
little deposit will be	3/32	215·5°	1·087
formed............→	4/32	216·7°	1·116
	5/32	217·9°	1·145
	6/32	219·1°	1·174
	7/32	220·3°	1·203
	8/32	221·5°	1·232
	9/32	222·7°	1·261
	10/32	223·8°	1·290
	11/32	225·0°	1·319
	12/32	226·1°	1·348 saturated solution.

As a general rule, the atmospheric boiling point of the water should never be allowed to exceed 216°, when the barometer stands at 30 inches. The temperature must be ascertained by drawing off a small quantity of the brine, and boiling it in a deep copper vessel in the engine-room, a correction being made, as nearly as possible, for the state of the barometer.

The following table shows the height of the boiling point of pure water at different heights of the barometer:—

Barometer. Inches.	Boiling Point.	Barometer. Inches.	Boiling Point.
27	206·96°	29½	211·20°
27½	207·84°	30	212°
28	208·69°	30½	212·79°
28½	209·55°	31	213·57°
29	210·38°		

In testing brine by the hydrometer, care must be taken that it has the particular temperature for which the hydrometer-scale was calculated. This is usually 200° Fahr. About 3° of temperature make a difference of ·0001 of the specific gravity, or ·036 of the usual hydrometer degree, or ·0036 of the density of sea-water. The steam raised from salt-water and fresh is precisely the same in every respect; but it has been found by experiment that water of the density which it usually acquires in marine boilers, demands about one-tenth more of heat to convert it into steam than if it were fresh-water, its "capacity for heat" being greater to this extent. It is needless to say, that salt itself will not be deposited until the brine arrives at its point of greatest saturation, or three times the density which the water should ever be allowed to acquire; but what the engineer has to guard against is, the deposition of a solid stone-like incrustation, composed of the sulphate and carbonate of lime, and the carbonate of magnesia. These are at first held in solution by the water, but are subsequently rendered insoluble, and become deposited on the plates and tubes of the boiler, partly from the free carbonic acid being expelled by the boiling of the water, and partly by its continued saturation.

Surface condensation.

Many, though hitherto unsuccessful, attempts have been made to obviate the necessity for this expensive process of blowing off. The only effectual remedy is the employment of fresh water in place of salt in the boilers; but this can only be accomplished by the adoption of "surface condensation." By this term is understood the condensation of the steam by contact with a large extent of cold metallic surface, instead of the usual method of condensing by a jet of sea-water. This principle, though occasionally adopted, has generally proved more or less inefficient, and the invention of a really effective method of surface condensation is still a problem in marine engineering. It is believed that an economy of about 15 per cent. in consumption of fuel, results from the use of fresh-water in the boilers of marine engines, with a longer duration of the boiler, and the saving of much valuable time consumed in cleaning. The average duration of boilers using salt-water does not exceed six years, while those using fresh-water last eight or nine; but the life of a boiler is very uncertain, depending so much on the care and attention bestowed upon it.

Process of "scaling."

The process of "scaling" a boiler, or removing the deposit from the internal surfaces, is a very tedious and troublesome one, the scale being detached by hammers and chisels, after being loosened as much as possible by lighting fires in the furnaces of the empty boiler. In some recent experiments on this subject made at Portsmouth by Mr Lindsay, the boiler was filled with hot air at a temperature of 400°, which acted most successfully in detaching the scale by the rapid expansion induced. The boiler was afterwards filled for service, and so soon as a pressure of steam was obtained, the bottom blow-off cocks were opened, and most of the scale previously detached was "blown off" into the sea.

Donkey-engine.

Almost all boilers are now fitted with an auxiliary or "donkey" engine, for the purpose of keeping up the requisite supply of feed, while the regular feed-pumps attached to the large engines are not working. The "donkey" is also made useful for pumping water either from the sea or the bilge, and is an invaluable aid in case of fire.

Feed-water heaters.

In many steamers the feed-water is heated to a point considerably above the temperature of the condenser, by means of the waste heat of the boiler itself; being brought into contact either with the brine which is blown off, or with the hot air at the foot of the chimney. By this means its temperature may be raised from about 100° to 180° or 200°; and as modern practice shows the advantage of freshening the boiler by a plentiful admission of feed, it is very desirable that its temperature should be thus previously raised. Various modes of effecting this will be found mentioned in the descriptions to the plates accompanying this article. The feed-water heater of the Great Eastern has acquired an unfortunate notoriety from the sad consequences attending its explosion, though there is no inherent danger in the arrangement there adopted, which has been safely and successfully applied in many other vessels.

"Priming."

When the ebullition inside a boiler is so rapid and violent that the water rises with the steam in considerable quantity, and is carried over with it to the engines, or is blown up the waste steam-pipe, the boiler is then said to "prime." This is one of the most dangerous and troublesome propensities to which a boiler can be subject, as it may occasion a break-down in the engines by the shock of the piston upon the incompressible fluid (if escape-valves of sufficient capacity are not fitted), and in all cases it entails a great loss of heat carried off by the hot water which boils over.

Causes of priming.

Priming may arise from a variety of causes, but the prevalent one, more especially in the government service, is a too contracted steam space over the water of the boiler. For where the reservoir of steam from which the engines are supplied is very small, there must be constant pulsations of pressure in the boiler; and each time that the surface of the boiling water is relieved of a certain amount of pressure by the rapid withdrawal of a cylinder full of steam, it boils up with great violence, and possibly overflows into the steam-pipe. The only remedy for this is an addition to the size of the steam-chest, and an increased height above the surface of the water to the steam-pipe orifice. Priming, however, is frequently the result of accidental causes, apart from the construction of the boiler. Water charged with mud or mucilage, which forms a viscid scum on the surface, is sure to induce it; also while the ship is passing from fresh-water into salt, and *vice versâ*. A new boiler with clean "raw" surfaces, is more liable to prime than after it has contracted a coating of scale, in consequence of the brisker ebullition going on, as well as from the dirt and grease left in a new boiler by the workmen. It is a usual practice to put tallow in a boiler as a *preventive* of priming, but this is not always attended with the desired effect. When the boiler primes very much, it is necessary to slow the fires, so as to prevent the too rapid formation of steam.

"Wet" steam.

All boilers are subject to the loss of a certain quantity of water, which rises with the steam in the shape of fine spray, and passes over with it into the cylinders of the engines. When much of this is present, the steam is said to be "wet;" but it is believed that all steam raised in the ordinary way is more or less charged with water in a state of fine subdivision. To evaporate and utilize this water is one of the principal incentives to the use of surcharged or "superheated" steam. The other advantage arising from its use, namely, the prevention of condensation in the cylinders, has been already referred to while treating of expansive working.

Superheating apparatus.

The steam in the boiler may be superheated in a variety of ways, but those methods seem preferable which use for this purpose the spare heat at the bottom of the chimney, which would otherwise be almost entirely lost. The accompanying sketch (fig. 21) explains the method which has

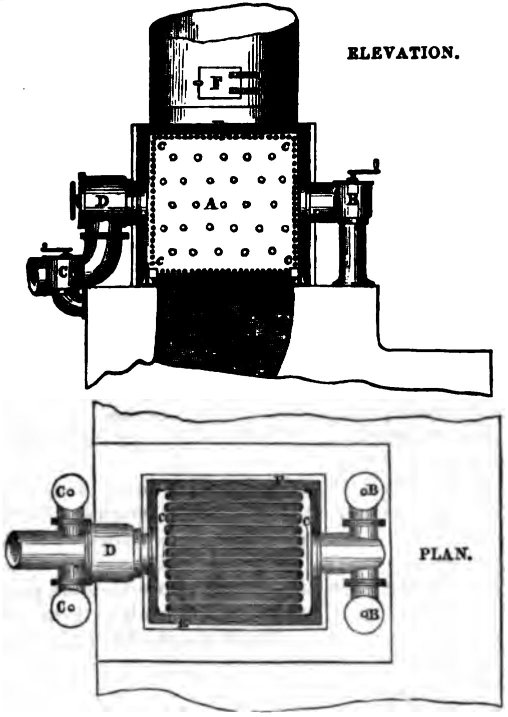

Fig. 21.
Lamb and Summers' Superheating Apparatus.

been already largely employed in the steamships of the Peninsular and Oriental Steam Navigation Company, those of the Union Steam Packet Company (carrying the Cape mails), and many others at Southampton, and which has been attended with the most undoubted success. It will be observed that the steam, in its way from the boilers to the engines, passes through the superheating chest A, at the foot of the chimney, the steam occupying the narrow spaces between the sheet-flues through which the smoke and hot air pass.

BB are stop-valves for admitting the steam to the apparatus, or excluding it if necessary.

CCC are stop-valves for passing the steam direct from the boilers to the engines without going through the apparatus.

DD are stop-valves for admitting the superheated steam to the engines, or shutting it off when common steam only is used.

EE is a square casing enclosing the apparatus, and forming the foot of the chimney, the smoke and hot air of which entirely surround the superheating chest. Other casings of thin iron are fitted outside this, to prevent the radiation of heat.

F is a door for getting into the chimney, and examining the flues of the apparatus.

The chimney is not rigidly fastened to the square casing, but ships over the projecting part HH, the space between being filled with clay. This mode of carrying the chimney is adopted, so that, in the event of collision, the loss of the chimney should not entail the destruction of the apparatus and its connexions.

It is found, from experience, that a heating surface of about 4 square feet per nominal horse-power of boiler is required to superheat the steam under ordinary circumstances. The temperature of the steam, when issuing from this apparatus, is generally found to be about 320° to 360°; and in the slide-jacket, from 20° to 30° less, according to the length of the steam-pipe.

The saving of fuel in the steamships of the Peninsular and Oriental Company, by the use of this apparatus, is stated to vary from 15 to 30 per cent., without any injurious effects resulting to the piston-packings, &c.

A high temperature not required.

By this simple and inexpensive process the whole steam given off by the boiler is "superheated" from the temperature due to its pressure (which for steam of 15 pounds pressure would be 250°) to a temperature of from 320° to 350°, which has been proved to be amply sufficient for obtaining all the benefit derivable from the process. That much of the heat of superheated steam is really employed in evaporating the particles of water held in suspension seems to be proved by this fact, that its temperature will fall as much as 25 or 30 degrees, in some cases, during its passage from the boiler to the engine, though there is no perceptible escape of heat by radiation from the surface of the well-protected steam-pipe. The heat thus apparently lost is undoubtedly taken up (in the latent form) by the steam resulting from the vaporization of these watery particles, by which means the heat already contained in the water is turned to good account, and the evaporative power of the boiler is virtually increased.

Economy of the process.

A great many experiments have been made to test the actual economy of the process by comparison with the existing consumption of coal before the superheating apparatus was fitted, and in every instance there has been a perceptible improvement. This sometimes takes the shape of increased speed in the engines and vessel, sometimes a saving of fuel alone is effected, and in other instances both of these are combined in the same vessel in variable proportions. Where the speed of the vessel has been kept a constant quantity, there would appear to be an actual saving of from 15 to 25 per cent. of fuel, according to the nature and qualities of the boiler to which the process has been applied, and the amount of expansion in the cylinders. The high rates of economy are naturally shown by those boilers which were previously the worst to keep steam with, and which required very hard firing to do so. Those addicted to priming and wet steam rank next in apparent economy, while those boilers which show the least were originally the best specimens of their class. There is no question, however, but that the process is beneficial *in all cases*, though not equally so; and that it enables the steam to be raised in the boilers without "hard firing" being resorted to, being in this respect a great boon to the stokers.

Wethered's *mixed* superheated steam.

It is believed that no advantage over the ordinary methods of superheating the steam is due to Mr Wethered's system of mixing superheated and ordinary steam together at the point where they enter the valve-jacket. To this gentleman's patent, however, we owe, in a great measure, the general awakening of marine engineers to the undoubted advantages of the process, which have been till now so unaccountably overlooked.

Conservatism in marine engines.

The plan adopted by the government of contracting for their steam machinery with only a few favoured and old-established houses, though perhaps justifiable in other respects, has undoubtedly tended to promote conservatism in marine engines, and to repress innovations and improvements, the wholesome though often unpalatable principle of competition being scarcely roused into action. These lordly manufacturers have nothing to gain, in fact, by breaking new ground, being well assured of their accustomed orders from the Admiralty, and not caring, perhaps, to raise the question whether their beautifully constructed machinery might not possibly content itself with a more moderate allowance of fuel. In the case of those manufacturers, however, who have not the *entrée* at Whitehall, but who are dependent upon the custom of the great steam shipping companies, and other private owners of steam-vessels, who have a strong interest in this question, there exists an active competition, and consequently a powerful inducement to improve upon the economical performance of their machinery. We find, accordingly, that it is this class who have taken the lead in the steam reformation which has recently set in.

Marine boilers.

There are three principal kinds of marine boilers in use in this country, namely, the rectangular-flue boiler (which is now very generally discarded); the multitubular boiler, or, as it is more usually called, the *tubular* boiler; and the sheet-flue boiler. The tubular boiler (as shown in Plates XIX. and XX.) is that in most general use. This construction enables a very large quantity of heating surface to be crowded into comparatively small space; while the form of the tubes, which vary from 2½ to 4 in. in diameter, affords great strength, at the same time that the thinness of the metal composing them offers little impediment to the conduction of heat. They are attended with this inconvenience, however, that the flame arising from the combustion of the inflammable gases in the furnace is prematurely extinguished by the minute subdivision and rapid reduction of temperature to which it is exposed in passing through these small tubes.

The tubular boiler.

It is well known that flame requires a very high temperature for its maintenance, and is easily extinguished by contact with a comparatively cool surface; as for instance, in passing through the wire-gauze of the miner's safety-lamp. A precisely similar effect is produced by the boiler-tubes, whose temperature, from their being surrounded with water, must be considered low when compared with that of the flame and hot gases passing through them.

Vertical-tube boiler.

The Americans have adopted a different form of tubular boiler (as shown in the accompanying wood-cut, fig. 22), in which the tubes are disposed vertically, the smoke and flame passing round the *outside* of the tubes, and the water being contained *inside*. These vertical-tube boilers are very effective in generating steam, and partly for this reason, that the flame reaches further amongst their tubes than in the case of a horizontal boiler, in consequence of the greater space outside the tubes in which the flame may develop itself. The importance of this, while using the bituminous *flaming* coal of the northern coal-fields, is very great. The absorbent surface of the vertical-tube boilers is, of course, greater than that of the horizontal in proportion as the external diameter of the tubes exceeds their internal diameter, and the weight of water it is necessary to carry is much less.

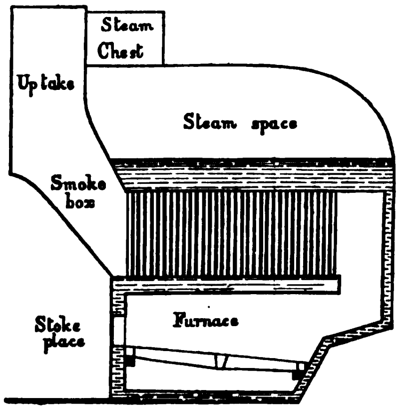

Fig. 22.

American upright-tube Boiler.

Sheet-flue boiler.

Sheet-flue boilers are constructed with numerous flat, narrow water-spaces, alternating with flues of the same form in place of tubes. The width of the water-spaces in "Lamb and Summers' patent sheet-flue boilers" varies from 1½ to 2 inches, and the flues from 2½ to 3 inches. They are extensively used in the steamers of the Peninsular and Oriental Company, where they give much satisfaction from their durability, and economy in repairs.

Explosions of boilers. Causes.

When a marine boiler explodes, the presumption is, either that the boiler has been originally weak in one particular place, where it has given way under a pressure but slightly exceeding that at which it is usually worked: or, secondly, that the safety-valve has not acted properly, or has been over-weighted, and the boiler has burst simply from excess of pressure: or, thirdly, that the water has been allowed to fall too low, and thus expose the tops of the flues or furnaces, or the boiler-tubes, which, getting red-hot by the action of the flame, have suddenly generated such a rush of steam, upon the re-admission of the feed, as to cause a rupture of the weakened plates. Explosions most frequently happen at the moment of opening or shutting a safety-valve or communication-valve, which shows that so long as the steam remains undisturbed within the boiler, it will sustain a very high pressure without bursting; but should a wave or pulsation be carried through it, the equilibrium is instantly destroyed, and a rupture takes place. The very act of suddenly opening a safety-valve, or a communication-valve to the engines, would cause the water to boil up with great violence, and an immense volume of steam to be instantly liberated, in consequence of the water being relieved from a certain amount of pressure.

Precautions, &c.

In the event, therefore, of the discovery being made that any portion of the boiler has become overheated from want of water, the engineer should neither open the safety-valve nor admit the feed, but throw open the fire-doors, close the dampers, and draw the fires, after which the safety-valves may be cautiously relieved, and the feed gradually admitted, until the overheated surfaces are covered with water.

In those parts of the boiler where the heat is most intense (as at the backs of the furnaces) the plates will gradually become oxidated and weakened by the fire, even although kept constantly in contact with water. This is probably owing to the rapid disengagement of steam from the surface, which interposes a non-conducting film of steam between the iron and the water, and thus permits the former to get overheated. Thick plates, or overlapped joints, in such a position, "burn out" quicker than thin ones, from the imperfect conduction of the heat through the metal, and this is of course much aggravated when the plates are coated with scale. Plenty of steam room is a safeguard to a boiler, as tending to diffuse and neutralize any dangerous oscillation or sudden accession of steam. The immense rush of steam which always follows an explosion is satisfactorily explained, when we consider that the instant the water contained in the boiler is relieved of pressure it throws off steam with great rapidity, and continues to do so until the whole mass of the water is reduced to the atmospheric condition of 212° Fahr. To make matters worse, the steam-chests of all the boilers are usually in communication.

Rarity of explosions in steamers.

It is gratifying to find that explosions occur so rarely as they do on board of steam vessels in this country—a result which is doubtless to be attributed, in a great measure, to the supervision of the Board of Trade: and it is worthy of remark that the majority of such accidents have happened to tug-boats, which, from not carrying passengers, are exempt from Government interference.

Requirements of the Merchant Shipping Act.

By the Merchant Shipping Act of 1854 the Board of Trade are empowered to enforce certain provisions of equipment of the vessel and her machinery, conducive to the safety of the passengers and ship. The principal points to which attention is directed by this act are, that the masters and mates of steamers shall have proper certificates of competency; that the hull and machinery generally shall be of sufficient strength; that the number of passengers carried shall be in proportion to the accommodation; that a sufficient number of boats be

Steam Navigation.

carried; that proper water-tight bulkheads be fitted, as well as pumps, fire-pumps and hose, life-buoys, lights, compasses, &c., &c. Each boiler is required to have one safety-valve, and recommended for further security to have two, the weights upon which have been sanctioned by the Board through their surveyor. One of these valves (called the government safety-valve) is to be kept locked beyond the control of the engineer of the boat, the key being placed under the master's charge. Every passenger-steamer is required by this act to renew her certificate of efficiency or sea-worthiness twice a-year, after periodical surveys have been held upon her hull and machinery; and if such certificate is not granted, she is debarred from carrying passengers until the required provisions are complied with.

Qualities of Coal.

It will now be desirable to convey some practical information regarding the coals used in steam-vessels. The qualities it is most desirable for steam coals to possess may be summed up as follows:—1. They should have a high evaporative power, or, in other words, they should be capable of converting much water into steam with a small consumption of fuel. 2. They should not be highly bituminous, as such coals produce a dense black smoke which it is difficult to consume in the furnace, and the soot and tarry matter evolved are found to clog the tubes and flues, and detract from the evaporative power of the boiler. 3. The coal should light quickly, and be capable of a rapid combustion. 4. It should be sufficiently cohesive in its nature to bear the constant attrition it is subjected to without becoming broken into small fragments. 5. It should combine a considerable density with such a mechanical structure as may admit of its being stowed in the smallest possible space, this involving a difference of 20 per cent. between coals of different kinds. 6. It should be as free as possible from sulphur, which induces progressive decay and spontaneous combustion.

Steam viga

Admi expe ment coals the R Navy

Table, showing an Abstract of the Principal Results obtained from the Best Coals of the United Kingdom, collated from the Admiralty Reports on Coals suited to the Steam Navy.

Name of Fuel.	Evaporative power or No. of lbs. of Water converted into Steam by 1 lb. of Coal.	Weight of cubic foot in lbs.	Space occupied by 1 ton in cubic feet.	Cohesive Power percentage of large Coals.	Evaporative Power after deducting for Combustible Matter in residua.	Evaporative Power per Hour per Square Foot of Grate surface.	Lbs. of Clinker per ton.
Graigola	9·35	60·17	37·23	49·3	9·66	...	30·6
Anthracite (James and Awbrey)	9·46	58·25	38·45	68·5	9·7	...	0
Pentrefelin	6·36	66·17	33·85	52·7	7·4	40·6	22·7
Duffryn	10·14	53·22	42·09	56·2	11·8	69·8	0
Oldcastle Fiery Vein	8·94	50·92	43·99	57·7	...	71·0	0
Ward's Fiery Vein	9·40	57·43	39·0	46·5	10·6	87·8	54·5
Binea	9·94	57·08	39·24	51·2	10·3	...	0
Llangennech	8·86	56·93	39·34	53·5	9·2	...	68·6
Pentrepoth	8·72	57·72	38·80	46·5	8·98	61·5	80·2
Mynydd Newydd	9·52	56·33	39·76	53·7	10·59	79·6	59·1
Three-quarter Rock Vein	8·84	56·39	39·72	52·7	...	88·3	42·8
Cwm Frood Rock Vein	8·70	55·28	40·52	72·5	9·35	...	40·8
Cwm Nanty-gros	8·42	56·00	40·00	55·7	8·82	71·3	23·7
Resolven	9·53	58·66	38·19	35·0	10·44	71·4	0
Pontypool	7·47	55·70	40·22	57·50	8·04	55·0	20·9
Bedwas	9·79	50·50	44·32	54·00	9·99	90·5	25·2
Ebbw Vale	10·21	53·30	42·26	45·00	10·64	90·5	9·3
Porth-Mawr	7·53	53·30	42·02	62·00	7·75	77·3	27·0
Coleshill	8·00	53·00	42·26	62·00	8·34	75·7	39·5
Neath Abbey	9·38	59·30	37·77	50·00	9·65	116·0	19·2
Llynvi	9·19	53·30	42·02	...	9·58	89·0	36·0
Rock Vawr	7·68	55·00	40·72	65·5	7·88	91·0	38·0
Aberdare Company's Merthyr	9·73	49·30	45·43	74·5	10·27	92·4	9·8
Thomas's Merthyr	10·16	53·00	42·26	57·5	10·72	111·8	3·9
Nixon's Merthyr	9·96	51·70	43·32	64·5	10·70	102·6	5·7
Hill's Plymouth Works	9·75	51·20	43·74	64·0	10·18	119·8	7·5
Slievardagh (Irish Anthracite)	9·85	62·80	35·66	74·0	10·49	84·5	18·0
Dalkeith Jewel Seam	7·08	49·8	44·98	85·7	7·10	63·0	62·2
Wallsend Elgin	8·46	54·6	41·02	64·0	8·67	91·0	14·6
Grangemouth	7·40	54·25	40·13	69·7	7·91	71·4	16·4
Eglinton	7·37	52·0	43·07	79·5	7·48	90·0	8·2
Newcastle Hartley	8·23	50·5	44·35	78·5	8·65	62·0	17·0
Carr's Hartley	7·71	47·8	46·86	77·5	8·13	84·6	5·0
North Percy Hartley	7·57	49·1	45·62	60·0	7·72	94·0	7·8
Hasting's Hartley	7·77	48·5	46·18	75·5	7·96	104·0	1·7
Hedley's Hartley	8·16	52·0	43·07	85·5	8·71	74·8	14·4
Original Hartley	6·82	49·1	45·62	80·0	6·98	106·5	10·1
Derwentwater's Hartley	7·42	50·4	44·44	63·5	7·66	95·0	28·3
Gadley Four-feet Seam	9·29	51·6	43·41	68·5	10·73	96·5	11·6
Haswell's Coal Company's Steamboat	7·48	49·5	45·25	79·5	7·85	61·0	9·8
Davison's West Hartley	7·61	47·7	46·96	76·5	7·83	96·5	2·1
Cowpen and Sydney Hartley	6·79	47·9	46·76	74·0	7·02	84·0	3·7
Balcarres Lindsay Mine	7·44	51·1	43·83	70·0	7·58	93·5	22·3
„ Haigh Yard	7·90	50·8	44·13	80·0	8·23	79·0	26·4
Johnson and Wirthington's Sir John	6·32	51·6	43·41	82·0	6·62	80·5	34·4
Wylam's Patent Fuel	8·92	65·08	34·41	...	9·74	72·4	61·6
Bell's „ „	8·53	65·3	34·30	...	8·65	91·5	76·1
Warlich's „ „	10·36	69·05	32·44	...	10·60	96·5	29·7
Lyon's „ „	9·58	61·10	36·66	...	9·77	93·0	38·7
Watney's Anthracite	11·08	67·0	33·43	87·5	11·40	127·4	24·6

Average properties of coal.

Properties.	Average of Seventeen Samples of Welsh. lb.	Average of Six Samples of Newcastle. lb.
Theoretical evaporative power	15·785	14·208
Specific gravity	1·325	1·259
Coke	86·87	66·1
Moisture	0·88	5·07
Frangibility, large	79·2	85·0
„ small	20·8	15·0

Average Chemical Analysis of 100 *parts of Dried Coal.*

Ash	2·24	4·32
Carbon	89·13	78·45
Hydrogen	4·23	5·11
Nitrogen	1·27	1.79
Sulphur	1·01	1·36
Oxygen	2·12	8·97

In the foregoing tables the "theoretical evaporative power" is deduced from the composition of each coal as determined by chemical analysis. It gives the maximum amount of heat which each coal could produce, calculated in terms of the number of pounds of water at 212°, which would be converted into steam at 212° by the complete combustion of 1lb. of each variety of coal.

Evaporative power of coal.

Anthracite.

Welsh coal.

1lb. of pure carbon (according to the most accurate experiments) emits, by its combustion, an amount of heat sufficient to evaporate 14·88 lb. of water at 212° into steam at 212°; and 1lb. of hydrogen, when burned, emits heat enough to convert 63·56lb. water at 212° into steam of the same temperature. It is found experimentally that the quantity of water capable of being evaporated by any coal is (as nearly as possible) directly as the quantity of coke which can be produced from that coal; the fact being, that in the case of bituminous coals, as burned in an ordinary furnace, as much heat is required for liberating the volatile products of the coal as is afterwards produced by the combustion of these volatile products, taking into account the cooling effect of the air admitted to maintain their combustion. Hence the very high evaporative power of anthracite coal, which, unfortunately, has certain countervailing disadvantages, that preclude its use in the boilers of a steam-vessel under ordinary circumstances. It is not only very difficult to light, but when lighted can be maintained in active combustion only by the aid of artificial draught, when the heat evolved is so intense as rapidly to destroy the fire-bars, as well as the material of the boiler itself. Welsh coal, which holds an intermediate rank as to its evaporative power between anthracite and the bituminous coals of the northern district, is considered the most suitable for steamers in general, and is much more easily stoked than bituminous coal.

Treatment of bituminous coals.

As Newcastle and other bituminous coals demand careful and peculiar treatment in the furnace, it may not be out of place here to give some directions for stoking it. The fires should be kept at a uniform thickness of from 12 to 14 inches. When the furnaces of one boiler are being charged, the fresh coal should be thrown upon the right-hand half of each fire in succession for one charge, and then upon the left-hand half of each fire during the next charge, and so on alternately, so that the whole fire may never be covered with "green" coals at once. The green coal is to be thrown upon the front half of the fire only, and never at the back of the fire, but when necessary the red burning fuel must be pushed back by the shovel, to keep up the proper thickness of the fires at the bridge. Where no means are provided for admitting air through the fire-doors, these must be left slightly open, after charging with fresh coal. By a due observance of the three last directions, the formation of black smoke with north country coal may be prevented. The cinders, as they fall through the spaces between the fire-bars, are to be raked forward in the ash-pits, and at every fresh charge a portion of them is to be thrown upon the fires after the green coal, so that nothing is removed from the stoke-hole but clinkers and ashes. The spaces between the fire-bars are at all times to be kept clear of clinkers and ashes, so that the air may have free access to the burning fuel. When the coals cake on the bars, the poker must be gently used to raise and open them for the admission of air to the mass of the burning fuel.

Patent fuels.

Some of the "patent fuels" have a very high evaporative power, but they are all, more or less, difficult to manage in the furnace, and should never be used where the stokers are unaccustomed to their peculiarities. They are very valuable in special cases, from the compactness with which they may be stowed.

Marine engines.

Marine governor.

We shall now advert to a few particulars having reference to the general construction and management of the ENGINES of steam-vessels. The first valve through which the steam passes after leaving the boiler is the *throttle-valve*, by means of which the flow of steam to the engines is regulated or shut off entirely by hand. In the event of a ship pitching very much in a heavy sea, it is often necessary to station a man at the throttle-valve to shut off the steam from the engine whenever it begins to "race," or fly off at a high velocity, according as the resistance is removed by the propeller becoming raised out of the water. Both paddle and screw engines are subject to this dangerous action, but particularly the latter, on account of the screw being, from its position in the ship, more exposed to sudden variations of "dip" or immersion. To mitigate this (in some measure), the contrivance called a "governor" has been successfully applied in many cases of screw-steamers, whose consumption of fuel in bad weather has been thereby much diminished, as well as the working of the machinery rendered more regular. Indeed, the commander of a screw-steamer has often found it practicable, after this little instrument had been fitted to his machinery, to keep his vessel head to wind in such weather as would have formerly necessitated his laying to.

Description of Silver's governor.

The annexed figure (28) represents the best, and indeed the only, species of marine governor that has (we believe) been successfully applied. It is called "Silver's momentum-wheel governor," constructed by Messrs J. Hamilton and Company of Glasgow, who have purchased the patent. "It consists of a momentum-wheel A, fixed on the boss of a pinion B, which works loosely on the spindle C, and gears into the two-toothed sectors DD. These two sectors, being supported on a crosshead E, made fast to and carried with the spindle C, work in opposite directions on the pinion B; and as they are linked by the rods FF to the sliding collar G, which receives and works the forked lever H, communicate motion to the throttle-valve T. MM are vanes, and N is a spiral spring, both of which are adjustable."

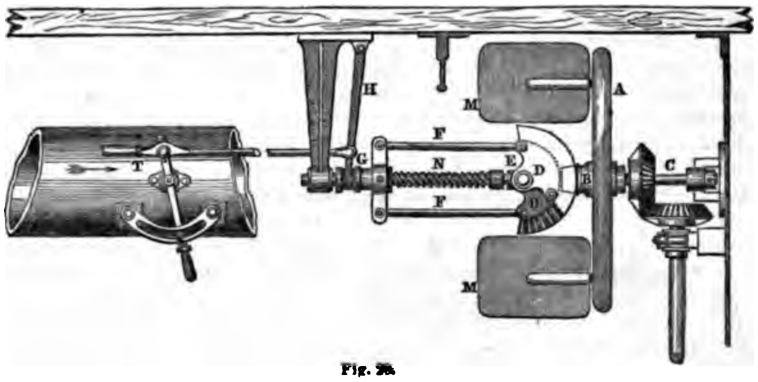

Fig. 28.
Silver's Marine English Governor.

Steam Navigation.

"The action of the above instrument is as follows:—When the spindle of the governor is turned by the engine to which it is attached, the two-toothed sectors, which are carried on the fixed crosshead, being geared into the pinion on the momentum-wheel, have the tendency to turn round on this pinion; but as they are linked to the sliding collar, they necessarily pull inwards this collar, and so compress the spiral spring, and this spring reacting on the collar, and consequently on the toothed sectors, serves to turn round the momentum-wheel, while the vanes on the momentum-wheel balance the action of this spring by the resistance the atmosphere offers to their progress through it. As the leverage action of the toothed sectors upon the momentum-wheel pinion increases (as the spring becomes distended, and *vice versâ*), it will be seen that the reaction of the spring in propelling the momentum-wheel will at all times be uniform, and as much only is required as will carry round the momentum-wheel with its vanes at its proper speed, and overcome the friction of working the throttle-valve and throttle-valve connections. When the momentum-wheel is in motion, it will rotate with the engine to which it is attached at a velocity proportioned to that at which it is fixed by the connecting gear; and while the engine, from the usual causes, may attempt to vary this velocity, it cannot affect the momentum-wheel, but leaves it free to act upon the sliding collar, and consequently upon the throttle-valve—at one time closing the throttle-valve by its action in resisting any increase of velocity, and at another time opening the throttle-valve by its action in resisting any decrease of velocity on the part of the engine. A momentum-wheel of 2 feet 8 inches in diameter, and 2 inches breadth of periphery, running at a speed of 180 revolutions per minute, is found to be sufficient to work with promptness and ease the largest throttle-valve."

The same engineers have also introduced, for this purpose, an ingenious modification of the ordinary Watt's centrifugal governor, called "Silver's four-ball governor," in which the action of a spiral-spring is substituted for that of gravity, and the whole apparatus (like the preceding one) is balanced, so as to remain undisturbed in its action by the pitching or rolling of the vessel. The performance of the four-ball governor, however, is not nearly so satisfactory as that of the one previously described.

Expansion-valve.

The steam, after passing the throttle-valve, next enters the *expansion-valve*, where it is cut off at any desired portion of the stroke, by the action of an eccentric, or cam, on the main shaft. Such an arrangement is shown in Plate XV. The valve usually employed for this purpose is the "equilibrium" or "double-beat" valve, as shown in the annexed engraving. This kind of valve has the advantage of being opened and shut with great facility, since, from its construction, the pressure of the steam has no tendency to jam it against its seat, the objection to which all single flat valves are subject. It is also apparent that a slight rise of this valve gives a large opening for the steam to pass. In the engraving, the valves *a a* are made of *brass*, and the valve-box, and the spindles connecting the valves, are of *iron*. In this instance the valves are purposely connected by iron spindles, in order that the linear expansion of the sides of the box containing the valves, and of the spindle connecting them, may be equal in amount, and therefore have no tendency to raise the upper valve off its seat, which would certainly ensue were the valves connected by a brass spindle, in consequence of the greater expansion of that metal by heat. This arrangement of the metals will be seen to be of special importance when superheated steam is used, and the temperature thereby increased.

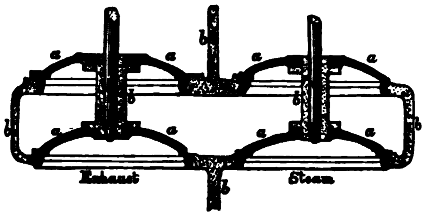

Fig. 24.

Slide-valves.

Having passed the expansion-valves, the steam now enters the jacket of the cylinder *slide-valves*. These are usually so constructed and arranged as to fulfil the following conditions for the admission and exclusion of the steam, independently of the action of the expansion-valves:—1*st*, The steam is shut off a little before the end of the stroke, by the valve prematurely closing the steam-port aperture. The use of this is to check the velocity of the piston, by causing it to finish the stroke by the expansion of the enclosed steam only. This is effected by giving "lap" to the valve. 2*d*, The eduction-port, or the passage to the condenser, is closed a little before the end of the stroke, which is called *cushioning* the piston, because it then completes the stroke against an elastic *cushion* of vapour shut up between it and the top or bottom of the cylinder. 3*d*, The port is opened for the admission of steam to the cylinder a very little before the piston begins the return-stroke, in order that the steam may have filled the passages and the "clearance" of the piston, and have acquired its full pressure, by the time that the crank shall have turned the centre. This is effected by giving what is called "lead" to the valve. 4*th*, The communication with the condenser is opened a little before the end of the stroke, so as to have a vacuum ready made in the cylinder so soon as the return-stroke begins. In this way each operation which takes place in the cylinder is slightly *anticipated* by the mode of setting the valves. In the case of screw-engines especially (which run at a high velocity), it is of the greatest importance that the steam-passages and valves should be of ample size, and those valves only should be used which give a large opening for the steam, with a short "travel" of the valve.

Condenser

As the nature and limits of this article preclude a minute description of the details of the marine engine (which indeed are very similar to those of the stationary condensing engine, already given in the article STEAM-ENGINE in *Ency. Brit.*), we will not attempt this, but at once follow the steam from the cylinder into the *condenser*. In this magical little chamber the whole of those perplexing processes we have been considering are at once reversed, and all the labour and expense incurred in generating the steam in the boilers (themselves about twenty times larger than the condenser), are, as it were, instantly annihilated. The condensation of the steam is usually effected by the dispersion of a jet of cold sea-water amongst it, which is the most effectual means yet known for producing that instantaneous condensation, upon which the efficacy of the process is entirely dependent. Many attempts have been made, as we have before stated, to condense the steam by contact with cold metallic surfaces without the use of the water-jet, but they have mostly failed, more or less, from the condensation not being sufficiently sudden. The plan known as "Hall's Condensers" is, indeed, partially successful; but, owing to their weight, bulk, complexity, and expense, they are very little used, although it is now twenty years since their first introduction. Mr J. F. Spencer has been very successful in his adaptation of this principle, and now that it is being taken up in earnest by other talented engineers (as Mr E. Humphrys), we may anticipate a more favourable result. In most surface-condensers the steam is passed through a great many small copper pipes, contained in a cistern of cold water, through which a current from the sea is made to flow by means of a force-pump. In such an arrangement, the loss of water arising from leakage, or from blowing-off at the valves, is compensated to the boiler by employing a small apparatus to distil sea-water, by the aid of which the boilers are kept constantly supplied with fresh water. A close connection exists between the temperature of the condenser and the vacuum,

Surface-condensers

Best vacuum for the condenser.

Superheated steam condenses freely.

the latter being of course more complete as the temperature is reduced. There is a limit, however, beyond which any further reduction of temperature, by injecting more sea-water, is attended by a loss of power. It is found in practice, that a temperature of from 95° to 105° (depending upon the pressure of the steam), is the most economical, with which a vacuum of from 27½ to 26 inches of mercury is obtained when the weather barometer stands at 29½ inches, the standard of this country. It is a curious fact, and contrary to what might at first sight have been anticipitated, that a better vacuum, and a lower temperature of the condenser, is obtained with superheated steam, than with common steam, being probably owing to the more perfect condensation of the steam, when not mixed with particles of hot water held in mechanical suspension. This fact appears also to indicate, that the extra dose of heat contained in the superheated steam has been all previously and usefully expended in the cylinder (by supplying the expanding steam with latent heat), and that no portion of it survives to enter the condenser. Whatever the cause may be, the result is, that considerably less injection-water is required when superheated steam is used, much to the surprise of the engineer in charge.

Contents of the condenser.

The air-pump.

According to Dr Ure's experiments, uncondensed watery vapour at a temperature of 100° balances 1·86 inch of mercury; at 110°, 2·45 inches; at 120, 3·3 inches; at 130°, 4·366 inches; at 140°, 5·77 inches; and at 150°, 7·53 inches of mercury, or exerts a pressure of 3¼ pounds per square inch. In addition to the uncondensed vapour, a considerable quantity of atmospheric air is always present in the condenser, having entered it in combination with the condensing water. The contents of the condenser, therefore, are sea-water used for condensation, condensed steam, uncondensed watery vapour, and atmospheric air. To remove these is the duty of the *air-pump*. It has a capacity of about ⅛ths of that of the cylinder, and is furnished with a "bucket" and valves, which are now usually formed of stout circular discs of vulcanised India-rubber. The air-pump draws its contents from the condenser through the *foot-valve*, and then passes them on through the *delivery-valve* and the *discharge-pipe* into the sea, a small portion of the hot water being abstracted by the feed-pumps to supply the boilers. The very remarkable and ingenious apparatus, known as Giffard's patent injector, although perhaps well suited to take the place of the ordinary feed-pumps in stationary or locomotive-engines, does not appear to have given satisfaction in the case of the few marine-engines where it has been tried in this country; its action being unquestionably rendered capricious, if not altogether stopped, by the use of hot water for the feed.

Marine engines should be simple.

The machinery of a sea-going steamer should be as simple in design, and possess as few moving parts, as possible. In all vessels designed for long voyages, as well as in those which are intended for foreign stations, it is much better to dispense with new and ingenious contrivances for saving infinitesimal quantities of fuel, than to run any risk of derangement. During a long run, as from Aden to Australia, for instance, the chances of derangement of the machinery are much increased by the mere inability to make the usual adjustments demanded by ordinary wear and tear; and it is surely wise to avoid the additional risk attending a great multiplicity of parts, the failure of any of which may cause the stoppage of the engines. When we consider that a large pair of engines may very possibly have five hundred different centres all in motion at once, and that each of these parts is making a thousand rotations, or double oscillations, each half hour, for twenty days consecutively, it can scarcely be wondered at that accidents should occasionally happen. But allowing that everything goes well with this complicated machinery, it is not by the use of such finical refinements of mechanism that any great saving of fuel can be effected (for this is the main point aimed at), but rather by the careful and judicious management of the boilers and engines. The fortunate selection of a good chief-engineer for the vessel will generally effect more saving in fuel than the most ingenious and expensive "modern improvements." These remarks are not intended to apply to the obvious advantages obtained by superheating the steam, large expansion, careful clothing (or jacketing) of the cylinders and steam-pipes, &c., which do not add much to the complexity of the engines.

Large bearings necessary.

The tendency of modern practice is to run the pistons of steam-engines at a much higher speed than formerly. This is more especially the case with screw-engines, whose pistons frequently run at the rate of 400 feet per minute, in place of Watt's old rule of 220 as a maximum. Although theory does not impose larger dimensions on the moving parts of a machine on this account, it is found in practice that the shafts of screw-engines running at a high velocity must be considerably increased in size to avoid accident. This arises partly from the increased momentum of the parts in motion; partly from the greater tendency of the bearings to heat from friction; and partly from the more rapid wear and tear of the brasses and sockets, by which the accurate fitting of the parts is destroyed, and these are consequently subjected to unequal jerks and strains. The simple remedy for such disorders is to enlarge the main shafts and bearings, the latter being also made unusually long, so as to diminish the effects of friction and wear and tear.

Linings of bearings.

The iron shafts of marine engines revolve in sockets or bearings lined with brass or gun-metal. These give rise to little friction, but as their wear is rapid, they require frequent attention to keep the lining screwed up to the neck of the shaft, and they must be renewed when much worn. In the case of screw-ships, where the bearings of the screw-shaft are not readily accessible, this rapid wear occasions much inconvenience, and can only be counteracted by largely increasing the bearing surfaces. Bearings lined with *lignum vitæ* are found to be subject to exceedingly little wear or friction. A plan has been therefore adopted of fitting these bearings with rings of *lignum vitæ* alternating with rings of gun-metal, which answers very satisfactorily.

Deterioration of shafts.

Before leaving the subject of shafts, it may be remarked that these, whether paddle or screw, appear liable to deteriorate by continued use, and finally to give way, sometimes suddenly, but oftener gradually. It is contended by some that the iron of which they are formed has a tendency to lose its toughness, and assume a crystalline texture, from long exposure to the shocks and vibrations to which all such shafts are subject. Having had very many opportunities of observing broken shafts, the author does not hold with this theory, but thinks the following explanation to be more probable. It is allowed to be a difficult operation to make large shafts perfectly sound in the centre, where the bars of iron of which they are built up are not always thoroughly welded into one homogeneous mass. These imperfections, when they exist, are of course not visible on the outside, nor do they seriously affect the strength of the shaft at first; but as the continued jarring and twisting goes on from year to year, they become more and more developed, and the shaft becomes loose in the centre, acquiring a "reedy" structure, which gradually extends to the surface. A fracture then takes place, if the crack be not observed and the shaft renewed.

Lubrication of the machinery.

The efficient lubrication of the bearings and other working parts of the engine with oil or melted tallow is a material point to be attended to, both as regards the smooth working of the machinery and its preservation from injury. From want of this simple precaution the bearings get strongly heated by the friction, and may either be damaged by the consequent expansion which takes place, or else cracked by the cold water which is usually poured on them from a hose, to cool them down again. Self-lubricating apparatus is preferable for this purpose, wherever it can be applied, as it is both more economical of oil and more certain in its operation. Although compactness in an engine is desirable within certain limits, this should never be carried to such an excess that the engineer is unable to get conveniently about his engine while it is at work, in order to lubricate the parts, and tighten brasses and packings.

Engineer's Log.

Every chief engineer of a steam-ship should be furnished with a printed form of Engineer's Log to be filled up by the engineer in charge during each watch of four hours. It should be arranged in a manner somewhat similar to the annexed form:—

Steamer .... ENGINE-ROOM REGISTER.

Proceeding from .... *To* ....

Date.	Watch ending.	Pressure on Steam-gauge.	Revolutions per minute.	Consumption of Coals.	Barometer, Starboard-Engine.	Barometer, Port-Engine.	Barometer, Atmospheric.	Density of Water of Boilers.	Temperature of the Sea.	Temperature of the Hot Well.	Total Expenditure per 24 hours.							Remarks on the State of the Sea and Wind, &c.
											Coals.				Stores.			
											For Engines.		For Ship.		Oil.	Tallow.	Waste or Okum.	
	Hour.	Lb.	No.	Lb.	In.	In.	In.	Deg.	Deg.	Deg.	Tons.	Cwt.	Tons.	Cwt.	Galls.	Lb.	Lb.	

Note.—Indicator-diagrams to be taken occasionally.

Steam-vessels are propelled either by paddle-wheels or screws.

Paddle-wheel;

1. Paddle-Wheels.—There are two kinds of paddle-wheels in general use in this country, namely, the common wheel, and that with feathering floats. The common paddle-wheel, notwithstanding many attempts to supersede it, still maintains a high place as a simple and efficient propelling agent; the faults which have been attributed to it being, it is believed, more apparent than real. When a steam-vessel is moored in a harbour and prevented from moving, or when first commencing motion after having been at rest, the defects of the common paddle-wheel appear to be very great. The paddle-boards, on entering the water, press obliquely down into it, tending to raise or lift the vessel up out of the water with a force which produces no useful effect. Again, when the paddle-board is leaving the water, it seems to do little more than raise or drive the water upwards in the form of back-water. It is only, therefore, in the middle of its path that the propulsion of the paddle seems to be exerted in forwarding the boat, and that only for a short time. A large part of the force of the steam-engine seems thus to be expended in raising the vessel, and in elevating the back-water, and only a small portion in carrying the ship forward.

its defects are more apparent than real.

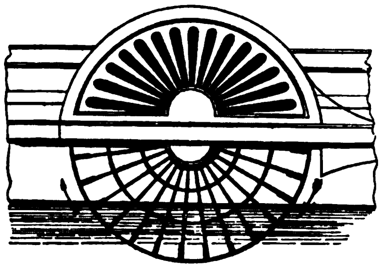
Fig. 25.
The Common Paddle-wheel.

This is the case of a vessel at rest, or not in rapid motion; but the phenomena of a paddle-wheel revolving when the vessel is in motion differ essentially from the phenomena of a wheel revolving on a vessel at rest. When it is just starting, or as yet moving very slowly, the evils here mentioned do in some degree take place; but by the motion of the vessel forwards (which is the result of the revolution of the paddles), the faults complained of are at once remedied, and the paddle-float of a common wheel in a quick vessel is virtually "feathered" as perfectly as the most practised rower could feather his oar. A little study of the geometrical conditions of a paddle moving forwards and in a circle at the same time renders this plain. The paths described by the boards are trachoidal curves, being of the family of the cycloid; and from the study of the motion actually performed by the paddle-board of the common wheel, it is seen, first, that the board is inserted into the water in an angular position resembling closely the entrance of an oar into the water; secondly, that it is then made to act horizontally on the water during a short interval; and thirdly, that it is withdrawn from the water edgeways, with an easy and graceful movement.

Its actual motion.

Feathering paddle wheel.

When the paddle-wheel is either badly proportioned, immersed too deep in the water, or attached to a very slow boat, its action becomes much impaired or impeded. Hence much attention has been devoted to the construction of a paddle that should be more effective in these unfavourable circumstances than the common wheel. Some of the contrivances invented for this purpose have failed for want of perception of the precise motion it was necessary to give to the paddle-board; others from the complexity of the mechanism employed. In the year 1829 a patent was granted to Elijah Galloway for a paddle-wheel with movable boards, which patent was purchased by Mr William Morgan, who made some unimportant alterations in the mechanism. This, called the feathering paddle-wheel, is represented by the above wood-engraving (fig. 26), by

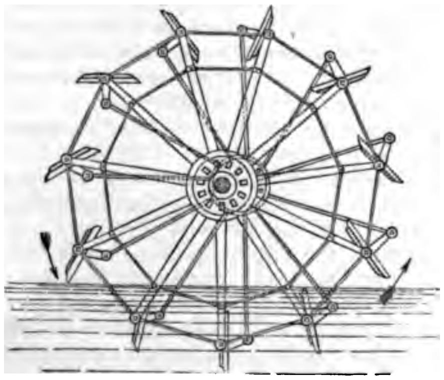
Fig. 26.
Feathering Paddle-wheel.

inspecting which it will be seen that a distinct feathering movement is imparted to the boards on entering and leaving the water. This movement, it will be observed, is derived from the excentric motion of the periphery of the second paddle-centre, to which are hinged the long rods that communicate the desired movement to the boards turning on pivots. Wheels made on this principle, though considerably heavier and more expensive than the common paddle-wheels are very frequently preferred for sea-going steamers subject to much variation of draught. They have been known to improve the average speed of a steamer by more than a knot an hour, and they are always accompanied with less vibration than the common paddles.

Slip of the paddle.

The "slip" of the paddle-wheel, by which is meant the excess of its velocity above that of the vessel, may be generally taken at ⅙th (or 16⅔ per cent.) of the vessel's speed when the wheel is well proportioned, and the vessel tolerably fast. Feathering wheels have less slip.

Want of power in a steamer to start a load.

The captains of steamers are frequently both surprised and disappointed to find how powerless their vessel is to drag a stranded ship off the shore, even when the whole power of their engines is exerted for this purpose. A slight consideration of the subject will show that the requirements of such a case are very unfavourable to the proper development of the power of a steamer.

Explanation.

We will suppose a vessel fitted with a pair of paddle-wheel engines of 500 horse-power collectively. The diameter of each cylinder will then be, say, 80 inches, and the stroke 6 feet. The length of the crank will therefore be 3 feet, driving a paddle-wheel of, we will suppose, 28 feet effective diameter, reckoned at one-third of the depth of the boards from their extreme edge. When the piston of each engine alternately arrives at the top or bottom of its stroke, that engine is then powerless, and the whole of the work devolves upon the other engine, which is then at half-stroke, with the crank nearly at right angles to the thrust, and therefore in the most advantageous position for transferring the power. By bringing the pistons of both engines to ¾ stroke, we obviously improve upon this, for now both engines are assisting to turn the shaft, though acting at a reduced leverage in the proportion of 3 feet to 2·15 feet nearly. By calculating the pressure upon the two pistons, we find the statical power exerted by the engines (the one *pushing* and the other *pulling*); but as the thrust thus found is transmitted by a lever of the second order, the short arm of which is the crank, and the long arm the radius of the paddle-wheel, it is necessarily reduced in the inverse ratio which these bear to each other, or as 14 : 2·15. The calculation would then be as follows:—

$$\overset{\text{Sq. in.}}{5026{\cdot}5}\ (\text{area of cyl.}) \times \overset{\text{lb.}}{22} \left\{\begin{matrix}\text{supposed effective press.}\\ \text{per sq. inch of piston...}\end{matrix}\right\} \times 2\ (\text{for both cylinders}) = 221{\cdot}166 \text{ lb.} = 98{\cdot}75 \text{ tons total pressure on pistons.}$$

$$\text{Then as } 14 : 2{\cdot}15 :: 98{\cdot}75 : \underline{15{\cdot}16 \text{ tons.}}$$

This being further reduced by 20 or 25 per cent. for the friction of the machinery, working the air-pumps, &c., leaves scarcely eleven tons of thrust available for starting a weight, or dragging a stranded vessel off the shore, by a steamer of 500 nominal horse-power.

A similar calculation made for screw-engines shows a like result.

Definition of a screw.

2. *Screw-Propeller.*—A screw as used for propelling vessels may be defined as a metal plate wound, edgeways, round a cylinder or spindle, as shown in the accompanying sketch (fig. 27 *a*), which represents one full turn of the common screw. This would be a single-threaded screw, but it is evident that two, three, or more threads, if kept uniformly parallel to each other, may in the same way be wound round the spindle without interfering with each other. We should thus have a two-threaded or a three-threaded screw, the former being chiefly used for propelling in the navy, and the latter in the merchant service.

Pitch of the screw.

The whole length of one complete turn of the screw, measured in a straight line along the spindle, is called the PITCH of the screw. In the preceding engraving, therefore, the pitch is measured by the length of the spindle (fig. 27 *a*), since the thread makes one complete turn upon it. It is also apparent, that if this screw were turned once round in a piece of soft wood (in the same manner as a carpenter's screw), it would advance through the wood the exact distance between the cut ends of the thread, which (we have seen) is the pitch. Hence, by the pitch of a screw, we understand always its linear progression for one revolution, and the speed of the screw is measured by multiplying the pitch into the number of revolutions.

Slip of the screw.

If the screw were working in a solid, the speed thus found would give its actual linear advance; but as it revolves in water, which is a yielding medium, the water gives way to some extent, and the screw does not advance the full amount of its pitch, this deficiency in its progress being called the SLIP of the screw.

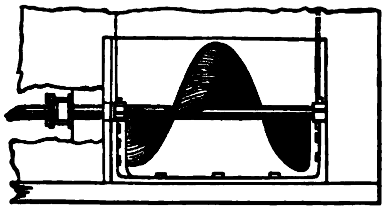

Fig. 27 *a*.

Fig. 27 *b*.

Form of the screw-propeller.

Now, if the screw represented by fig. 27 *a* be cut into several portions by planes passing across it at right angles to the axis, each of these sections would have the appearance of the vane of a windmill. If the screw were two-threaded, the vanes or "blades," as they are called, would be exactly opposite each other, as shown in fig. 27 *b*, or as in the annexed sketch, fig. 28 *b*, which represents a two-bladed screw as used in propelling. The screw here represented is about one-sixth part only of the whole length, or *pitch*, of the full turn of the screw shown by fig. 27 *a*, this small fraction of the pitch being found sufficient to absorb the whole power of the engines, so that any greater length of screw would only be hurtful by causing unnecessary friction, as well as by increasing the size of the aperture in which it works. By the LENGTH of the screw, therefore, is meant the fraction of the pitch employed, measured along the axis of the screw. By the DIAMETER of the screw is meant the diameter of the circle described by the extremities of the blades during their revolution.

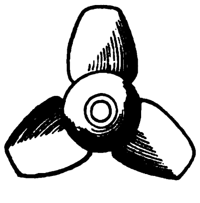

Fig. 28 *a*.

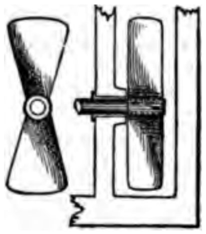

Fig. 28 *b*.

Action of the screw in propelling.

The effect produced in propelling the ship will be best understood by supposing the screw represented by fig. 27 *a*, to be revolving rapidly in a trough full of water. It would then send the water away from it with great force; but as action and reaction are equal, it would be itself, at the same time, urged in the opposite direction with exactly the same degree of force. If we suppose it, then, to be fixed in a ship, the ship will be pushed *forward* with the same force that is exerted by the screw in pushing *back* against the water. If the screw is made to revolve in the opposite direction, the converse of this takes place, and the ship is then pushed backwards by the reaction of the screw.

Different forms of screws. The screw-propeller has been subjected by would-be inventors to an endless variety of form; but these have generally shown themselves more or less inefficient according as they may have departed from the principle of the true screw. **Woodcroft's propeller.** The first patent of any interest connected with this subject is that of Mr B. Woodcroft, taken out in 1832, for an "increasing pitch" screw-propeller. His specification describes "A spiral worm-blade or screw coiled round a shaft or cylinder of any convenient length and diameter, in such form that the angle of inclination which the worm makes with the axis of the cylinder continually increases, and the pitch or distance between the coils or revolutions of the spiral continually increases throughout the whole length of the shaft or cylinder upon which the spiral is formed." Mr Woodcroft's idea, that the after-part of the screw would thus be made to act with increased efficiency upon the water which had been previously acted upon by the foremost part, is undoubtedly correct in principle, and had a full turn of the thread been found necessary for propelling (as was at first thought), this plan would probably have been found practically advantageous; but when the length of the screw was cut down by Lowe to one-sixth part of the pitch, very little scope was afforded for Mr Woodcroft's refinement, and it has proved to be really of little or no value.

Smith's screw. Mr F. P. Smith's patent was secured in 1836 for "a sort of screw or worm made to revolve rapidly under water in a recess or open space formed in that part of the after-part of the vessel commonly called the dead rising or deadwood of the run." Mr Smith's original drawings showed a screw with two whole turns of the thread, which was afterwards altered in 1839 to one whole turn.

Lowe's screw-blades. Mr James Lowe obtained a patent in 1838 for a screw-propeller formed of "curved blades, each a portion of a curve, which, if continued, would form a screw." The drawings attached to his specification show a shaft with one blade, a shaft with two blades, and a shaft with four blades. The screw-propeller now generally used (see fig. 27 *b*, and fig. 28 *b*), may be considered as a combination of Smith's screw and Lowe's blades, its present form having been in a great measure determined by the series of experiments with the Rattler in 1844. (See page 132.)

Griffith's propeller. Griffith's screw-propeller, first patented in 1849, is probably the best modification of the common screw which has yet been produced. Its principal feature consists in the employment of a large sphere occupying the central portion of the screw. The second peculiarity of Griffith's screw consists in the peculiar form of the blades, which, unlike those of the common screw, are larger towards the centre, and tapering towards the extremities. The extremities of the blades are curved from the front or propelling side towards the vessel, which causes the screw to take a greater hold of the water, and drive it towards the inner or central portion, which, in Griffith's screw, is the most effective part.

Description. This propeller is represented in its simplest form by the wood-engraving (fig. 28 *a*), and as recently improved by the annexed engraving (fig. 29.) It will be seen that this propeller consists of three main parts, viz., the boss which is keyed on to the screw-shaft in the usual manner; and the two blades, which have turned shanks fitting into bored recesses in the boss. Each blade is retained in its position by a key, which is adjusted into its place after the blade has been inserted and turned in its socket about ninety degrees, or until the arrow marked on the flange points to the pitch which it is desired the screw shall have, of which several have been previously measured, and marked upon the screw.

Feat ing- not fal. When Griffith's screw was first introduced, it was expected that great advantages would result from an arrangement in its construction (which it shared with Maudslay's feathering screw), by which the pitch or angle of the blades could with facility either be increased, diminished, or "feathered" during the voyage, to suit the varying exigencies of a steam-vessel at sea. Experience, however, has proved that the risk of derangement incident to the machinery requisite for this purpose is too great to admit of practical success, and also that the advantages to be obtained by such an arrangement are far less than was supposed. The use of screws to feather at sea has, therefore, been very generally abandoned. **Adv tages Griff screw** It will be observed, by looking at the engraving, that the blades of Griffith's screw are quite distinct from the boss, into which they are inserted and keyed in such a manner that their angle or pitch may be altered and fixed before the voyage, though not at sea. The use of this arrangement is, that the engineer may find out *experimentally* the particular pitch of his screw which is most suitable to the engines and ship, experience having shown how very difficult a thing it is to hit upon the right pitch by previous calculation alone. Another advantage resulting from this arrangement is, that when a blade is accidentally broken, it can be replaced without having to remove the centre part, which in Griffith's form of screw is tolerably safe from injury. It is unnecessary, therefore, to carry a spare screw, but only a couple of blades. When the ship is placed under canvass alone, the screw is brought into a position with the blades vertical, in a line with the stern-post, when little resistance is offered to the water. Although Griffith's screw cannot be said to have shown any very decided superiority in speed over a common screw of the best form, it is certainly not inferior in this respect, while it is attended with less vibration, is less affected by a rough sea, and is more manageable under canvass from offering less resistance to the water, and less obstruction to the free action of the rudder.

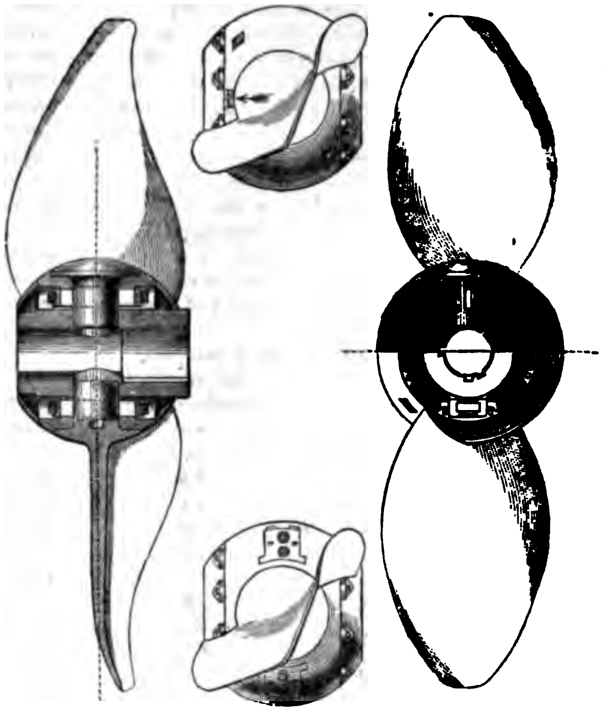

Fig. 29.

Griffith's Improved Patent Screw-propeller.

Comı screw When the common screw is employed in merchant-steamers, a three-bladed screw is usually preferred, since this causes less vibration, and gives a steadier motion in a rough sea than the two-bladed screw. **Resis to sai** The resistance which such a screw occasions to the vessel, when sailing under canvass alone, is very serious, in addition to the difficulty experienced in steering; and it is found in practice, that but little advantage is gained by disconnecting the screw from the engines, and letting it revolve in its bearings, in preference to *dragging* it through the water. Hence, in the case of steamships which depend much upon their canvass, one of three remedies must be adopted: namely, the screw must either be hoisted bodily out of the water; it must be feathered; or, thirdly, such a form must be employed (as Griffith's two-bladed screw, for instance), which will not interfere much with the sailing and steering of the ship, when the blades are placed vertical, and the screw left down in its place.

Hoisting screw.

The *hoisting* screw has been adopted generally for war-steamers, which are supposed to make great use of their sails, and which have a larger number of men available for quickly hoisting and lowering it. The annexed engraving shows the manner in which this is effected in the royal navy.

Description.

A is the screw (of gun-metal); B is the hoisting-frame (also of gun-metal) which lifts the screw, with its bearings, bodily out of the stern-frame of the ship; C is a gun-metal rack, to hold the hoisting-frame at any portion of its ascent; D is the chain and pulley used in hoisting; E is a clutch upon the screw-shaft, to enable the screw to be disconnected, and rise when brought into a vertical position; F is the gun-metal lining of the screw-shaft, which passes water-tight through the inner stern-post I; G is the iron screw-shaft; H is the outer stern-post; K is the "trunk" through which the screw is raised to the main-deck, when the blades are brought vertical.

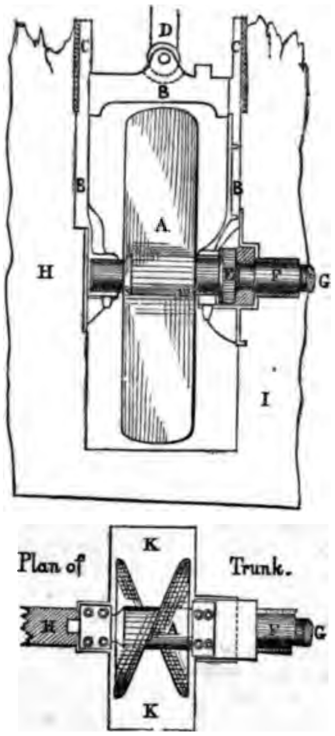

Fig. 30.

Having now seen what are the principal forms of screw-propellers in general use in this country, let us briefly examine some of the qualities inherent in the screw itself.

Functions of the pitch of a screw.

1. *Pitch.* The question between the relative values of fine and coarsely pitched screws still remains, in a great measure, undecided. In fact, our experience hitherto has only tended to show, that nothing but actual trial of different pitches can satisfactorily establish the best pitch of screw for any particular vessel. The points to be considered in reference to this inquiry are so numerous and complicated in their bearings upon each other, that they utterly defy previous calculation of their effects; some vessels giving the best results with coarsely-pitched screws running at a low speed, while other vessels, not very dissimilar, attain their highest velocity with a finely-pitched screw running fast. It is generally acknowledged, however, that a coarsely-pitched screw is the best for a vessel with fine after-lines, and a finely-pitched screw for vessels with full sterns. The form of the after-lines has undoubtedly a very great influence on the most advantageous pitch of screw for that particular ship, depending on the amount of "back-water" in which the screw works, and the velocity with which it follows the ship. It is by no means an uncommon thing for one vessel to gain a knot an hour by an alteration of the pitch; while in the case of another vessel, perhaps, no improvement is effected by a similar alteration.

Diameter.

2. *Diameter.* This is made simply as great as the draught of water will admit. In sea-going steamers the top of the screw should be submerged about 18 inches or 2 feet at the average trim, to allow for the undulations of the sea.

Area and length.

3. *Area and Length.* By the area of the screw is generally understood the plane projection of the resisting surface of the blades. In the experiments made with the Dwarf, it was found that the speed of the vessel remained almost a constant quantity, although the length of her screw was successively diminished from 2 feet 6 inches to 1 foot, the *area* corresponding to each of these lengths being respectively 22·2 and 8·96 square feet. The slight improvement which did take place in the speed of the boat attended the diminished area. It seems at first sight extraordinary that so great a variation in the resisting surface should cause so little disturbance either in the speed of the engines or of the vessel, thus showing plainly how small a segment of the whole pitch is required to absorb all the power which the reaction of the water is capable of imparting, any extra length of screw beyond this point only retarding by friction. The Rattler's experiments were in the same way commenced with a screw 5 feet 9 inches long, which was gradually shortened until it reached its point of maximum effect at 15 inches only. It is now a common practice to make the length of the screw ⅙th of the pitch.

Slip.

4. *Slip.* The apparent slip of the screw depends upon a great variety of circumstances. It is modified by the diameter and by the speed, being generally found to diminish as these increase. Thus, the diameter of the Rattler's screw, during her experiments, was 10 feet, and her average slip 15 per cent.; while the Dwarf and Fairy, with screws of 5 or 6 feet diameter, show an average slip of about 35 per cent. The form of the after-lines of the vessel has a very notable effect on the apparent slip of the screw, which must not be regarded as a measure of the efficiency with which the propeller is acting. On the contrary, many vessels whose lines are most unfavourable for speed show an exceedingly small slip of the propeller; and in some instances of this kind there is not only *no slip* apparent, but the screw has actually what is called *negative slip*, which implies that the vessel is going faster than the rate at which the screw which propels it would advance if working in a solid. This curious and paradoxical result is due to the current which all ships, more or less, but especially those with full sterns, carry in their wake; and since the screw acts in this current, the *apparent* slip will be positive or negative in proportion as the *real* slip, or the velocity of the current, may preponderate; but in every case the screw must have some slip relatively to the water in which it acts. Suppose, for instance, that a badly formed ship has a current of water following in its wake, and closing in upon the screw at a velocity of 4 miles an hour, while the *real* slip of the screw is but 3 miles an hour, the result will be that the screw will show an apparent negative slip of 1 mile an hour. It must not be supposed that in such a case the power of the engines is economically applied, for, in fact, much power is uselessly consumed in dragging this current of water after the ship. The same apparent diminution of slip is always found when the vessel is advancing with a tide or current. Anomalies of this kind most frequently occur in auxiliary screw-steamers, where the vessel, after attaining a high velocity by sails alone, still continues to receive a propelling thrust from the screw, even after the speed of the latter *appears* to be less than that of the vessel.

Negative slip.

Trials of screws in the Rattler.

In order to give the reader some perception of what really are the conditions of the screw most conducive to speed in the vessel, I have selected the trials of twelve different screws made in the same vessel, the Rattler, arranging them in the order of their relative efficiency, beginning with the lowest.

1. With a four-threaded Woodcroft's increasing pitch screw, 9 feet diameter, 1 foot 7 inches long, and the pitch varying from 11 feet to 11 feet 6 inches (mean 11·275), the speed of the vessel was 8·159 knots; the engines making 24·15 revolutions per minute, and the screw 96—slip, 23·5 per cent.

2. With a three-threaded common screw, 9 feet diameter, 3 feet long and 11 feet pitch, the speed of the vessel was 8·23 knots; the engines making 24·2 revolutions, and the screw 94·3—slip 19·66 per cent.

3. With Sunderland's propeller, 8 feet in diameter, the speed of the ship was 8·38 knots; the engines making 17·49 revolutions, and the screw-shaft 69·97.

4. With the same screw as No. 2, reduced in length to 1 foot 7½ inches, the speed of the vessel was 8·57 knots; the engines making 24·8 revolutions, and the screw 98·4—slip, 19·7 per cent.

5. With the same screw as No. 1, but with two of the blades cut off, the vessel's speed advanced to 8·63 knots; the engines making 27·07 revolutions, and the screw 107·5—slip, 25·97 per cent.

6. With a two-threaded common screw, 10 feet diameter, 3 feet long, and 11 feet pitch, the speed of the vessel was 8·958 knots; the engines making 24 revolutions, and the screw 95—slip, 13·8 per cent.

7. With a four-threaded common screw, 9 feet diameter, 1 foot 7 inches long, and 11 feet pitch, the speed of the vessel was 9·18 knots; the engines making 26 3 revolutions, and the screw 104·4—slip, 27·7 per cent.

8. With a two-threaded common screw, 9 feet diameter, 3 feet long, and 11 feet pitch, the speed of the vessel was 9·25 knots; the engines making 26·8 revolutions, and the screw 106—slip, 19·5 per cent.

9. With the same screw as No. 6, shortened to 2 feet, the vessel's speed increased to 9·448 knots; the engines making 25·5 revolutions, and the screw 107—slip, 13·5 per cent.

10. With the same screw as No. 6 further reduced in length to 1 foot 6 inches, the speed of the vessel was 9·811 knots; the engines making 27·92 revolutions, and the screw 110·7—slip, 18·3 per cent.

11. With the same screw as No. 2 further reduced in length to 1 foot 2 inches, the speed of the vessel was 9·88 knots; the engines making 27·39 revolutions, and the screw 108·4—slip, 15·97 per cent.

12. With the same screw as No. 6 further reduced in length to 1 foot 3 inches, the speed of the vessel increased to 10·74 knots; the engines making 26·19 revolutions, and the screw 103·97—slip, 10·42 per cent.

Trials made with her Majesty's Steamer Flying Fish.

Screw.								Indicated horse-power of Engines.	Speed of Ship.
Description of Screw.	Diameter.		Pitch.		Revolutions of.	Speed of.	Slip p. ct.		
	Ft.	in.	Ft.	in.	No.	Knots.		H.P.	Knots.
Common Screw,	11	0	21	4	82	17·263	32⅞	1302·26	11·585
	11	0	21	4	79½	16·737	32½	1154·86	11·298
	13	2	20	0	75	14·802	20¾	1166·76	11·736
	13	2	20	0	74½	14·704	21	1160·60	11·603
Griffith's Screw with feathering blades,	13	1½	19	0	71½	13·406	15⅞	1198·56	11·284
	13	1½	17	0	77½	13·00	10½	1287·00	11·640
	13	1½	16	0	77¼	12·197	4⅜	1265·00	11.568
	13	1½	15	0	83	12·286	3¾	1358·80	11·832
	13	1½	18	0	75½	13·411	14½	1226·20	11·461
	13	1½	17	0	77½	13·00	11⅛	1265·80	11·552

Trials of screws in the Doris.

A very interesting series of experiments has been recently made with the screw-frigate Doris, to determine the most suitable form of screw-propeller for our steam-vessels of war. The following is a resumé of the principal results arrived at, the first five trials having been made with the common or admiralty screw, and the last three with Griffith's propeller. The engines of the Doris (by Messrs J. Penn and Son) are of 800 nominal horse-power. The draught of water while under trial was kept constant at about 19 ft. 6 in. forward and 21 ft. 9 in. aft—exact mean, 20 ft. 6 in.; giving an immersed midship-section of 7421 square feet. Pressure of steam in boilers, 20 lbs.; indicated horse-power, about 3000. The first trial with the admiralty screw was with a diameter of 18 feet, the vessel's speed being 11·823 knots. On the second trial, with the diameter increased to 20 feet, the speed realized was 11·826 knots, with a great increase of vibration; steering imperfect. On the third trial, the "leading" corner of each blade was cut off, and in this form the common screw attained its greatest speed, giving a result of 12·032 knots, with 50 revolutions of engines per minute, and 2384 indicated horse-power; vibration reduced, and steering good. On the fourth trial, both the corners of each blade were cut off, so as to assimilate the blades to Griffith's form, when, with a greater number of revolutions, the speed fell off to 12·012 knots. In the fifth trial, with the "following" corner of each blade cut off, but the screw restored to its perfect form in every other respect, a result of 11·815 knots was obtained. The common screw was then removed, and the next trial was made with Griffith's propeller, 20 feet diameter and 32 feet pitch; this gave a result of 11·981 knots, there being scarcely any vibration, and the ship steering well. The second trial, with the same Griffith's propeller, having the blades set at 26 ft. 6 in. pitch, gave a speed of 12·269 knots, being the highest of the series; steering perfect, and no vibration perceptible; indicated horse-power, 3091. The third trial of Griffith's 20-feet screw, with the blades set at a medium pitch of 30 feet, gave 12·158 knots.

Results of Doris's trials.

Several important points connected with the screw-propeller seem to have been proved by these trials—1*st*, That the leading edge of the screw is the part that mostly affects the steering of the ship, and also causes the greater part of the vibration; 2*d*, That increased diameter of the screw is better than increased pitch for reducing the speed of the engines, but it considerably increases the vibration with the common screw; whereas with Griffith's it did not produce that effect, in consequence of its chief propelling surface being towards the centre. The common screw, when its blades are cut to the form of Griffith's, is not so effective as when the centre sphere is applied to them. The power required to obtain the same speed was very much the same for both screws.

The annexed sketch is interesting from the peculiar markings shown upon the surface of the screw, which is that of the steamer Crœsus. This vessel had on one occasion got under way while the paint on her screw was still wet, and on being docked soon afterwards the paint was found streaked by the water, as here shown.

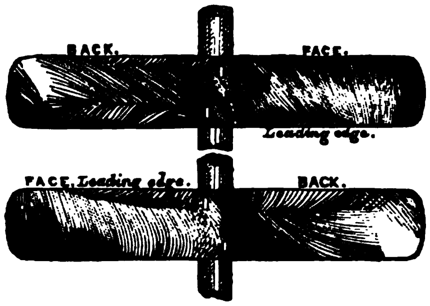

Fig. 31.

Official explanation of the Table of "Results of Trials made in her Majesty's Screw-ships."

"The numbers in the last two figure-columns of the table show approximately the relative excellence, in respect of speed, of the forms of the various vessels, conjointly with the relative efficiency of the propeller, as adapted to each of them.

"The formulæ by which the calculations are made are founded on the assumption that the resistance of a vessel varies as the square of her velocity, and, therefore, that the power required to produce that velocity varies as the cube, and that the usual effect of the engine—that is, the effect which remains after deducting the power absorbed in overcoming friction, working air-pumps, &c.—bears a constant ratio to the power developed in the cylinder, known by the term 'Indicated horse-power.' The resistance is, in the first of these columns, assumed to vary, *cæteris paribus*, as the area of the midship-section, and in the last column as the square of the cube-root of the displacement.

"None of these assumptions, however, more especially the last two, are absolutely correct, but probably they are not so far from the truth as to render useless and uninteresting a comparison, of which they are the basis, made between the performances of any two screw-vessels; while between two vessels which do not materially differ in engines and displacement, or in the area of their midship-sections, such a comparison is not only highly interesting, but it may prove of great value in pointing out the forms of vessels and proportion of propellers which ought to be adopted. In some striking cases it is scarcely necessary to make any other comparison than that of speed. For example, as may be seen in the table printed in 1850, the Teazer, after her form had been improved, went above a knot an hour faster with 40-horse engines than she had previously gone with engines of 100 horse-power. Again, these engines of 100 horse, when transferred to the Rifleman—a vessel approaching to double the tonnage—drove her, after her form had been altered, as fast as she was previously driven by engines of double the power, and nearly two knots faster than the same engines drove the smaller vessel before the alteration of her after-body.—Admiralty, August 1856."

Ruthven's water-jet propeller.

The only other mode of steam-propulsion which has been attended with any considerable success is that known as Ruthven's water-jet system, in which the propelling power is derived from the reaction, or recoil, of two jets of water projected, at a high velocity, from nozzles at the ship's side. The first experimental vessel on this principle was built by Messrs. Ruthven, of Edinburgh, in 1843, and was tried on the Firth of Forth, when it attained a speed of from 6¼ to 7 miles an hour. This was an iron-boat, 40 feet long. More recently, in 1853, the Enterprise was constructed on Ruthven's principle, for deep-sea fishing, a preference being given to the jet propeller in this case, from its being less likely to interfere with the fishing-nets than the screw or the paddles. The dimensions of the Enterprise are as follow:—length of deck, 95 feet; length on the water-line, 87 feet; breadth of beam, 16 feet; depth, 8 feet; draught at load-line, 4 feet; burthen, 100 tons. The propelling power is derived from two pairs of horizontal oscillating cylinders, each 12 inches in diameter, and 24 inches stroke (condensing), working a vertical shaft. There is one cylindrical boiler, 6 feet in diameter, and 5 feet long, with two fire-tubes running through it, each 22 inches diameter, and 105 return flue-tubes, each 5 feet long, and 2 inches internal diameter. The propeller consists of a fan-wheel, or centrifugal pump, 7 feet in diameter, with curved blades, keyed on the lower end of the vertical crank-shaft; this revolves horizontally in a water-tight casing into which the water from the sea flows (along a covered passage), through crescent-shaped openings in the bottom of the hull. The water is expelled laterally, from the fan-wheel, in two continuous streams, through curved pipes with nozzles, 10 inches in diameter, protruding from the sides of the hull. The nozzles turn in collars fixed to the ship's side, so that they can be pointed a-stern or a-head, as required, for forward or backward motion, or downwards, when the vessel is to remain at rest. These changes can be made rapidly and easily from the deck, since the nozzles alone require to be operated upon, while the engine continues to work at full speed. Again, by setting the nozzles in opposite directions, one pointing a-head and the other a-stern, the vessel can be turned on the spot, swinging on her beam without the aid of the rudder; and she could thus be steered by the nozzles in case of the rudder being lost or disabled, the manœuvring of the vessel being entirely in the hands of the officers on deck. The vessel progressed very smoothly, without tremulous motion.

The Enterprise.

In a trial trip with the Enterprise on the 16th of January 1854, from Granton to Kirkcaldy, in the Firth of Forth, and back, a distance of 10¼ miles each way, the speeds obtained were 9·69 statute miles per hour going, and 9 miles per hour returning, giving an average of 9·85 miles per hour—the engine making 50 revolutions per minute. On another occasion, she is stated to have made a considerably higher speed, the engine making 65 revolutions per minute. The draught of the vessel, during the trial, was 3 feet 2 inches; and the immersed midship-section, 40·5 square feet. The indicated horse-power of the engine was not known, no indicator-diagrams having been taken. In such an arrangement, much power is necessarily lost in communicating to the water which enters the propeller a velocity equal to that of the ship, besides a considerable loss from friction, eddies, &c.; but upon the whole, the power of the engine seems to be applied to considerable advantage. Even allowing that the speed attained does not equal that from paddles or screw, the jet-propeller possesses other undoubted advantages which recommend it for special cases, as for instance, in the Government floating-batteries and steam-rams, where the screw and the rudder are particularly liable to be fouled by wreck and cordage. It would also be preferable to the screw in cases of river-steamers of very light draught, where the paddle might not be applicable. Several of the large floating fire-engines on the Thames have been fitted with this propeller, the water being ejected by the powerful steam-pumps with which these vessels are fitted. The speed, however, has in these cases not proved satisfactory. A steamer, called the Albert, propelled on this principle, was placed on the Rhine, as a passenger-boat, a few years since, but did not attain a speed proportional to her power or consumption of fuel.

Advantages of the water-jet propeller.

Paddle and screw compared.

It is frequently asked, Whether is the paddle-wheel or the screw the most efficient propeller? This question may now be safely answered, by asserting, that when both are in their best trim, and both are equally well proportioned to the engines and vessel, they are, as nearly as possible, equally efficient. It follows, therefore, that the preference for one or the other, in any particular case, depends entirely upon the class of vessel and the nature of her service. The objections to the paddle, as compared with the screw, may be thus briefly stated, namely, the unequal immersion of the wheels, according as the vessel swims light or deep; the obstruction to the *sailing* of the ship caused by the resistance of the paddle-boxes to the wind; and the dragging of the paddle-boards through the water when the engine power is not used, and the wheels are not disconnected; and, in the case of steam-vessels of war, the exposure of the wheels and machinery to an enemy's shot. The *advantages* of the paddles, on the other hand, are, that they are not so much affected by the pitching motion of the ship, when steaming head to wind, as the screw is; that they do not require such a speed of engine (or else gearing); and that, from the disposition of the weights in respect to the centre of gravity of displacement, the movements of the vessel are easier than those of a screw-steamer, a matter of considerable interest to the *passengers* at least. With regard to the screw, its efficiency is but little impaired by variations of trim in the ship, but it is most injuriously affected by the pitching motion. Its advantages in facilitating the sailing of the ship are self-evident, and have been already alluded to. In fine, the superiority of the screw for sea-going steamers appears to amount to this, that it retains its efficacy as a propelling agent under a greater variety of conditions of sea, weather, and trim, than the paddles, and that it admits of more use being made of the sails and a greater display of seamanship in the navigation of the vessel. Under proper management, therefore, it appears to be more economical of steam-power than the paddle-wheels; and this, it may be remarked, is the actual experience of the Peninsular and Oriental Company, whose steam fleet is composed of vessels on both principles.

Having thus briefly considered, firstly, the engine-power of the steamship, and secondly, the immediate propelling agents employed to produce locomotion, it will now be necessary to view her as a completed whole, and to examine some of the general properties and qualifications inherent in, or demanded by, this complicated structure, as well as the relations they severally bear to each other. The construction of the steamer's hull will be found amply detailed under SHIP-BUILDING, so this need not be here adverted to.

Resistances offered to a steamer.

When a steamer is once set in motion, the motion is, of course, continued by her momentum, and she would then evidently continue to advance at a uniform speed, without any more force being applied to her, were it not for the opposition of external causes. These external forces which she encounters, and which are constantly at work to destroy her momentum, and bring her to a state of rest, are the resistance of the water to her hull, and the resistance of the air to her upper works and rigging; the *impetus* of the waves and the winds being exerted sometimes in her favour, and at other times against her. The power of the steam-machinery is therefore applied to counteract these retarding forces, and to maintain a certain amount of progressive motion in the ship, depending upon the resistance on the one hand, and the power of the engines on the other.

The resistance offered by the water to the passage of the hull must be divided into two parts; firstly, that due to the dividing and displacing of the water, to make room for the hull of the ship to pass through, which (according to Mr Scott Russell) is analogous to scooping out a long trough or canal, of the full breadth of the ship; and, secondly, the resistance arising from the friction of the water upon the sides and bottom of the vessel. Of these resistances, the first is by much the more serious, although the second must not be overlooked.

Direct resistance.

The resistance offered to the passage of the hull depends mainly upon the area of the immersed midship-section of the ship (or its greatest cross-section), but also very materially upon the form of the vessel's lines under the water. There is considerable discrepancy of opinion as to the relative value of these two functions of the ship; one naval constructor relying for speed upon a small immersed midship-section, while another holds that fine lines for dividing and closing the water are still more essential.

Influence of form.

The lines of a ship undoubtedly exert a great influence upon her speed, as has been shown experimentally in numerous instances. In the case of the Government dispatch-boat, Flying Fish, (already referred to at page 132), this vessel, of 1050 tons displacement, attained a speed of only 11·73 knots, with 1166 indicated horse-power. That performance did not equal the expectations of the Admiralty authorities; and without making any variation in the other parts of the vessel, they added, not a *new* bow, but an elongated bow, 18 feet in length, in advance of the original one, to divide the water more freely. The result was, that with the same draught of water, the velocity of the vessel increased from 11·73 knots to 12·55 knots an hour.

Mr J. Scott Russell, in the course of a discussion on this subject at the Institution of Civil Engineers,[1] has given some very interesting results of experiments, all tending to show that the shape of the vessel has a very decided influence upon her speed, irrespective of her engine-power. He relates that he had, on one occasion, the control of four timber ships of the same dimensions, the same displacement, and the same horse-power; but each had different lines, being constructed by different shipbuilders. The engines were all alike, being made by the same firm. The result was that, upon a run of 16 miles, their several speeds were 12½, 12, under 11, and between 10 and 11 miles an hour. In another instance, a steamer, constructed to go both ways, but built with one end finer than the other as an experiment, went fully a knot faster one way than the other, although the midship section and the horse-power were necessarily identical at all times. A third case was the following:—Two vessels were built of the respective lengths of 190 feet and 186 feet, their breadths being equal. The engines were the same in each, the cylinders being 48 inches diameter and 4 feet 6 inches in stroke, making 39 revolutions per minute. The speed attained by the first vessel, however, was 15·03 knots, while that of the second was but 11·32 knots. The difference in the two vessels consisted mainly in the shape, the other and minor elements being much in favour of the slower vessel. For instance, the faster vessel had 124 feet of midship-section, whilst the slower vessel had but 71 feet of midship-section to drag through the water. The faster vessel drew 6 feet 8 inches of water, whilst the slower vessel drew only 2 feet 10 inches. The difference in length was only 4 feet, yet a radical difference in shape thus reduced the velocity, with equal power, from 15 knots to 11 knots per hour.

Colonel Beaufoy's experiments determined the resistance of the water to a ship with a square head only, and it has since been found that a semicircular or round head offers two-thirds of the resistance derived from his formula $\left(R = aw\frac{v^2}{2g}\right)$, and an eliptical head considerably less.[2] By making the bow still finer, the resistance had been gradually reduced to one-sixth, and one-eighth, of that given by the formula; and Mr Scott Russell believes that the engine-power required to drive a large vessel through the water has now, in some cases, been reduced as low as one-twelfth. We learn from the same authority (the highest, indeed, which it is possible to adduce on this subject), that with a vessel of proper form, measuring about 1500 tons, the resistance of a ship can be reduced to 50 lb. per square foot of immersed midship section, while steaming at the rate of 10 knots an hour. This is the direct resistance of the water upon the hull, and Mr Scott Russell asserts that he has thus been enabled to calculate confidently, to within a quarter of a knot, the amount of steam-power necessary to propel a given ship at a given speed, basing the calculation upon his own peculiar form of "wave-line," there being necessarily a shape for every speed. For instance, when a speed of 10 knots an hour was desired, he provided engine-power for 50lb. per square foot of immersed midship-section (exclusive of the resistance of the machinery, which brought it up to 65 lb. per square foot), for a vessel of about 1500 tons, built on the "wave-line" construction. These figures, 50 lb. and 65 lb., are *gross* resistances, and include friction of skin.

With regard to the absorption of power by the friction of the skin, it is a difficult matter to estimate this correctly, but that it must be very considerable is sufficiently proved by our every day's experience of how much a vessel will fall off in speed by even a slight fouling of her bottom. This often amounts to a loss of one-fifth of her original speed, the engine-power exerted remaining the same; so that, under these circumstances, double the power would be required to attain the same speed as before. An iron steamer has been known to fall off a knot an hour by her bottom becoming only so rough as the skin of a walnut. The total immersed surface of the Rattler's hull has been calculated at 7000 square feet, and according to Beaufoy's experiments on the friction of immersed surfaces, the resistance thus arising would be eight-tenths of a pound per square foot for a speed of 10 knots an hour, and nearly 1 lb. per square foot at 11 knots. At the speed and friction first named, the power absorbed would be equivalent to nearly 170 I.H.P., the total I.H.P. of the engines amounting to 428 H.P. only. In the case of the Himalaya, an immersed surface of about 18,000 square feet is exposed, the friction from which, at a velocity of 13 knots an hour,

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[1] See *Transactions of Institute of Civil Engineers*, Session 1856–57.

[2] In the formula in the above sentence a represents the midship section in square feet, v the velocity of the vessel in linear feet per second, g the accelerating force of gravity = 32⅙, and w the weight of a cubic foot of sea-water at 64¼ lb. avoirdupois.

would absorb about 650 I.H.P., supposing the bottom to be perfectly clean.

Effect of increased length.

The consideration of frictional resistance, of course, places a limit to increase of length in a steamer, although many instances have occurred in which the vessel has gone as fast, or very nearly as fast, with the same engines, and on the same draught of water, after some 30 or 40 feet have been added in midships. The Candia is a remarkable instance of this, as will be seen by the following comparison of her speed when originally built, and after she was lengthened in midships by 33½ feet, her load displacement being thereby increased about 470 tons:—

Date of trial.	Draught of water.	Length.	Displacement.	Weight on board.	Revls. of engines.	Pressure of steam.	Indicated H. P.	Pitch of screw.	Number of blades.	Speed of vessel.
	Ft.	Ft.	Tons	Tons	No.	lb.	H. P.	Ft.		Knots.
May 31, 1854...	18·6	281	2·520	650	36½	22	1672	20	2	12·651
Aug. 12, 1857..	19·0	314·6	3·090	1000	33	20	1462	21	3	12·443

Although in this instance, from some unexplained cause (owing possibly to improved trim, or circumstances of wind and sea), it would appear from the trial trips that a considerable increase of length has been obtained without any corresponding absorption of power, there must necessarily be a limit where further extension of length is more than neutralized by increased frictional resistance.

Law of resistance.

It is universally admitted that the gross resistances (direct and frictional) to which a vessel is subject increase as the square of the velocity, and therefore, as a necessary consequence, the power expended in producing this velocity varies as the cube of the velocity. For instance, if the resistance to one square foot of midship-section propelled through the water at 5 miles an hour be 5 lb., then the resistance at 10 miles an hour would be four times 5, or 20 lb. But the latter resistance has acted over double the space, so that the result must be again doubled for the measure of the power expended; and hence it follows that the power exerted must always be in the ratio of the *cube* of the velocity. This rule cannot be expected to hold strictly good in all steamers alike, looking to the great diversity of form and displacement which exists, but in the great majority of cases it is fully borne out in practice. Thus, in H.M. screw-steamer Desperate, the following relation between power and speed was found to obtain:—

Relation of power to velocity

	Indicated Horse-Power.	Knots.	Coal per I.H.P. p. hour.
			lbs.
With 4 boilers and 4 cylinders	805·89	9·15	4·61
With 3 boilers and 4 cylinders, working expansively	579·32	8·25	5·13
With 2 boilers and 4 cylinders, do. ...	363·87	7·35	5·58
With 1 boiler and 2 cylinders, do. ...	169·32	5·98	5·89

The Retribution, paddle-wheel steamer, had a speed of 10·4 knots with 1092 I.H.P., and a speed of 6·22 knots with 226 I.H.P. The Onyx, with 2 boilers and 533 I.H.P., realized a speed of 13·16 knots, whilst with one boiler and 158 I.H.P. the speed was 8·6 knots. The Minx, with 234 I.H.P., made 9·14 knots, and with 31·6 I.H.P. 4·51 knots. These, and many other instances, are all in accordance with the rule, that the power and consumption of fuel vary as the cube of the velocity.

Practical examples.

The practical value of this rule will be made apparent by the following examples:—

1. If it be wished to find the speed corresponding to a diminished consumption of fuel for any particular steam-vessel, the calculation will be effected thus:—The vessel, we will suppose, has engines which propel her at the rate of 12 knots, with a consumption of 35 tons of coal per diem, and we wish to find the speed corresponding to a consumption of 25 tons per diem; then—

$$35 : 25 :: 12^3 : V^3 \text{ (cube of required velocity).}$$

When reduced, $7 : 5 :: 1728 : V^3$

As an equation, $5 \times 1728 = 7\ V^3$;

or, $\dfrac{8640}{7} = V^3.$

And $\sqrt[3]{1234} = V^3\ 10{\cdot}726$ knots $= V$, the required velocity.

It is thus seen, that by reducing the consumption of fuel by 10 tons per diem, we lose in this instance about 1¼ knot per hour.

2. If it be wished to increase the speed of the vessel, on the other hand, from 9 to 11 knots, and we desire to know the increased consumption attending the increase of speed, this will be in the proportion of 9^3 to 11^3, or as the numbers 729 : 1331, or as 1 : 1·825. All we have to do, therefore, is to multiply the present consumption by this latter number.

3. If a certain steamer consumes, say 220 tons of coal, during a run of 1600 miles, performed at the average speed of 11 knots per hour, and we wish to find her probable consumption of coal for a longer voyage of 2400 miles, at a reduced speed of 9 miles, the calculation will then be as follows:—

220 tons coal : C (required consumption) :: 11^2 knots × 1600 : 9^2 knots × 2400 miles,

Then $C \times 121 \times 1600 = 220 \times 81 \times 2400$;

or, $C \times 193{,}600 = 42{,}768{,}000.$

Reduced to $C = \dfrac{427{,}680}{1936} = 220{\cdot}9$ tons, required consumption.

It is thus seen that the consumption of fuel is almost exactly equal in these two cases, showing that the same vessel would steam 1600 miles at 11 knots, or 2400 miles at 9 knots, with the same quantity of coals.

4. Supposing that we have a steamer with stowage-room for only 460 tons of coal, which she has nearly expended during a trip of 1800 miles, while steaming at the speed of 11·5 knots an hour, and we wish to place her upon another station, where she must run 2500 miles without coaling, it is required to find at what reduced speed she must steam so as not to run short of coals?

$$\overset{\text{tons.}}{460} \times \overset{\text{knots.}}{11{\cdot}5^2} \times \overset{\text{knots.}}{1800} = \overset{\text{tons.}}{460} \times \overset{\text{knots.}}{2500} \times V^2 \text{ required velocity;}$$

or, $460 \times 132{\cdot}25 \times 1800 = 460 \times 2500 \times V^2$;

reduced to $109{\cdot}503 = 1150\ V^2$;

or, $V^2 = \dfrac{109503}{1150} = 95{\cdot}04.$

Therefore, $V = \sqrt{95{\cdot}04} = 9{\cdot}75$ knots, required velocity

We thus find that the same vessel which ran 1800 miles at a speed of 11·5 knots, and with a consumption of 460 tons of coal, must reduce her speed to 9¾ knots, to enable her to run 2500 miles with the same consumption.

Efficiency of a steamer.

The preceding examples all show that an increase of speed is obtained only by the expenditure of a very great increase of power. Hence, to draw even the most superficial comparison between the efficiency of different steam-vessels, their speeds must first be reduced to a common standard, and the relation must then be found between the consumption of fuel at the standard speed, and the size or tonnage of the vessel, the *maximum* speed of each being treated as a separate question. The value of the term *efficiency* also varies so much for different classes of vessels, that steamers of the same class only can be justly compared together. The number of tons displacement that 100 gross or indicated horse-power will propel, at the rate of 10 knots an hour, has been proposed as a standard of comparison between different steamers.

Modes of comparison.

A vessel, for instance, is known to have a speed of 12 knots an hour, the engines exerting 1620 indicated horse-power, at a displacement of 2240 tons.

Then, as 12 knots : 10 knots :: $\sqrt[3]{1620 \text{ H.P.}} : \sqrt[3]{\text{Ind. H.P. required}}$;

or, 1728 : 1000 :: 1620 : 937·5;

and 937·5 : 2240 :: 100 : 238·9 = tons displacement propelled by 100 I.H.P., at 10 knots an hour.

By making similar calculations for other vessels, their relative efficiency may be, to a certain extent, compared one with the other. It is found, in practice, however, that the form of the vessel influences the ratio existing, theoretically, between the power exerted and the resulting speed.

Steam Navigation.

Thus, in the Flying Fish, before she was altered, an increase of only 1·68 knots in the speed of the ship was obtained by doubling the indicated horse-power; but after a fine bow was fitted, she gained 2·452 knots by doubling the power, the latter increase of speed being just proportional to the cube of the extra power exerted.

Formulæ for determining steamship performances.

A formula frequently employed in comparing the relative merits of vessels is $\frac{V^3 D^{\frac{2}{3}}}{\text{I.H.P.}}$, which is thus expressed in words:—The cube of the speed in knots, multiplied by the square of the cube-root of the displacement, and divided by the indicated horse-power. The resultant number is called the co-efficient of dynamic duty for that particular steamer, and forms a criterion of the cost at which she performs her work, the higher the co-efficient the greater being the economy. In a steamer of good average performance, the co-efficient, as calculated by this rule, should lie between 250 and 320, or thereabouts.

As the preceding formula does not take note of the area of immersed midship-section, the following is also useful as a means of comparison: $\frac{V^3 \times \left\{\begin{smallmatrix}\text{midship-}\\\text{section.}\end{smallmatrix}\right.}{\text{I.H.P.}}$

The two formulæ next to be given are used indiscriminately for estimating the probable speed of a steamer, viz.—

No. 1. $V^3 = \frac{\sqrt{\text{H.P.} \times \text{C,}}}{D^{\frac{2}{3}}}$; or, when expressed in words, the cube of the velocity equals the square-root of the nominal horse-power, multiplied by the diameter of the cylinder in inches, divided by the square of the cube-root of the displacement.

$$\text{No. 2. } V^2 = \frac{\sqrt[3]{\text{I.H.P.}} \times 100}{\text{mid. sect.}}$$

The speed of the Candia, when measured by the first of these rules, is 11·38 knots, and by the second, 11·28 knots; while her actual speed, under the same conditions of displacement, &c., is 11·93 knots. In the same way the speed of the Pera, by the first rule, is 11·22; by the second, 11·28; and actual, 12·55 knots. The actual speed, in both of these cases, is therefore in excess of that calculated by the formulæ.

Proportion of horse-power to tonnage.

In proportioning the horse-power of a steamer, the fact must be borne in mind that the effective power of the engines increases in a higher ratio than simply as the tonnage, since the resistance varies as the square of the cube root of the tonnage. Thus, if a vessel of 1200 tons and 400 horse-power have a speed of 12 knots, a similarly constructed vessel of 1650 tons and 550 horse-power (with the same proportion of power to tonnage), ought to have a considerably higher speed, since the square of the cube root of 1200 being 112·78, and the square of the cube root of 1650 being 139·47, the proportion will then be 112·78 : 400 : : 139·47 : 494·6 horse-power, instead of 550 horse-power.

The proportion of horse-power to tonnage recommended for different classes of ocean steamships may be stated as follows:—For full-powered passenger paddle-steamers of from 500 to 1200 tons (builders' O.M.), 1 horse-power to 3 tons; for ditto, of from 1200 to 3000 tons, 1 horse-power to 4 tons; for full-powered passenger screw-steamers of from 500 to 1200 tons, 1 horse-power to 4 tons; for ditto, of from 1200 to 3000 tons, 1 horse-power to 5 tons; for auxiliary screw-steamers, 1 horse-power to 6, 7, or 8 tons, according to size.

It must not be supposed that a steamer can, or ever will be constructed by the sole aid of "formulæ," which are themselves, for the most part, empirical. They serve, however, to assist in estimating the value and tendency of the several proportions and attributes of the structure, a wide margin being left for the exercise of practical sagacity and experience on the part of the constructor.

Main elements of steamship economy.

To sum up, in a few words, the main elements upon which economy in steam navigation seems to depend, these are—a fine form, a moderate speed, considerable magnitude, a clean bottom, and a high ratio of length to breadth; to which may be added, effective engines, and a properly proportioned propeller. Again, after the naval constructor and engineer have each done their best, much still remains for the skill of the commander and officers of the ship.

Proportions of length, breadth, and depth

With regard to the relative proportions of the hull, our fastest and most successful ocean merchant-steamers of the present day have their length and breadth as 7, 7·5, or even 8 to 1 for iron screw-steamers, wooden hulls being generally confined to 6·5 and 7 times the beam. The proportion of depth varies very much, but this should never exceed eight-tenths of the breadth, and is better limited to six-tenths. A very deep steamer is always unweatherly and unmanageable, and often dangerous. The proportions in actual use will be seen by inspecting the tables of steamers in the royal navy, and the table of merchant-steamers, at pages 141, 142, 143,

Management of a steamer at sea.

With reference to the management of steamers at sea, a full-powered passenger-steamer is generally so tied to time that she cannot afford to disuse any portion of her steam-power, contenting herself with expanding more or less in the cylinders, according as the wind and sea are propitious or otherwise. Every opportunity of a fair wind, however, should be eagerly seized for hoisting sail, which, in the case of a screw-steamer especially, affords a great addition to the power of the engines. Steam-vessels of war, on the other hand, are expressly designed to sail well, in addition to their steaming powers; and in estimating the performance of a Government steamer, we should rather look to the direct distance run by the combined action of steam and sails, at a moderate but uninterrupted speed, and with a small consumption of fuel, than to the attainment of a high velocity, which is seldom wanted in war-steamers. In steaming against a strong head wind, with a paddle-wheel steamer of moderate steam-power, it is found preferable to keep the vessel in a direct course as long as possible; but, so soon as her head begins to fall off for want of good steerage way, the fore and aft sails should be set, and the vessel tacked, the engines being kept working. In the screw-steamer, on the other hand, there is no economy in keeping a direct course against a head wind and sea, after her speed is reduced to three or four knots an hour, since the engines keep up their usual number of revolutions, and the steam is mostly wasted in slip, or during the "racing" of the machinery. In such a case, therefore, the ship's course should be altered, and the sails set to assist the screw, so soon as the speed falls to this amount. In paddle-wheel engines, the waste of steam is not so great while going head to wind, since the revolutions decrease with the speed of the vessel. When a vessel is steaming against an opposing stream or tide, it is found that her engine-power is most economically applied when she goes half as fast again as the velocity of the stream. Notwithstanding the many undoubted improvements which have been recently introduced in the application of the screw propeller, and the extended experience we have now had of its operation in different classes of ships, and under every variety of trial, the position which it holds in the merchant service, either as an antagonist to the paddle-wheel in full-powered steamers, or as an auxiliary to the sails in sailing ships, is still far from being well defined.

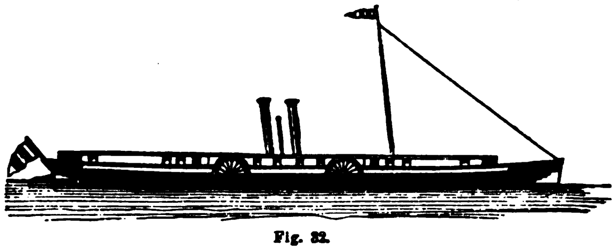


Fig. 32.
Paddle-steamer for the rivers of India.

Before bringing this article to a close, it is proposed to give a few examples of steam-vessels which have either proved unusually successful, and may, therefore, stand as *types* of their class, or have some peculiarity of structure which seems to point them out for special notice.

1. **Duke of Wellington**, 131 guns, steamship of the line, is 240 feet 6 inches long between perpendiculars, and 60 feet broad. Tonnage, 3826, builders' O.M. Has two horizontal, geared, screw-engines. Diameter of cylinders, 94½ inches, and 4 feet 6 inches stroke. Nominal H.P., 780; indicated do., 2500. Machinery by Robert Napier & Sons, of Glasgow. Has 4 tubular boilers, each containing 5 furnaces of the following dimensions, viz.—7 feet 4 inches long + 2 feet 9½ inches wide; the total space occupied by the machinery being 70 feet in length. The diameter of the screw shaft next the engines is 12½ inches. The screw itself is double threaded, 18 feet diameter, 16 feet 3 inches pitch, and 3 feet 4 inches long. The driving-wheel of screw-gearing is 10 feet 6 inches diameter, working into a pinion (with wooden cogs), 4 feet 6 inches diameter, and 4 feet 5 inches broad. The speed of the vessel at her trial trip was 10·2 knots.

2. **Mersey**, 40 guns, screw steam-frigate, is 300 feet long between perpendiculars, and 52 feet beam. Tonnage, 3726; nominal H.P., 1000; indicated H.P., 4000. Makers of the machinery, J. Penn and Son. Pressure of steam, 20 lb.; mean number of revolutions of engines (direct), 55½. Screw, diameter, 20 feet; pitch, 29 feet; immersion at trial, 6 inches; revolutions of screw, 55½. Draught of water of ship, forward, 20 feet 8 inches; aft, 22 feet 7 inches. Coals on board, 850 tons; consumption of fuel at full speed, about 140 tons per day of 24 hours. Number of furnaces, 32; length of stoke-hole, 68 feet 10 inches; breadth of ditto, 10 feet; temperature of ditto, 100° Fahr. The tops of the boilers are 4 feet under the water-line; fitted with three auxiliary engines, two of which supply the boilers, and the third acts as a steam fire-engine. Weight of shot fired by one broadside, 1652 lb. Speed at trial, 13·29 knots.

3. **Rattler**, screw-sloop, 179 feet 6 inches long between perpendiculars; 32 feet 8½ inches beam; 888 tons builders' O.M.; 13 feet 6 inches mean draught of water at trial; area of immersed midship-section, 330 square feet; displacement at trial, 1078 tons; nominal H.P., 200; ditto, indicated, 436; diameter of cylinders, four of 40⅛ inches each; length of stroke, 4 feet. Revolutions during trial, 27. Diameter of screw, 10 feet; pitch, 11 feet; length, 1 foot 3 inches; multiple of gearing, 4 : 1; revolutions of screw per minute, 107·9; slip per cent., 17·67. Description of engines, vertical geared. Makers of the machinery, Maudslay, Sons, and Field. Maximum speed of the vessel at trial, 10 knots.

4. **Growler**, screw gun-boat. Length between perpendiculars, 100 feet; breadth, 22 feet; draught of water, mean, 6 feet 10½ inches; immersed midship-section at this draught, 130 square feet; horse-power—nominal, 60; indicated, 200; high pressure engines working direct, with 2 cylinders, each 15½ inches in diameter, and 18 inches stroke. Makers of the machinery, Maudslay, Sons, and Field. Pressure of steam, 50 to 60 lb.; weight of engines, 8 tons 14 cwt. Boilers, 3 in number, are cylindrical, with internal tubes. Length of boilers, 15 feet 4 inches × 4 feet diameter, with one furnace in each, 2 feet 2 inches broad × 4 feet 6 inches long. Each boiler contains 82 iron tubes, 2 inches in diameter and 8 feet long. Total grate-bar surface in the three boilers, 29·25 square feet; weight of the three boilers complete, 13 tons 1 cwt.; weight of water in the three boilers, 9 tons. Screw, two-threaded, 6 feet diameter; 8 feet pitch; 16 inches long; weight, 840 lb. Total weight of the machinery with spare gear, 32½ tons. Coals carried in bunkers, 28 tons. Speed at above immersion, 8·38 knots; speed of engines and screw, 154 revolutions per minute; slip, 31 per cent.

5. **Warrior**, iron-cased steam-frigate, is built of iron; extreme length, 380 feet; breadth, 58 feet; depth, 41 feet 6 inches; tonnage, 6177. Weight of hull, about 5700 tons; fitted with engines of 1250 nominal horse-power, weighing 950 tons. Builders of the ship, the Thames Iron Co.; makers of the machinery, J. Penn & Son. She will carry 950 tons of coal, and the weight of armament, masts, stores, &c., will amount to about 1200 tons. The total weight at sea will thus be about 9000 tons. Sheathed with wrought-iron armour-plates 4½ inches thick from 5 feet below the water-line to the level of the upper deck for 220 feet of the broadside, each plate being 15 feet long by 4 feet broad. Behind the iron armour-plates there is a thickness of 24 inches of teak, protecting all the fighting portion of the vessel. The bow and stern are not thus sheathed, being merely plated with thick iron plates in the usual way, and crossed by several water-tight bulkheads. Armament will consist of Armstrong guns, each capable of throwing a 100 lb. shot a distance of 5 miles. The total cost of each frigate will be about L.320,000. Estimated speed, 14 knots an hour.

6. **Victoria and Albert**, H.M. steam-yacht, is built of timber, and has the following dimensions:—Length between the perpendiculars, 200 feet 1 inch; breadth of beam, 33 feet; depth of hold, 23 feet 9 inches; burthen in tons, builders' O.M. 2343; horse-power, noninal, 600; horse-power, indicated, at trial 2980. Propelled by paddle-wheels. Has oscillating engines by J. Penn and Son, with two cylinders, each 88 inches in diameter and 7 feet stroke, the total weight of her machinery being 401½ tons. Her draught of water when complete for sea, with stores and coals on board, is 15 feet forward and 15 feet 9 inches aft. Revolutions of engines at this draught, 22; displacement at medium load-draught, 2120 tons. Has four tubular boilers, containing in all 3024 brass tubes, each 6 feet 5 inches long by 2½ inches external diameter. The boilers have altogether, 24 furnaces, each 7 feet long by 3 feet wide, fired from two stoke-holes. The pressure of steam on the safety-valves is 20 lb. The steam is superheated; has two funnels, each 5 feet 6 inches diameter, and 40 feet 3 inches high from top of boiler. The coal-boxes contain 410 tons of coal. The paddle-wheels are feathering, 29 feet extreme diameter, 14 boards to each wheel, each board 11 feet 6 inches by 4 feet 2 inches. The wheels can be disconnected by a friction-disc and break. Speed at trial trip, 17·022 knots.

7. **Fairy**, H.M.'s screw steam-yacht, is built of iron, and has the following dimensions:—Length between the perpendiculars, 144 feet 8 inches; breadth extreme, 21 feet 1½ inches; mean draught of water at trial, 4 feet 10 inches; area of immersed midship-section, 71·5 square feet; mean displacement at trial, 168 tons. Tonnage, builder's O.M., 312; nominal horse-power, 128; indicated horse-power, 364. Builders, Mare & Co.; machinery by J. Penn & Son. Diameter of screw, 5 feet 4 inches; pitch, 8 feet; length, 1 foot. Revolutions of screw at trial, 258 per minute; slip of the screw, 34 per cent. Has two vertical, oscillating, geared engines, the cylinders 42 inches diameter, and 3 feet stroke, making 51½ revolutions per minute. Speed of the vessel at trial, 13·324 knots.

8. **Himalaya**, steam troop-ship, propelled by the screw, is built of iron, and has the following dimensions:—Length between the perpendiculars, 341 feet; breadth, extreme, 46 feet 4 inches; depth of hold, 35 feet; tonnage, 3560; horse-power, nominal, 700. Has horizontal direct engines, with cylinders 84⅜ inches diameter, and 3 feet 6 inches stroke, making 59 revolutions per minute. Boilers on Lamb and Summer's sheet-flue principle. Pressure of steam, 14 lb. She can stow 1000 tons of coal; her daily consumption, at full speed, being 70¾ tons. Fitted with the common 3-bladed screw, 18 feet diameter, by 28 feet pitch, making 59 revolutions per minute. Speed at trial, 13·9 knots. This steamer has proved eminently successful, having made the trip from England to Alexandria, on several occasions, at an average speed of 12 knots an hour; and with a favourable breeze, she has been known to run 16 knots within the hour.

9. **Troop River-steamers** for India. These are now being built for Government of the following proportions:—Length on the water-line, 350 feet; length over all, 375 feet; breadth, 46 feet. Built of steel-plates, weighing about 5 lb. per superficial foot, with the exception of the keel-strakes, which are 7 lb., and the girder-strakes 15 lb. per square foot. They are flat-bottomed, to draw only 2 feet of water, with machinery, fuel, stores, and 800 troops on board. The hulls are estimated to weigh only 370 tons. They are to be propelled by paddle-wheel engines of 200 horse-power. They will be steered by two large patent steering-blades. The hull is stiffened by two iron girders, rising above the deck, and running for 300 feet of the length, from which vertical and diagonal trusses are carried. They will be sent to India in parts, after being put together and tried in this country. Estimated speed, 12 miles an hour.

10. **Great Eastern**, of iron. Length between the perpendiculars, 680 feet; length on deck, 691 feet; breadth, extreme, 83 feet; depth of side, 58 feet; draught of water, from 29 to 30 feet. Gross tonnage, 22,500. Nominal horse-power, 2600. Builder, J. Scott Russell. Her screw-engines of 1600 horse-power, by James Watt and Company; and paddle-engines of 1000 horse-power, by J. Scott Russell. The screw-engines are horizontal direct, with 4 cylinders, each 84 inches diameter, by 4 ft. stroke, making 45 strokes per minute; with tubular boilers, carrying 25 lb. pressure. The screw is of the common construction, with four blades, 24 ft. diameter, with a pitch of 44 ft. The paddle-wheel engines are oscillating, with 4 cylinders, each 74 in. diameter, by 14 ft. stroke. Boilers, tubular, 25 lb. pressure. Paddle-wheels are of the common construction, 50 ft. diameter, 13 ft. length of floats, and 3 ft. depth. Total coals carried, 10,000 tons. Coals burnt per hour, 12 to 13 tons. Speed about 15 knots. Her ship-draught is shown in the plates illustrating article SHIP-BUILDING.

11. **Persia**, transatlantic mail-steamship, of iron, has the following dimensions:—Length between the perpendiculars, 360 feet; breadth of beam, 45 feet; depth of hold, 29 feet 8 inches. Medium load-draught of water, 21·3 feet. Displacement at this draught,

5285 tons. Area of immersed midship-section, 818 square feet. Tonnage, builders' O.M., 3586. Builders of vessel and makers of the machinery, Robert Napier and Sons. The bottom plates of the hull are 15/16 inch thick, tapering to ¾ inch at the load water-line, and above this 11/16 inch, except round the gunwale, where they are ⅞ inch. The hull is divided into 7 water-tight compartments, and has a double-iron bottom for a considerable portion of her length. The launching weight of the iron hull was 2200 tons, her displacement with machinery, coals, and stores on board being about 5400 tons, on a draught of 23 feet. Accommodation is provided for 250 passengers (besides a crew of 150 persons), and stowage room is found for 1200 tons measurement goods. Coals carried are 1400 tons. The engines are on the side-lever construction, with 2 cylinders, each 100½ inches diameter, and 10 feet stroke, 850 nominal horse-power, and about 3000 indicated horse-power. Diameter of paddle-shaft, 23½ inches. There are 8 tubular boilers, containing, in all, 40 furnaces, each 7 feet long by 2 feet 9 inches wide. Total length occupied by the machinery is 107 feet 6 inches. The paddle-wheels are of the common construction, 38 feet 6 inches diameter to extremity of boards, which are 10 feet 8 inches long, 2 feet 1 inch broad, on 28 arms. On the occasion of the Persia's trial trip from Glasgow to Liverpool, she ran 175 knots in 10 hours 43 minutes; thus accomplishing an average speed of 16 knots, or nearly 19 British statute miles an hour.

12. PERA, Alexandria mail screw-steamship, is of iron, and has the following dimensions:—Length between the perpendiculars, 303 feet 7 inches; breadth extreme, 42 feet 3 inches; depth of hold, 27 feet 2 inches; gross tonnage, 2613; nominal horse-power, 450; indicated horse-power, 1500. Builders of the vessel, Mare and Company; makers of the machinery, Messrs Rennie. She has vertical trunk-engines, geared, with 2 cylinders each 70½ inches diameter (trunk 30 inches diameter), and 4 feet length of stroke. Strokes of engine per minute, 29½. There are four sheet-flue boilers; pressure of steam 16 lb., superheated. 700 tons of coal are carried in boxes; coals burned per day of 24 hours, 44 tons (in place of 56 before superheating apparatus was fitted). Screw propeller has 3 blades, is 15 feet 6 inches diameter, 21 feet pitch, making 60 revolutions per minute. Speed at trial trip, 12·5 knots. The Pera has made some very remarkable passages. Thus, in the month of July 1859, she ran from Southampton to Gibraltar, 1000 miles, in 3 days 21 hours (being at the rate of 10¾ knots per hour); thence to Malta, another 1000 miles, in 3 days 12 hours (11·9 knots per hour); and from Malta to Alexandria, 1000 miles, in 2 days 19 hours (14·92 knots per hour). The Pera's lines are shown in the plates of article SHIP-BUILDING.

13. LEINSTER, ULSTER, MUNSTER, CONNAUGHT, new Holyhead mail-packets, are of iron, and propelled by paddle-wheels. They have the following dimensions:—Length extreme, 350 feet; breadth, 35 feet; depth, 20 feet; draught of water, 12 to 13 feet; builder's tonnage, 2000; nominal horse-power, 700; indicated horse power (estimated), 3500. Average speed contracted for, 20 miles an hour. The engines are oscillating, and the paddle-wheels have feathering floats. Three of the vessels are built by Messrs Laird, and one by Messrs Samuda; and the machinery is by Messrs Ravenhill, Salkeld, and Company, and Messrs James Watt and Company. They are rigged very lightly, for fore and aft sails only, their great engine-power making them independent of the wind. They have 9 water-tight bulkheads, extending to the upper deck, one of which divides the engine and boiler rooms; this latter bulkhead constituting an important element of safety and strength, which might be advantageously introduced into iron steamers much more frequently than it is. The cabins are 9 feet 6 inches high; the principal saloon being 60 feet long.

We are enabled to give the following additional particulars of the Leinster through the kindness of her constructor, Mr Samuda:—Length between the perpendiculars, 328 feet; length on deck, 346 feet; breadth of beam, extreme, 35 feet; depth in engine-room, 21 feet; burthen in tons, builders' old measurement, 2000. Draft of water at official trial at Stokes Bay, 26th July 1860—forward, 12 feet 2½ inches; aft, 13 feet 2½ inches (12 feet 8½ inches mean). Area of midship section at this draft = 336 square feet. Displacement at same draft = 1880 tons. Area of horizontal water-line section at the same draft = 7974 square feet. The form of the Leinster midship section may be thus described: A round bilge, having a radius of about 8 feet, joining the straight of the side at the 11½ feet water-line, and sloping down with an easy sweep to the keel, which it meets at an angle of about 12 degrees from the horizontal line. Her mean speed at the measured mile at Stokes Bay, as above, was 17·797 knots, or 20·502 English statute miles; mean revolutions of engines, 26½ per minute. The engines (oscillating) are by Messrs Ravenhill, Salkeld, and Company, and have the following dimensions:—Diameter of cylinders, 98 inches; length of stroke, 6 feet 6 inches; revolutions per minute, 26; nominal horse-power, 700; indicated horse power at trial, 4200; pressure of steam in the boilers (tubular), 25 lbs.; consumption of fuel during trial trip, at the rate of 7 tons per hour; coals on board during the trial (on starting), 30 tons; stowage for coals in bunkers, 90 tons; estimated consumption while at regular work, 6 tons per hour. Feathering wheels, 27 feet diameter to centre of axis of floats. The exceptional character of the Holyhead packets is made further apparent by the following statement of the official tonnage of Leinster:—Gross tonnage, 1382; engine-room tonnage, 997; leaving only 385 for the register tonnage.

14. BREMEN, screw-clipper steamship, is built of iron, and has the following dimensions:—Length between the perpendiculars, 318 feet; breadth of beam, 40 feet; depth of hold, 26 feet; mean draught of water at trial, 18 feet 6 inches. Displacement at this draught, 3440 tons. Area of immersed midship section, 606 square feet. Rate of displacement at load draught, 25 tons per square inch. Builders of the ship and makers of the machinery, Messrs Caird and Company. The engines of the Bremen consist of two direct-acting inverted cylinders, each 90 inches diameter and 3 feet 6 inches stroke. Nominal horse-power, 500; indicated horse-power at trial, 1624. Speed at trial trip, 13·15 knots per hour. The average performance at sea, between Bremen and New York, with a mean displacement of 2950 tons, was found to be 11·05 knots, the engine showing a mean indicated horse-power of 1045. The superiority shown by the Bremen is believed to be principally due to her fine form of body, and judicious proportions. Her ship-draught will be found amongst the plates illustrating SHIP-BUILDING.

15. WINDSOR CASTLE, Clyde river-steamer, propelled by paddle-wheels, is built of steel-plates, and has the following dimensions:—Length, 190 feet; breadth, 20 feet; depth, 7 feet 6 inches; tonnage, gross, 190; register, 93. Mean draught at trial, 3 feet 1 inch. Immersed midship-section at this draught, 52 square feet. Average number of revolutions, 43. Nominal horse-power, 115. Indicated horse-power at trial, 620. Pressure of steam in the boilers, 40 lb. Builders of the vessel and makers of the machinery, Messrs Caird and Company. The cylinders are placed diagonally; they are 40 inches in diameter and 5 feet stroke, cutting off steam after 12 inches. The steam is supplied by an upright tubular boiler, and is superheated in the funnel to a temperature of 375° Fahr. before entering the cylinders. The boilers have 76 square feet of fire-grate surface, and 1526 square feet of total heating surface, consuming about 20 cwt. of coal per hour. The paddle-wheels are feathering, 15 feet diameter, each having 10 boards, 8 feet long by 2 feet 3 inches broad. Speed at trial trip, 17·083 knots, or 19·679 British statute miles an hour. In this steamer *weight* is economised in every possible way, and only 10 tons of coal are carried.

16. TACHTALIA, river-steamer for shallow navigation, is built of iron, and has the following dimensions:—Length, 150 feet; breadth, 20 feet; draught of water, with machinery and passengers on board, 12½ inches. Builders of the vessel and makers of the machinery, Messrs J. and A. Blyth. She is propelled by 4 condensing engines, of the collective power of 40 horses, acting through 4 paddle-wheels, each 6 feet in diameter and 6 feet wide; the forward engines making 87 revolutions and the after-engines 96 revolutions per minute, and the speed through still water being about 11 miles per hour. The hull is formed of very thin plates, stiffened by frequent transverse bulkheads, and webs of plate surrounding the vessel internally. By employing 2 pairs of paddle-wheels, each pair driven by a distinct pair of steam-engines, not only are the weights of the machinery, water, and coals diffused over the vessel, but the propelling power is also widely distributed over the structure. The use of 4 paddle wheels in place of 2 greatly improves the steering of the vessel, always a matter of much difficulty with boats of shallow draught running on swift rivers. Lightness of machinery in this vessel is promoted by the substitution of gun-metal for cast-iron in the condensers, &c., and of cast-steel and wrought-iron for the framing of the engines. The boilers are constructed of Lowmoor plates throughout, without angle-irons, to save weight. Vessels of this class are well adapted for the rivers of India. A representation of the Tachtalia is given at page 136.

17. SCREW-STEAMER for the rivers of INDIA, built of iron. Length, 70 feet; breadth, 7 feet 6 inches; depth, 3 feet 6 inches; draught of water, 2 feet. Boat and machinery constructed by Messrs G. Rennie and Sons. Propelled by two screws, one on each quarter (see annexed wood engraving, fig. 33); diameter of the screws, 2 feet 2 inches; pitch, 4 feet. Driven by a pair of disc engines acting direct. Speed of the engines and screws, 260 revolutions per minute. Speed of the boat, 10 knots per hour. Weight of the boat, 3 tons 8 cwt.; weight of the machinery, 3 tons. Consumption of coal, per hour, 100 lb. Power of traction, at slow speed, 250 tons. Cost of trackage, ½ of 1d. per ton per mile.

18. AMERICAN STEAMBOATS (by a correspondent of *The Engineer*).—"Going aboard at a late hour in the evening, the scene

which presented itself to our eyes was novel in the highest degree. Painted a pure white, as nearly all American river-steamboats are (for the anthracite coal burned under their boilers makes no smoke whatever), the enormous mass of the vessel rose like a giant iceberg above the water. Hurrying over the broad gangway, we found ourselves in a crowd of nearly 700 passengers, more than one-third of whom were ladies. We were upon the main-deck, although under a lofty ceiling, over which was a grand saloon of palatial proportions and magnificence. Looking aft, a broad entrance, flanked with gilded columns and luxurious drapery, opened to the ladies' saloon—a *sanctum sanctorum* not to be profaned by the footsteps of a bachelor, although steamboat etiquette was not so strict, nor steamboat regulations so inflexible, as to forbid the momentary presence there of gentlemen accompanying their wives, or other fair charges, to be intrusted to the care of the stewardess. On either side of this entrance were broad staircases descending to an immense lower cabin, along the sides of which were more than 400 berths. The supper tables were then set out with a degree of splendour for which an English traveller would be altogether unprepared. Nearly amidships, on the main-deck, a grand staircase, sweeping both to the right and left, conducted to the great saloon, or state-room hall, nearly 300 feet in length, several yards in width, and having an upper gallery, with a second story of state-rooms—a lofty arched ceiling, glazed with ground and coloured glass, and supported by richly-carved columns, covering the whole. In its construction, this steamboat (the New World) is totally unlike anything ever seen in British waters. It is of enormous size. Originally 376 feet long, it was afterwards lengthened to 468 feet over all. With a breadth of beam of 50 feet, the main deck is extended by means of platforms, or "guards," projecting over the water to the full width across the paddle-boxes, 85 feet, being thus wider than the main-deck of the Great Eastern. Yet the vessel, which is flat-bottomed, with bilges nearly or quite square, draws only 5½ feet of water, the whole displacement being about 2500 tons, and the immersed mid-section 275 square feet. All American boats have wooden hulls, and how to stiffen such a vast and shallow craft, flat-bottomed as Noah's Ark? There are no tubular cells, no 'double skins,' nor is there a hundredweight of boiler-plate, excepting in the boilers themselves, in the whole structure. As if to increase the strain the boilers, weighing, with water, 75 tons each, are placed upon the "guards" outside the hull, and of course several feet above the load-line. To make the whole as rigid as a tubular girder, two enormous arched trusses, placed one over each side of the hull, extend over nearly 350 feet of the length of the boat. These great bows, like the arches of a bow-string bridge, are connected to king-posts and queen posts, and strapped and fastened, so that the whole is as stiff as a man of war. Then there are four or five large king-posts, or masts, stepped upon the keel, and carrying the weight of the projecting 'guards' by long diagonal tension rods. These masts carry no spars, booms, or rigging of any kind, all of which would be so much top hamper, worse than useless, at a speed of 20 miles an hour. These posts, like nearly all the rest of the wood-work, are painted a dazzling white, and surmounted by gilded balls. The lines of the hull are very sharp, and at 22 statute miles an hour, a speed not unfrequently attained, there is only a thin spurt of water breaking into spray to mark the keen entrance of the cutwater."

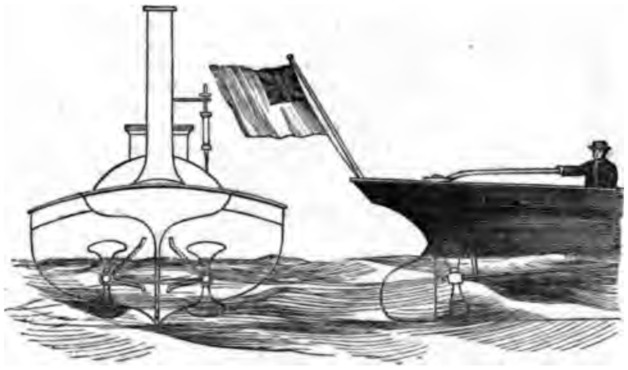


Fig. 33.
Screw-steamer for the rivers of India.

We subjoin a list of those parts which are considered most necessary to be carried as SPARE GEAR for sea-going PADDLE-WHEEL ENGINES of a large class:—

100 bolts and nuts for paddle-wheels; 50 bolts and nuts for paddle-floats; 6 paddle-floats; 2 sets of gearing for paddle-floats (feathering-wheels); 1 connecting-rod for ditto, ditto; 1 driving-arm for ditto, ditto; 4 large pins and 2 small for brackets, ditto; 2 radius boss pins for ditto, ditto; 2 bushes for ditto, ditto; 8 brass washers for gearing, ditto; 4 bolts and nuts for radius-boss, ditto; 4 segments of paddle-centres; 4 arms for paddle-wheels; 18 iron washer-plates; 2 brass linings for outer-bearings; 120 brushes for boiler-tubes; 36 stoking-irons; 60 scrapers, circular and forked; 1 set of stocks, taps, and dies, from ¼ to 1¼ inch; 1 air-pump rod and nut; 1 cylinder-cover, bush, and gland; 1 piston and rod; 1 piston-rod cap, complete; 2 complete sets of all India-rubber valves; ½ set of fire-bars; 1 set of bearing-bars for one furnace; boiler-plate, about 6 or 8 cwt.; 60 boiler-tubes; 300 ferules for boiler-tubes; 8 handles for boiler-tube brushes; 24 drifts (short and long) for tubing; 12 mandrils for ditto; 1 crank-pin for engine; 1 eccentric-band, complete; 1 feed-pump rod, complete; 1 bilge-pump rod; 1 gross iron washers of various sizes; 120 bolts and nuts; 8 glass gauge-tubes for boilers; 2 glass tubes for barometers.

The following is a list of SPARE-GEAR for SCREW-ENGINES of a large class:—

1 Cylinder-cover, complete; 1 connecting-rod; 1 centre-bonnet, for cylinder; 1 air-pump rod; 1 piston and rod, complete; 1 feed-pump rod; 1 bilge-pump rod; 1 slide-rod, complete; 1 eccentric strap, complete; 1 spiral-spring, for escape-valve; 1 cross head; 1 guide-block and brass (if so made), complete; 1 cap for thrust-block, fitted with white metal; 2 screws for thrust-block; soft metal bearings, various; 2 complete sets of India-rubber valves; 1 wrench for piston-rod nuts; 1 set of taps and dies, complete; 50 bolts, assorted (iron and metal); 80 bolts and nuts (assorted); 40 spanners, various; ½ set of fire-bars; 60 fire-irons, assorted; 110 scrapers (50 circular and 60 forked); 3 bearing-bars; 100 boiler-tubes; 300 ferules for boiler-tubes; 40 drifts and mandrils for boiler-tubes; 200 tube-brushes, and 4 handles; 140 washers for boiler-tubes; 3 boiler-plates; 16 glass gauge-tubes, and 60 India-rubber rings.

Actual Weights of Steam Machinery in the Royal Navy.

Name of the Vessel.	Nominal Horse-power.	Engines complete.	Boilers and apparatus.	Propeller and gear.	Coal-boxes.	Sundries.	Spare gear.	Total weight of machinery.	Water in boilers.	Grand Total.
	H.P.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Mersey	1000	213·4	263·7	65·9	17·3	25·8	43·7	629·8	136	765·8
Shannon	600	84·	128·6	51·2	8·1	15·	21·8	308·7	...	...
Melpomene	600	78·9	135·9	48·9	9·3	23·8	13·7	310·5	...	...
Algiers	450	128·4	169·2	46·9	12·7	13·5	...	370·8	85	455·8
Cornwallis	200	18·8	45·4	14·3	4·7	9·6	4·7	97·5	30	127·5
Marlborough	800	200·9	211·8	35·9	14·8	37·	26·4	526·8	112	638·8
Royal Sovereign	800	210·7	210·7	21·2	11·6	26·	24·8	505·8	112	617·8
Victoria and Albert	600	183·2	170·4	*73·3	15·0	31·7	26·0	499·6	...	...

* Paddles.

Steam Navigation.

DESCRIPTION OF THE PLATES.

Plate XV. represents the usual type of the side-lever marine-engine. The principal parts are—A the cylinder, B the valve-chest, C the condenser, D the hot well, E the air-pump, F the feed and bilge pumps, GG the great lever, G′ its main gudgeon, H the cylinder side-rods, I the cross-head, K the piston-rod, LL the parallel motion, M the air-pump cross-head, N the air-pump side-rods, O the air-pump piston-rod, P the connecting-rod cross-tail links, Q the cross-tail, R the connecting-rod, S the crank, U the eccentric pulley or cam, *u u u* the eccentric rod, V the valve-shaft, WW the valve-lever and counterbalance lever.

The apparatus for working the valves expansively is distinctly shown. On the crank-axle, T, is placed a series of cams *t t t*, which act upon the roller of the expansion-valve tumbler. Y *y y y* are the expansion-valve connecting-rods and levers. Z is the valve-chest, and the valve is of the kind called equilibrium-valves, or crown-valves.

Plates XVI., XVII., and XVIII., represent a pair of direct screw-engines of 500 horse-power (nominal), as constructed by Messrs Ravenhill, Salkeld, and Company, for various ships in the royal navy. The following vessels have been fitted with machinery on this plan, viz.—the Waterloo and Nelson, 98 guns, 500 H.P.; the Undaunted, Glasgow, and Newcastle, 50-gun frigates, and 600 H.P.; the Narcissus, 50 guns, and the Jason, 21 guns, each of 400 H.P. These engines have given much satisfaction, being at once compact, and at the same time easy of access to all the working parts.

The following are the principal dimensions of the 500-horse screw-engines:—

Diameter of the cylinders (two)	71 inches.
Length of stroke	3 feet.
Revolutions of engines and screw-shaft, per min.	50
Pressure of steam in the boilers per sq. inch	20 lb.
Diameter of the screw	18 feet.
Pitch of do. mean..	20 feet.
Description of screw	Griffith's.
Mean draught of the ship (H.M.S. Nelson)	24 ft. 9½ in.
Speed at the measured mile	109 knots.
Indicated horse-power	2150 horses.

The various parts of the engines will be recognised by reference to the following letters:—AA are the cylinders; B the piston-rods, of which there are two to each cylinder; C the connecting-rods, working between the guiding surfaces DD, and giving motion to the main cranks EE; F is the screw-shaft; G the thrust-block, on which the thrust of the screw is taken; H the coupling for disconnecting the shaft; I a worm-wheel for turning the engines by hand; K the steam-pipe from the boilers; L the throttle-valve; M the expansion-valves; N the cylinder slide-valves; O the exhaust-passages; P the condenser; Q the air-pump-rods, which work direct from the piston, passing steam-tight through the cylinder covers like small piston-rods. The air-pumps themselves cannot be seen, being concealed by the condenser. R the discharge-pipes; S the feed and bilge plunger pumps; eccentrics and gear for working the slide-valves.

Plates XIX. and XX. represent the engines and boilers of the screw steamship Thunder, which are possessed of several interesting peculiarities and appliances for economising fuel and steam. The vessel (built by Messrs Lungley of London) is of iron, 240 feet long, 30 feet beam, 22 feet 6 inches deep, and 1062 tons B.O.M. Her draught of water is 13 feet 8 inches aft, and 10 feet 8 inches forward. The engines are constructed by Messrs Dudgeon, of Millwall, London, and have the following dimensions:—

Diameter of cylinders (two)	55	inches.
Length of stroke	36	,,
Revolutions of engines and screw per min.	58	,,
Diameter of screw	15	feet.
Pitch of screw	29½	,,
Nominal horse-power	210	horses.
Indicated horse-power with full steam .... 950 to	1000	,,
Do., with expansion when cutting off after ¼th	696	,,
Speed, with an immersed midship-section of 342 square feet and displacement of 1175 tons, the engines making 54 revolutions per minute, and cutting off steam after ¼th of the stroke	14	knots.
Maximum speed at trial with full power	15	,,

The cylinders of these engines are inverted, and are fixed directly over the crank-shaft. They have separate expansion-slides, and double-port steam-slides. The exhaust is carried round the cylinders by broad belts (see O, Plate XIX.) into the condenser P, the belts thus acting as steam-jackets to the cylinders to preserve their temperature. The condensers themselves form part of the framing on which the cylinders stand. The shaft is forged with solid cranks, and the thrust of the screw is taken by the long collared bearing at C, which is supported independently of the engine framing. The pressure of steam in the boilers is 19 lb., the steam being cut off in the cylinders (when working most expansively) after one-fourth of the stroke.

The letters of reference, previously given, indicate the same portions of the machinery for this and all the remaining plates.

The boilers are tubular, two in number, with four furnaces, and are fired from each end. Each boiler has 360 tubes, 3½ inches external diameter, and 7 feet long. The boilers are fitted with superheating apparatus (A), on Mr Beardmore's plan; each consists of two steam-chambers, placed one on each side of the chimney, connected by 172 tubes in each, each tube being 2 inches in diameter. The lower end of the chimney is expanded so as to encase the tubes, through which all the steam from the boilers passes on its way to the cylinders. These boilers generate steam with much facility. The advantage of having two funnels in this case is, that the draught thus becomes more direct, and therefore sharper than it would be with one large funnel. The temperature of the superheated steam is about 320°.

These engines have exhibited a very remarkable economy of fuel, the consumption, under favourable circumstances, not exceeding 1½ lb. per I.H.P. per hour; and when the vessel was deeply laden, this did not exceed from 2 to 2½ lb. during a ten days' voyage at sea. The Thunder ran from Plymouth to St Vincent in 9 days 14 hours, the chief engineer writing thus from the latter place:—"We have run 285 miles during the last 24 hours; and our average speed has been throughout the voyage 11 knots per hour, on a consumption of 15 tons of coal per 24 hours. Pressure of steam 10 lb.; 44 revolutions per minute. Temperature of steam in superheaters, 310°." This is equal to a consumption of about 12 cwt. of coal per hour while steaming at the rate of 11 knots, which, for a displacement of 2000 tons, is an extraordinary result. Whilst on her trial trip her displacement was only half the above, when, under the most favourable circumstances, she went at the rate of 14 knots on a consumption of 8 cwt. per hour.

Plates XXV., XXVI., and XXVII., represent six varieties of marine engines, constructed by Messrs Maudsley, Sons, and Field—namely, oscillating-cylinder marine engines for paddle-wheels, double-cylinder engines for paddle-wheels, annular-cylinder engines for paddle-wheels, annular-cylinder engines for the screw-propeller, horizontal direct engines for the screw-propeller, and steeple-engines for river-navigation.

Plates XXI. and XXII. represent a pair of "combined-cylinder" paddle-wheel engines of 320 horse-power collectively (nominal), as constructed by Messrs Randolph, Elder, and Company, of Glasgow, in the steam-ships Callao, Lima, and Bogotá.

These vessels are 245 feet long, 36 feet broad, and 23 feet deep, and are designed with lines favourable for speed. Their tonnage is 1650 tons; draught of water, 11 feet forward, 12 feet aft; fitted with feathering wheels 25 feet 2 inches diameter.

The cylinders are four in number, viz., two of 52 inches diameter, and two of 90 inches diameter, and 5 feet stroke. It will be observed that they lie diagonally to each other. During the trial trips the engines made from 23 to 26 revolutions per minute, and indicated from 1000 to 1300 horse-power, the pressure of steam being 26 lb., and the speed of the ships from 12½ to 13 knots per hour. The boilers are tubular, and superheat the steam in the steam-chests by contact with the up-takes only, these being purposely divided and prolonged with this view. The cylinders are further provided with "jackets" kept well supplied with hot steam, to guard against condensation within the cylinders.

These engines have also been attended with a remarkable economy of fuel. The Bogotá lately ran from Glasgow to St Vincent, a distance of 2470 nautical miles, in 9 days 21 hours, on a consumption of 232 tons of coal, thus giving an average speed of 10·42 knots, on a consumption of 19 cwt. per hour. The average I.H.P. being 950, this gives an average of 2¼ lb. of coal per I.H. per hour.

Plate XXIII. represents a pair of combined-cylinder engines of the same description as shown in the preceding plates, and by the same makers, but designed for driving the screw-propeller. These, it will be observed, are geared engines, driving the screw-shaft by means of internal gearing.

The nature and presumed advantages of "combined-cylinder" engines have been already explained. It may be here repeated, however, that the steam is first admitted into the small cylinder for about one-third of the stroke; and after expanding during the remainder of the stroke in the small cylinder, it enters the large one, and completes its work there by further expanding to the end of its stroke.

Plate XXIV. is a section of inboard works of the paddle-steamer Delta, carrying the Indian mails from Southampton to Alexandria.

(E. M—Y.)

Table of Steamers in the Merchant Service, compiled from Returns made to the Board of Trade.

Name of the Vessel.	Port of Departure.	When built.	By whom built.	Iron or Wood.	Length per Register.	Breadth per Register.	Depth per Register.	Tonnage.		Draft of Water.		Makers of the Machinery.	Description of Engines.	Nominal Horse-Power.	Paddle or Screw.	Diameter of Cylinder.	Number of Cylinders.	Length of Stroke.	Revs. of Engines per minute.	Description of Boilers.	Number of Boilers.	Pressure of Steam.	Coals carried.	Maximum Speed at Load Draft.	Service.
								Register.	Gross.	Forward.	Aft.														
		Yr.			Feet.	Ft.	Ft.	Tns.	Tons.	F. In.	F. In.			H.P.		In.	No.	F. In.	No.		No.	lb.		Kts.	
African	Liverpool	1855	Smith & Rodgers	iron	280·8	34·2	23·7	1040	1529	20 0	21 0	Smith & Rodgers	Steeple 4 Piston-Rod	240	S. gear.	62	2	4 0	26	Tubular	2	14			Liverpool to Alexandria.
Agia Sofia	Liverpool	1857	Thomson	iron	259·3	34·6	22	977	1437	17 5	19 4	Thomson	Oscillating	193	S.direct	56	2	3 0	42	Tubular	2	25			Lpl. to Mediterranean.
Alhambra	Southampton	1855	Samuda	iron	209·3	27·1	16·3	373	642	12 4	13 4	Humphrys & Co.	Dble. P.-Rod	140	S.direct	50½	2	3 0	34	Sheet-flue	2	16	10 days	11	Peninsular Mails.
Alliance	Southampton	1855	Mare & Co.	iron	175·5	23·7	14·6	168	360	9 6	10 0	Seaward	Atmospheric	225	Paddle	62	3	4 6	25	Tubular	2	16	50 hours	13	Channel Islands (Mails).
Arabia	Liverpool	1852	R. Steele	wood	284·2	37·3	27·6	1359	2893	20 0	21 0	R. Napier & Sons	Side-Lever	930	Paddle	103	2	9 0	15	Tubular	4	18			Lpl. to Boston (Mails).
Atrato	Southampton	1853	Caird & Co.	iron	336·6	40·9	33·7	1969	3126	21 0	21 3	Caird & Co.	Side-Lever	800	Paddle	96	2	9 0	15	Sheet-flue & Tubular	4	16	16 days	13½	West India Mails.
Ava	Southampton	1855	Tod & M'Gregor	iron	257·6	35·3	16·2	930	1373	15 3	15 9	Tod & M'Gregor	Vert. Trunk	320	S. gear.	70	2	4 0	30	Sheet-flue	2	13½	500 tons	12	China Mails.
Bahiana	Liverpool	1854	J. Laird	iron	245·5	35	22·8	936	1530	18 0	19 6	Fawcett & Co.	Oscillating	197	S. gear.	54	2	4 0	38	Tubular	2	12			Liverpool to India.
Behar	Southampton	1856	J. Laird	iron	265	36·1	25·5	1090	1603	18 0	18 0	Fawcett & Preston	Horizontal	300	S.direct	56	2	2 6	50	Sheet-flue	4	16	12 days	11	Indian Mails.
Brighton	Weymouth	1857	Palmer & Co.	iron	183·5	20·9	10	180	285	6 0	7 6	Palmer & Co.	Oscillating	140	Paddle	44	2	4 0	34	Tubular	2	30	48 hours	12½	Channel Islands.
Celt	Southampton	1855	G. Lungley	iron	179	25	17	426	550	13 3	14 11	Summers & Day	Trunk	85	S. gear.	*34	2	2 9	36	Sheet-flue	1	12	45 days	9	Cape of Good Hope Mails.
Ceylon	Southampton	1858	Samuda	iron	306·1	40·9	27·8	1374	2020	20 0	20 6	Humphrys & Co.	Invert. Cylin.	450	S.direct	72	2	3 0	50	Sheet-flue	4	15	11½ days	12½	Alexandrian Mails.
China	Southampton	1855	J. Laird	iron	279	37·4	22·9	1366	2009	16 6	17 10	Humphrys & Co.	Invert. Cylin.	400	S.direct	64	2	2 8	62	Sheet-flue	4	20	14 days	11½	Alexandrian Mails.
City of Baltimore	Liverpool	1855	Tod & M'Gregor	iron	324·5	31·1	25·8	1224	2367	19 0	21 0	Tod & M'Gregor	Steep. 4 P.-R.	547	S. gear.	82	2	7 0	16	Tubular	4	14			Liverpool to New York.
C. of Washington	Liverpool	1855	Tod & M'Gregor	iron	319	40·1	19·2	1618	2380	20 0	21 0	Tod & M'Gregor	Steep. 4 P.-R.	460	S. gear.	76	2	6 0	17½	Tubular	4	12½			Liverpool to New York.
Colombo	Southampton	1853	R. Napier	iron	286·6	36	26·8	1190	1864	17 11	20 7	R. Napier & Sons	Beam	450	S. gear.	72	2	5 6	26	Sheet-flue	4	15	11½ days	12	Alexandrian Mails.
Courier	Southampton	1847	Ditchburn	iron	167	22·3	10·8	195	313	7 0	7 6	Maudslay & Field	Annular Pist.	200	Paddle	60¾	2	3 6	32	Tubular	2	15	32 hours	12	Channel Islands.
Cygnus	Weymouth	1854	Henderson	iron	177	24·6	16·7	421	530	13 1	14 6	M'Nab & Clark	Oscillating	120	Paddle	42	2	3 6	34	Tubular	2	25	48 hours	12	Channel Islands.
Delta	Southampton	1859	Thames Iron Shipbuilding Co.	iron	324·3	35·3	22·1	1019	1618	14 11	14 11	J. Penn & Son	Oscillating	400	Paddle	72	2	7 0	25	Sheet-flue	4	20	9 days	14	Alexandrian Mails.
Emerald	Southampton	1857	Summers	iron	105	14·1	8.1	43	69	4 10	5 2	Summers & Day	Oscillating	32	Paddle	23	2	2 9	42	Tubular	1	16	3 tons	10	Isle of Wight.
Empress	Dover	1855	Mare & Co.	iron	151·6	20	11	103	301	6 2	6 6	Ravenhill & Co.	Oscillating	100	Paddle	41	2	3 0	42	Tubular	1	25	12 tons	13½	Dover to Calais.
Etna	Liverpool	1855	Caird & Co.	iron	304·9	36	27	992	2215	21 0	22 0	Caird & Co.	Beam	438	S. gear.	76¼	2	5 3	24	Tubular	4	14			Liverpool to New York.
Euxine	Southampton	1847	Caird & Co.	iron	222·7	29·4	18·5	729	1164	17 6	18 0	Caird & Co.	Oscillating	400	Paddle	75	2	7 0	15	Sheet-flue	4	15½	10 days	12	Mediterranean Mails.
Garland	Glasgow	1855	R. Napier	iron	165·8	23·1	12·2	192	282	9 0	11 0	R. Napier & Sons	Hor. Trunk	80	S.direct	36	2	3 0	80	Tubular			30 tons	11	Coasting Trade.
Great Britain	Liverpool	1848	Patterson	iron	274	48·2	31·5	1733	3209	21 0	21 0	J. Penn & Son	Oscillating	500	S. gear.	82½	2	6 0	20	Tubular	6	10			Liverpool to Australia.
Great Eastern	Southampton	1859	J. Scott Russell	iron	680	83	55		22,500	25 0	25 0	Scott Russell, J. Watt & Co.	Oscillating Horizontal	1000 1600	Paddle S.direct	74 84	4 4	14 0 4 0	12 48	Tubular Tubular	4 6	25 25	10,000 tons	15	
Great Western	Bristol	1838	Patterson	wood	210	35·4	23·3		1340	16 0	17 0	Maudslay & Field	Side-Lever	450	Paddle	73	2	7 0					700 tons	11	First Transatlantic Str.
Havelock	Glasgow	1858	Thomson	iron	215	26	14·9	339	628	9 6	10 0	Thomson	Side-Lever	344	Paddle	62	2	5 6	26	Tubular		20	60 tons	12½	Coasting Trade.
Havre	Southampton	1856	Mare & Co.	iron	184·7	24	14·5	200	387	9 8	10 0	Seaward	Atmospheric	220	Paddle	62	3	4 6	25	Tubular	2	16	50 hours	12½	Hâvre Mails.
Her Majesty	Portsmouth	1850	Robinsons & Russell	iron	129·1	14	7·2	66	92	3 9	4 6	Robinsons & Russell	Oscillating	40	Paddle	27	2	2 6	55	Tubular	1	16	18 hours	12	Portsmouth and Ryde.
Himalaya	(Governmt.)	...	Mare & Co.	iron	341·0	46·4	35·0	2327	3438			J. Penn & Son	Horizontal	700	S. gear.	84½	2	3 6	59	Sheet-flue	4	14	1000 tons	13½	Government Transport.
Imperador	Liverpool	1854	J. Laird	iron	263·5	35·2	24·2	1315	1739	16 0	17 0	Fawcett & Co.	Inverted	173	S.direct	54	2	2 9	60	Tubular	2	15			Liverpool to India.
Indian	Liverpool	1854	Denny	iron	277·7	33·8	23·9	1154	1873	16 9	18 0	Tulloch & Denny	Inverted	250	S.direct	62	2	3 6	40	Tubular	2	12	(lost)		Liverpool to Quebec.
Indiana	London	1852	Ditchburn	iron	239	38·2	32·4	1798	2364	19 6	19 6	Maudslay & Field	Diagonal	300	S.direct	55	2	2 6	50	Tubular	2	12	20 days	9	Steam Transport.
Indus	Southampton	1847	Wigram	iron	241·2	34·1	29·7	1302	1950	17 6	18 6	Miller & Ravenhill	Oscillating	450	Paddle	75	2	7 0	15	Sheet-flue	4	13	11 days	10	Alexandrian Mails.
Iona	Glasgow	1858	Thomson	iron	225	20·4	9	173	324	4 6	4 6	Thomson	Oscillating	120	Paddle	46½	2	4 0	35	Tubular		34	25 tons	16	Cumbray and Skipness.
Ionia	Liverpool	1856	Marshall	iron	244·4	32·1	25·9	943	1388	18 0	20 0	Marshall	Inverted	210	S.direct	46	3	3 0	52	Tubular	3	16			Lpl. and Mediterranean.
Iron Duke	Liverpool	1844	T. Wilson	iron	225·2	28	17·1	385	732	10 0	11 0	Fawcett & Co.	Side-Lever	320	Paddle	63	2	7 0	17	Combined	2	15			Liverpool to Dublin.
Jeddo	Southampton	1859	J. Laird	iron	277·3	35·8	16·2	1109	1631	16 7	17 0	R. Napier & Sons	Hor. Trunk	450	S.direct	70	2	3 0	60	Sheet-flue	4	16	12 days	11½	China Mails.
Jupiter	London	1849	Pascoe	iron	165·0	18	9	91	145	4 3	4 9	Miller & Co.	Oscillating	80	Paddle	37	2	3 0	42	Tubular	1	20	10 tons	13½	Dover to Ramsgate.
Juba	Liverpool	1854	Thomson	iron	313·8	35·8	27·6	1067	2190	21 0	22 0	Thomson	Beam	433	S. gear.	76	2	5 5	26	Tubular	4	15			Liverpool to New York.
La Plata	Southampton	1851	R. Steele	wood	280·5	37·4	27·6	1474	2404	20 6	22 0	R. Napier & Sons	Side-Lever	875	Paddle	103	2	9 0	13	Tubular	4	16	14 days	12½	West India Mails.
Lyons	Newhaven	1856	Scott Russell	iron	192	22	10	139	269	6 2	6 7	Scott Russell	Oscillating	160	Paddle	48	2	4 6	36	Tubular	2	30	50 tons	14½	Newhaven to Dieppe.
Magdalena	Southampton	1851	Pitcher	wood	266	38·1	33·5	1866	2943	21 0	22 0	R. Napier & Sons	Side-Lever	800	Paddle	96	2	9 0	11	Rect.-flue	4	12	17 days	11½	West India Mails.
Mauritius	Southampton	1852	Mare & Co.	iron	251	39	25·7	1451	2134	19 0	20 0	Bolton & Watt	Horizontal	300	S.direct	55	2	2 6	50	Tubular	2	15	15 days	10	French Transport Serv.
Mersey	Southampton	1859	Samuda	iron	260·4	30·2	16·5	729	1001	18 0	19 0	Maudslay & Field	Oscillating	250	Paddle	60	2	5 0	30	Tubular	4	20	12 days	11½	West India Mails.
Northam	Southampton	1858	Summers & Co.	iron	274	34·7	21	904	1337	17 11	19 4	Summers & Day	Horizontal	400	S.direct	64	2	3 0	60	Sheet-flue	4	18	12 days	12½	Indian Mails.
North Briton	Liverpool	1858	Denny	iron	298·4	38	17·8	1487	2187	19 9	20 3	Tulloch & Denny	Inverted	280	S.direct	66	2	3 6	40	Tubular	4	18			Liverpool to Quebec.
Oneida	Southampton	1855	Scott & Sons	iron	306	38·9	19·2	1372	2285	20 2	20 7	A. & J. Inglis	Vert. Trunk	530	S. gear.	†82	2	4 6	26	Tubular	4	17	15 days	13	West India Mails.
Orissa	Southampton	1856	J. Laird	iron	264·6	35·9	26·6	1119	1646	18 0	18 0	Fawcett & Co.	Horizontal	300	S.direct	52	2	2 6	50	Tubular	4	15	11 days	10	East India Mails.
Parana	Southampton	1852	Wigram	wood	300	36·8	33·2	2048	3070	21 9	22 3	Caird & Co.	Side-Lever	800	Paddle	96	2	9 0	11	Rect.-flue	4	12	17 days	11½	West India Mails.
Parramatta (lost)	Southampton	1858	Thames Iron Shipbuilding Co.	iron	330	44·4	26·7	2166	3438	20 6	22 9	Maudslay & Field	Dble. Cylin.	764	Paddle	68	4	9 0	17	Tubular	4	16	17 days	13½	West India Mails.
Pera	Southampton	1855	Mare & Co.	iron	303·5	42·1	27·1	1261	2013	18 0	19 6	G. & J. Rennies	Trunk	450	S. gear.	*70½	2	4 0	32	Sheet-flue	4	16	12 days	12	Alexandrian Mails.
Persia	Liverpool	1855	R. Napier	iron	376	45·3	30	2079	3300	21 0	22 0	R. Napier & Sons	Side-Lever	950	Paddle	100	2	10 0	15	Tubular	8	23			Liverpool to New York.
Prince Consort	Portsmouth	1859	J. Scott Russell	iron	154·5	15·1	6·7	65	103	3 6	4 0	Scott Russell	Oscillating	50	Paddle	30	2	2 6	44	Tubular	1	20	20 hours	11	Portsmouth and Ryde.
Princess Royal	Portsmouth	1850	J. White	wood	107	13·4	8·3	57	88	4 6	5 6	Seaward	Oscillating	40	Paddle	28½	2	2 6	36	Tubular	1	13	20 hours	10½	Portsmouth and Ryde.
Prince Frederick William	Dover	1857	Thames Iron Shipbuilding Co.	iron	172	20	11	100	214	6 2	6 8	Ravenhill & Co.	Oscillating	120	Paddle	46	2	3 0	41	Tubular	2	25	20 tons	14	Dover to Ostend.
Queen	Dover	1855	Mare & Co.	iron	151·6	20	11	103	301	6 2	6 6	Ravenhill & Co.	Oscillating	100	Paddle	41	2	3 0	42	Tubular	1	25	12 tons	13½	Dover to Calais.
Rhone	Liverpool	1856	Smith & Rodgers	iron	257·2	34·6	22·5	943	1387	18 6	21 0	M'Nab & Clark	Inverted	166	S.direct	52	2	3 0	38	Tubular	2	17			Mediterranean Ports.
Ripon	Southampton	1846	Mare & Co.	iron	231·3	33·9	28·4	1308	1925	17 4	18 4	Miller & Ravenhill	Oscillating	450	Paddle	75	2	7 0	14½	Sheet-flue	4	13½	10 days	11	Alexandrian Mails.
Shannon	Southampton	1859	R. Napier	iron	330·4	44·5	26·2	2187	3471	19 6	21 0	R. Napier & Sons	Side-Lever	774	Paddle	97	2	9 0	18	Tubular	4	22	18 days	14	West India Mails.
Stag	Glasgow	1854	Denny	iron	213	23·6	13·3	314	498	9 0	9 6	Thomson	Side-Lever	240	Paddle	57	2	5 6	22	Tubular		16	72 tons	12	Home Trade.
Sultan	Southampton	1847	Tod & M'Gregor	iron	231	32	17·8	808	1124	10 6	11 6	Caird & Co.	Trunk	260	S.direct	42	2	4 0	55	Sheet-flue	2	15	12 days	10½	Peninsular Mails.
Tagus	Southampton	1837	Scott & Sons	wood	182	26	17·4	497	782	13 3	14 8	Scott & Sinclair	Side-Lever	280	Paddle	62½	2	5 10	19	Sheet-flue	2	12	10 days	9½	Peninsular Mails.
Tamar	Southampton	1854	Pitcher	wood	287·5	33·7	26·5	1501	1963	17 6	18 6	J. Penn & Son	Oscillating	400	Paddle	72	2	7 0	16½	Tubular	4	15½	13½ days	13	Brazil Mails.
Tasmanian	Southampton	1858	Laurence Hill & Co.	iron	346	39·2	20·1	1274	2253	20 0	20 0	A. & J. Inglis	Trunk	744	S.direct	71	3	3 6	50	Tubular	6	16	14 days	13½	Brazil Mails.
Thistle	Glasgow	1859	Laurence Hill & Co.	iron	184·5	25·2	12·5	206	386	9 0	11 6	A. & J. Inglis	Beam	155	S. gear.	44½	2	3 6	38	Tubular		19½	66 tons	11½	Home Trade.
Tyne	Southampton	1854	Miller & Ravenhill	iron	296·6	36·2	27·1	1788	2184	16 6	17 9	Miller & Co.	Oscillating	400	Paddle	72	2	7 0	16	Tubular	4	16	15 days	11	Brazil Mails.
Valetta	Southampton	1853	Mare & Co.	iron	225	27·6	17	507	769	12 0	13 3	J. Penn & Son	Oscillating	260	Paddle	62	2	4 6		Sheet-flue	2	20	10 days	14	Marseilles Mails.
Vectis	Southampton	1853	J. White	wood	229·5	30·4	16·9	473	751	12 3	13 0	J. Penn & Son	Oscillating	260	Paddle	62	2	4 6		Sheet-flue	2	20	10 days	14	Marseilles Mails.
Vivid	Dover	1846	Ditchburn	iron	141	21	11			6 0	6 6	J. Penn & Son	Oscillating	120	Paddle	43½	2	4 0	32	Tubular	2	18	15 tons	13	Dover to Ostend.
Windsor Castle	Glasgow	1859	Caird & Co.	iron	191·3	20	7 6	93	190	3 1½	3 3	Caird & Co.	Diagonal	115	Paddle	40	2	5 0	45	Tubular		40	10 tons	16½	Cumbray and Skipness.

Note.—The dimensions "per Register" are all *inside* measurements.——* The "Diameters of Cylinders" marked with an asterisk are "effective."——† The diameter of the trunk in the Oneida is 36¾ inches.

TABLE OF SCREW-STEAMERS IN THE ROYAL NAVY,

SHIP.															ENGINES.									
Name.	Tonnage.	Speed.	Date of Trial.	Where tried.	Length between the Perpendiculars.		Breadth Extreme.		Draught of Water.				Area of Midship Section.	Displacement.	Description of Engines.	Name of Manufacturer.	Cylinders.		Length of Stroke.		Number of Revolutions per minute.	Weight per square inch on the safety-valve.	Horse-Power.	
									Forward.		Aft.						Number.	Diameter.					Nominal.	Indicated.
	Tns.	Knts.			ft.	in.	ft.	in.	ft.	in.	ft.	in.	sq. ft.	Tns.				inches.	ft.	in.		lbs.	hrs.	hors.
AGAMEMNON	3074	11	2 Oct. 1852	Nore	230	0	55	4	17	7	20	4	816	3750	Horizontal, Trunk	John Penn and Son	2	=70½	3	6	60	17	600	1838·8
Ditto	3074	11·243	3 May 1853	Stokes Bay	230	0	55	4	23	1	23	8	1060	5080	Horizontal, Trunk	John Penn and Son	2	=70½	3	6	63	20	600	2268
ALGIERS	3347	9	1 June 1854	Plymouth	218	7	60	0	24	6	25	7	1053	4730	Horizontal	Fairbairn and Sons	4	61	3	3	27	10	450	1117
ARROGANT	1872	8·646	9 July 1853	Stokes Bay	200	0	45	8¾	19	1½	20	2½	615	2615	Horizontal, Trunk	John Penn and Son	2	=55	3	0	61	12	360	774
ARROW	477	11	22 Aug. 1854	Spithead	160	0	25	4	10	0	11	8	209	586	Horizontal	Humphrys, Tennant, & Co.	2	42	1	9	93	20	160	[illegible]
ASSURANCE	670	11·142	16 June 1856	Stokes Bay	180	0	28	4	10	4	11	4	240	781	Horizontal	Miller, Ravenhill, and Co.	2	45	2	0	87	20	200	744·6
CÆSAR	2767	10·274	3 Mar. 1854	Stokes Bay	207	4	56	0½	19	5	22	8	726	3230	Horizontal, Trunk	John Penn and Son	2	=58	3	3	60	22	400	1420
COLOSSUS	2590	9·312	16 Oct. 1854	Stokes Bay	190	0	57	0	23	2	25	7	892	3691	Horizontal, Trunk	John Penn and Son	2	=58	3	3	60	20	400	1458
CONFLICT	1038	8·837	16 July 1853	Stokes Bay	192	6½	34	4	15	9½	17	4½	472	1752	Horizontal	Seaward and Capel	4	46½	2	0	73	10	400	752
Ditto	1038	9·425	22 Aug. 1853	Stokes Bay	192	6½	34	4	15	9	17	3	470	1740	Horizontal	Seaward and Capel	4	46½	2	0	77	10	400	784
Ditto	1038	9·424	23 Aug. 1853	Stokes Bay	172	6½	34	4	15	9	17	5	472	1752	Horizontal	Seaward and Capel	4	46½	2	0	75·75	10	400	812
Ditto	1038	9·772	21 Sept. 1853	Stokes Bay	192	6½	34	4	15	10	17	4	472	1752	Horizontal	Seaward and Capel	4	46½	2	0	61·5	10	400	776
Ditto	1038	9·428	30 Sept. 1853	Stokes Bay	192	6½	34	4	15	9	17	4	471	1746	Horizontal	Seaward and Capel	4	46½	2	0	62·5	10	400	772
Ditto	1038	9·913	18 Oct. 1853	Stokes Bay	192	6½	34	4	15	9	17	4	471	1746	Horizontal	Seaward and Capel	4	46½	2	0	67·25	10	400	799
Ditto	1038	9·571	2 Nov. 1853	Stokes Bay	192	6½	34	4	15	10	17	4	472	1752	Horizontal	Seaward and Capel	4	46½	2	0	66	10	400	784
Ditto	1038	9·772	7 Nov. 1853	Stokes Bay	192	6½	34	4	15	9	17	4	471	1746	Horizontal	Seaward and Capel	4	46½	2	0	66·5	10	400	700
CONQUEROR	3224	10·806	16 June 1856	Plymouth	240	0	55	4	24	3	26	4	1122	5665	Horizontal, Trunk	John Penn and Son	2	=82	4	0	55	20	800	2812
COQUETTE	670	10·902	15 May 1856	Stokes Bay	180	0	28	4	10	1	11	5	238	772	Horizontal	Miller, Ravenhill, and Co.	2	45	2	0	86·75	20	200	709·4
CURACOA	1571	10·793	26 Sept. 1854	Stokes Bay	192	0	43	0¼	14	4	17	6	467	1735	Horizontal	Maudslay, Sons, and Field	2	57½	2	9	64	20	350	1124
DAUNTLESS	1575	10·016	12 Sept. 1850	Stokes Bay	219	6	39	9	16	4	16	10	542	2150	Horizontal, Geared	Robert Napier and Sons	2	84	4	0	31	10	580	1347
Ditto	1575	10·133	12 Oct. 1850	Stokes Bay	219	6	39	9	16	8	71	10	570	2480	Horizontal, Geared	Robert Napier and Sons	2	84	4	0	30·5	10	580	[illegible]
DESPERATE	1037	10·766	18 July 1850	Nore	192	4	34	4½	13	6	14	10	388	1393	Horizontal, Geared	Maudslay, Sons, and Field	4	55	2	6	37·77	8	400	[illegible]
Ditto	1037	9·86	11 Mar. 1852	Plymouth	192	4	24	4½	14	7	15	9	424	1545	Horizontal, Geared	Maudslay, Sons, and Field	4	55	2	6	38	8	400	810·9
D. OF WELLINGTON	3759	10·15	11 Apr. 1853	Stokes Bay	240	6	60	0	23	0	24	3	988	5080	Horizontal, Geared	Robert Napier and Sons	2	93½	4	6	29·6	15	700	1979
ENCOUNTER	953	10·699	10 June 1853	Stokes Bay	190	0	43	2½	13	7	13	10	382	1459	Horizontal, Trunk	John Penn and Son	2	=55	2	3	81·75	12	360	44
Ditto	1169	9·439	3 Jan. 1855	Stokes Bay	192	0	36	3	15	7	17	2	470	1757	Inclined, Oscillating	J. Scott Russell and Co.	2	50	2	9	68·5	18	250	857
Ditto	1169	9·219	8 Jan. 1855	Stokes Bay	192	0	36	3	15	7	17	2	470	1757	Inclined, Oscillating	J. Scott Russell and Co.	2	50	2	9	63	18	250	[illegible]
FAIRY	312	11·309	19 Sept. 1853	Stokes Bay	144	8	21	1½	5	1	7	1	86	210	Vertical, Oscillg., Geared	John Penn and Son	2	42	3	0	35·5	11	128	339·5
Ditto	312	12·26	24 Dec. 1853	Stokes Bay	144	8	21	1½	5	1	7	1	86	210	Vertical, Oscillg., Geared	John Penn and Son	2	42	3	0	34·8	11	128	348·6
Ditto	312	12·137	27 Dec. 1853	Stokes Bay	144	8	21	1½	5	1	7	1	86	210	Vertical, Oscillg., Geared	John Penn and Son	2	42	3	0	35·25	11	128	353·4
Ditto	312	11·699	29 Dec. 1853	Stokes Bay	144	8	21	1½	5	1	7	1	86	210	Vertical, Oscillg., Geared	John Penn and Son	2	42	3	0	45·25	11	128	355·1
Ditto	312	11·658	28 Mar. 1854	Stokes Bay	144	8	21	1½	4	9½	7	3½	85·4	207·4	Vertical, Oscillg., Geared	John Penn and Son	2	42	3	0	37·5	14	128	383·5
Ditto	312	13·033	24 June 1854	Stokes Bay	144	8	21	1½	4	10	7	1	84	203	Vertical, Oscillg., Geared	John Penn and Son	2	42	3	0	41·5	15	128	419
Ditto	312	13·27	11 July 1854	Stokes Bay	144	8	21	1½	4	10	7	1	84	203	Vertical, Oscillg., Geared	John Penn and Son	2	42	3	0	42·5	15	128	419
Ditto	312	13·229	14 Apr. 1855	Stokes Bay	144	8	21	1½	4	11½	7	0½	85	205	Vertical, Oscillg., Geared	John Penn and Son	2	42	3	0	41	15	128	406·8
Ditto	312	13·216	17 Apr. 1856	Stokes Bay	144	8	21	1½	5	1	7	1	86	210	Vertical, Oscillg., Geared	John Penn and Son	2	42	3	0	40·5	15	128	416
FLYING FISH	868	11·585	13 May 1856	Stokes Bay	200	0	30	4	10	9	12	3	281	1090	Horizontal	Maudslay, Sons, and Field	2	58	2	3	82	20	350	1302·3
Ditto	868	11·736	20 June 1856	Stokes Bay	200	0	30	4	10	4	12	11	272	1050	Horizontal	Maudslay, Sons, and Field	2	58	2	3	75	20	350	[illegible]
Ditto	868	11·603	3 July 1856	Stokes Bay	200	0	30	4	10	8	12	11	277	1072	Horizontal	Maudslay, Sons, and Field	2	58	2	3	74·5	20	350	1160·6
FORTH	1228	9·384	16 May 1856	Stokes Bay	159	0	42	2	17	7	18	9	516	1792	Horizontal, Tk., High Prs.	John Penn and Son	2	=30½	2	6	114	60	200	833·6
GLATTON, *Bat.*	1535	4·5	4 July 1855	Nore	172	6	45	2½	8	4	8	8	379	1640	Horizontal, High Press.	Miller, Ravenhill, and Co.	2	25½	2	0	127	62	150	693·4
HANNIBAL	3136	8·6	12 Apr. 1854	Nor	217	6	48	1½	20	6	20	7	777	3300	Horizontal, Geared	Scott, Sinclair, and Co.	2	71¼	4	0	27·5	12	450	1672·2
HIGHFLYER	1153	9·399	10 Apr. 1852	Thames	192	0	36	4	15	8	17	4	476	1775	Horizontal	Maudslay, Sons, and Field	2	55 3-16	2	6	53·37	14	250	702
HOGUE	1846	7·809	13 Dec. 1850	Stokes Bay	184	0	48	4½	20	10	23	10	799	3054	Horizontal	Seaward and Capel	4	51½	3	0	47	10	450	[illegible]
Ditto	1846	8·328	18 Dec. 1850	Stokes Bay	184	0	48	4½	21	2	23	10	805	3081	Horizontal	Seaward and Capel	4	51½	3	0	56	10	450	[illegible]
HORATIO	1090	8·855	17 June 1850	Nore	154	3	40	2½	12	1	18	8	391	1175	Horizontal, Geared	Seaward and Capel	2	54	3	0	41·28	13	250	[illegible]
IMPERIEUSE	2355	10·673	11 Jan. 1856	Nore	212	0	50	0	16	1	18	3	524	2225	Horizontal, Trunk	John Penn and Son	2	=55	3	0	67·7	13	360	[illegible]
JAMES WATT	3083	9·361	30 Mar. 1855	Stokes Bay	230	0	55	5	23	3	23	10	1040	4950	Horizontal	James Watt and Co.	4	52	3	0	51	16	600	[illegible]
LAPWING	670	11·021	27 May 1856	Stokes Bay	180	0	28	4	10	2	11	6	240	781	Horizontal	Miller, Ravenhill, and Co.	2	45	2	0	85	20	200	[illegible]
MARLBOROUGH	4000	11·866	12 May 1856	Stokes Bay	245	6	61	2½	21	1	22	10	928	4510	Horizontal	Maudslay, Sons, and Field	2	82	4	0	53·5	20	800	[illegible]
MEGÆRA	1395	10·241	28 Mar. 1850	Thames	207	0	37	10	11	4	15	3	383	1554	Horizontal	George and John Rennie	4	49½	2	0	74·21	8	350	[illegible]
METEOR, *Battery*	1469	5·77	16 May 1855	Thames	172	6	43	11	6	5	8	0	310	1346	Horizontal, High Press	Maudslay, Sons, and Field	2	26½	2	0	139	60	150	[illegible]
MIRANDA	1039	10·75	2 July 1853	Nore	196	0½	34	0	12	3	12	6	336	1350	Horizontal, Geared	Robert Napier	2	56½	3	9	28·5	13	250	[illegible]
MOHAWK	670	10·721	4 June 1856	Stokes Bay	180	0	28	4	10	3	11	6	242	785	Horizontal	Humphrys, Tennant, & Co.	2	42½	2	2	88	20	200	[illegible]
ORION	3232	11·446	2 May 1856	Stokes Bay	238	0	55	9	24	5	26	10	982	5070	Horizontal, Trunk	John Penn and Son	2	=70½	3	6	62·75	20	600	[illegible]
PEARL	1462	11·313	20 May 1856	Stokes Bay	200	0	40	4	16	2	19	9	540	2115	Horizontal, Trunk	John Penn and Son	2	=58 1-16	3	3	59	20	400	[illegible]
Ditto	1462	10·669	27 May 1856	Stokes Bay	200	0	40	4	16	4	19	9	544	2130	Horizontal, Trunk	John Penn and Son	2	=58 1-16	3	3	49	20	400	[illegible]
PIONEER	868	11·366	20 May 1856	Stokes Bay	200	0	30	4	10	6	12	0	273	1056	Horizontal	Miller, Ravenhill, and Co.	2	55	2	6	82	20	350	[illegible]
PLUMPER	490	7·218	21 July 1853	Stokes Bay	140	0	27	6	10	5½	10	7½	194	510	Vertical, Oscillating, Grd.	Miller, Ravenhill, and Co.	2	27	2	0	55·5	14	60	[illegible]
PRINCESS ROYAL	3129	11·031	2 Nov. 1853	Stokes Bay	217	0	58	1½	20	2½	21	7½	805	3400	Horizontal	Maudslay, Sons, and Field	2	64½	3	0	58	20	400	[illegible]
PYLADES	1278	10·119	31 Mar. 1855	Stokes Bay	192	9	38	5	16	0	19	0	522	1956	Horizontal, Trunk	John Penn and Son	2	=55	3	0	62·5	20	350	[illegible]
RATTLER	888	9·77	5 Sept. 1851	Thames	176	6	32	8½	10	11	12	1½	266	840	Vertical, Dbl. Cylrs., Grd.	Maudslay, Sons, and Field	4	40½	4	0	25·76	10	200	[illegible]
RIFLEMAN	486	7·15	25 Nov. 1853	Thames	150	0	26	7	11	3	11	10	233	678	Vertical, Oscillating, Grd.	Miller, Ravenhill, and Co.	2	34	2	9	35·57	10	100	[illegible]
RINGDOVE	670	10·824	20 May 1856	Stokes Bay	180	0	28	4	9	2	11	3	223	714	Horizontal	Miller, Ravenhill, and Co.	2	45	2	0	84	20	200	[illegible]
ROYAL ALBERT	3726	10	21 Nov. 1854	At Sea	232	9	61	0	24	8	27	4	1160	5571	Horizontal, Trunk	John Penn and Son	2	=64½	3	4	69	20	500	[illegible]
ROYAL GEORGE	2616	9·375	13 Dec. 1858	Nore	205	7	54	6½	22	10	23	10	945	4110	Horizontal, Trunk	John Penn and Son	2	=58	3	3	62	20	400	—
ST JEAN D'ACRE	3200	11·199	3 Dec. 1853	Stokes Bay	238	0	55	4	23	6	25	0	1067	5340	Horizontal, Trunk	John Penn and Son	2	=70½	3	6	61	20	600	[illegible]
SANS PAREIL	2339	9·3	12 Aug. 1855	At Sea	200	0	52	3	22	8	25	7½	994	3800	Horizontal	James Watt and Co.	2	64	3	0	58	15	400	[illegible]
SATELLITE	1462	11·4	18 June 1856	Plymouth	200	0	40	4	12	8	16	4	404	1500	Horizontal, Trunk	John Penn and Son	2	=58	3	3	63	20	400	[illegible]
SEAHORSE	1212	9·298	16 May 1856	Stokes Bay	159	0	41	10	17	8	18	9	518	1799	Horizontal, Tk., High Prs.	John Penn and Son	2	=30½	2	6	112·25	60	200	[illegible]
SHANNON	2651	11·807	5 June 1856	Stokes Bay	235	0	50	0	18	0	19	0	626	2948	Horizontal, Trunk	John Penn and Son	2	=70½	3	6	56	20	600	[illegible]
SHARPSHOOTER	503	9·327	9 Nov. 1852	Stokes Bay	150	5	26	7½	11	0	10	9	237·5	653	Horizontal, Geared	Miller, Ravenhill, and Co.	2	46	3	0	38·25	10	200	[illegible]
SIMOOM	1980	8·747	8 Feb. 1851	Stokes Bay	246	0	41	0	15	5	17	10	555	2700	Horizontal, Oscillating	Boulton and Watt	4	43½	2	6	52·5	10	350	[illegible]
Ditto	1980	10·647	16 Oct. 1855	Stokes Bay	246	0	41	0	15	3	19	2	578	2830	Horizontal	Portsmth. Yard (refitted)	2	62½	3	0	55	20	400	[illegible]
SPARROWHAWK	670	11·065	16 June 1856	Stokes Bay	180	0	28	4	10	3	11	5	240	781	Horizontal	Humphrys, Tennant, & Co.	2	42½	2	2	92	20	200	[illegible]
SURPRISE	670	11·149	14 July 1856	Stokes Bay	180	0	28	4	10	6	11	6	244	790	Horizontal	Miller, Ravenhill, and Co.	2	45	2	0	88	20	200	[illegible]
TERMAGANT	1547	8·781	2 Sept. 1852	Stokes Bay	210	1	40	6	15	5	17	5	562	2270	Horizontal, Geared	Seaward and Capel	4	62½	3	6	34·5	14	620	[illegible]
Ditto	1547	9·593	9 Oct. 1854	Stokes Bay	210	1	40	6	15	3	18	8	552	2230	Horizontal	Portsmth. Yard (refitted)	2	62½	3	0	53	15	400	[illegible]
TRIBUNE	1570	10·418	9 Nov. 1853	Stokes Bay	192	0	43	0	17	8	19	4	578	2220	Horizontal	Maudslay, Sons, and Field	2	56	2	6	72·5	20	300	[illegible]
VICTOR	851	11·583	12 May 1856	Stokes Bay	200	0	30	2	10	3	12	0	264	1019	Horizontal	Miller, Ravenhill, and Co.	2	55	2	6	82	20	350	[illegible]
VIPER	477	11·86	27 Sept. 1854	Nore	160	0	25	4	10	0	12	0	215	600	Horizontal	Maudslay, Sons, and Field	2	40½	2	0	86·5	20	160	[illegible]
WANDERER	670	10·733	13 May 1856	Stokes Bay	180	0	28	4	9	7	11	5	231	745	Horizontal	Maudslay, Sons, and Field	2	45	2	0	88·25	20	200	[illegible]

PROPELLER.														RATIO OF							
Dimensions.						Centre above bottom of false keel.		Immersion of centre at the time of trial.		Number of Revolutions per minute.	Rate in Knots per hour.	Slip.		Vessel's length to breadth.	Screw's pitch to Diameter.	Midship Section to Screw's disc.	Indicated Power.		$\frac{\text{Speed}^3 \times \text{Mid. Sec.}}{\text{Indicated Power.}}$	$\frac{\text{Speed}^3 \times \text{Displt.}^{\frac{2}{3}}}{\text{Indicated Power.}}$	REMARKS.
Diameter.		Pitch.		Length.								In Knots per hour.	Per Cent.				To Midship Section.	To Displacement ⅔.			
ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.		knts.	knts.									
18	0	20	6	3	4	11	5	8	11	60	12·183	1·133	9·34	4·16	1·14	3·21	2·25	7·62	590·7	174·7	Weather not favourable.
18	0	20	6	3	4	11	5	12	3	63	12·739	1·496	11·74	4·16	1·14	4·17	2·14	7·67	664·2	185·2	Weather very favourable.
17	0	14	0	2	4	11	9	13	10	69·12	9·545	0·545	5·71	3·65	0·80	4·64	1·06	3·96	687·2	183·9	Speed by common log.
15	6¾	15	2¾	2	5	10	1	10	1½	61	9·163	0·517	5·64	4·37	0·98	3·24	1·26	4·08	519·5	158·5	Slide-valve of forward engine defective.
11	0½	13	0	2	3½	7	1	4	7	93	11·926	0·926	7·76	6·32	1·18	2·18	2·85	8·48	468·3	156·9	Speed by patent log.
11	0	16	0	2	6	7	1	4	3	87	13·731	2·589	18·86	6·35	1·45	2·53	3·10	8·78	445·8	157·5	Calm.
17	1½	18	10½	2	11½	11	3	11	5	60	11·183	0·909	8·13	3·70	1·10	2·16	1·96	6·47	554·5	167·6	Wind No. 1.
17	1½	18	5½	2	10½	11	4	14	3	60	10·924	1·612	14·76	3·33	1·08	3·87	1·63	6·10	494·0	182·3	Wind No. 3 to No. 4.
13	5½	15	2	2	6½	8	10	8	6½	73	10·921	2·084	19·08	5·61	1·13	3·31	1·593	5·174	433·2	133·4	Spare propeller (cut). Wind No. 5.
13	5½	15	2	2	6½	8	10	8	5	77	11·520	2·094	18·18	5·61	1·13	3·29	1·668	5·419	501·9	154·5	Spare propeller, with wooden sphere attached to boss. Calm.
13	5½	15	2	2	6½	8	10	8	7	75·75	11·333	1·909	16·84	5·61	1·13	3·31	1·720	5·587	486·5	149·8	Same propeller as on the trial of the 16th July 1853.
13	8	19	10½	2	7	8	10	8	6	61·5	12·063	2·291	18·09	5·61	1·46	3·22	1·644	5·34	567·6	174·8	Common propeller (uncut). Calm.
13	8	19	10½	2	7	8	10	8	6	62·5	12·259	2·831	23·09	5·61	1·46	3·21	1·639	5·324	511·3	157·4	Common propeller, 1 foot cut off each corner of each blade. Wind No. 3 to No. 4.
13	7	20	1	2	10½	8	10	8	6	67·25	13·322	3·409	25·59	5·61	1·48	3·25	1·696	5·51	574·2	176·8	Bomerang propeller. Wind No. 1.
13	8	19	10½	2	6	8	10	8	6	66	12·946	3·375	26·07	5·61	1·46	3·22	1·661	5·305	527·8	162·5	Common propeller, surface reduced to that of Bomerang propeller. Wind No. 3 to No. 5.
13	8	19	10½	2	6	8	10	8	6	66·5	13·044	3·272	25·08	5·61	1·46	3·21	1·614	5·242	578·3	178·0	Common propeller, and edges of blades bevelled. Wind No. 1.
19	0	26	9	3	6	13	4	13	0	55	14·513	3·707	25·54	4·34	1·41	3·96	2·51	8·85	503·5	142·6	Strong breeze, with swell. Trial not considered satisfactory.
11	0	16	0	2	6	7	1	4	4	86·75	13·691	2·789	20·37	6·35	1·45	2·50	2·98	8·43	434·7	153·7	Wind No. 5 to No. 6.
14	1½	20	1	3	0½	9	6	8	0	64	12·678	1·885	14·87	4·46	1·42	2·98	2·41	7·78	522·4	161·5	Nearly a calm.
14	8½	16	4	2	10	9	7	7	3	70·556	11·368	1·352	11·89	5·52	1·11	3·18	2·48	7·62	404·3	131·9	
14	8½	17	3	3	0	9	7	8	8	69·418	11·812	1·679	14·21	5·52	1·17	3·35	2·23	7·25	446·7	143·6	
13	0	14	0	2	4	8	6	6	4	82·414	11·381	0·615	5·40	5·60	1·08	2·92	2·30	7·16	542·5	174·4	
13	0	14	0	2	4	8	6	7	3	82·916	11·450	1·590	13·89	5·60	1·08	3·19	1·91	6·07	501·2	158·0	Wind No. 5, with some swell.
18	0	16	3	2	9½	12	4	11	11	66·6	10·675	0·525	4·92	4·01	0·90	3·88	2·00	6·70	522·0	156·1	Wind No. 4.
12	0	15	9½	2	8	7	3½	6	6½	81·75	12·735	2·036	15·99	5·72	1·32	3·38	2·21	6·56	554·3	186·7	Calm. Ship fully rigged.
12	2½	18	9½	3	2	9	2	8	0	68·5	12·712	3·273	25·75	5·30	1·54	4·02	1·40	4·51	601·6	186·4	Griffiths's patent screw propeller. Wind No. 2.
12	0	20	0	3	2	9	2	8	0	63	12·429	3·210	25·83	5·30	1·67	4·16	1·26	4·07	622·1	192·7	Common propeller. Wind No. 2.
6	6	8	0	1	9	3	0	4	1	177·5	14·007	2·698	19·26	6·85	1·23	6·33	4·18	10·17	346·0	142·1	Scott's propeller. Calm.
6	6	9	9½	1	6	3	0	4	1	174	16·843	4·583	27·21	6·85	1·51	6·33	4·06	9·87	544·1	186·7	Common propeller, cut with blades like Griffiths's propeller. Wind No. 4.
6	6	9	9½	1	6	3	0	4	1	176·25	17·060	4·923	28·86	6·85	1·51	6·33	4·11	10·00	435·1	178·7	Common propeller, same as 24th Dec. 1853, with sphere attached to the boss. Wind No. 4.
5	10	7	8	2	4½	3	0	4	1	226·25	17·110	5·411	31·62	6·85	1·31	3·22	3·90	9·49	410·9	168·8	Bomerang propeller. Wind No. 4.
5	6½	14	1½	1	8	3	0	4	3½	187·5	26·124	14·466	55·37	6·85	2·54	3·51	4·49	10·95	352·8	144·8	Lowe's propeller. Calm.
6	0	7	11½	0	9½	3	0	4	1	207·5	16·332	3·299	20·20	6·85	1·33	2·97	4·88	11·87	453·6	186·5	Fisher's Venetian propeller with flange.
6	5½	8	3	1	7	3	0	4	1	212·5	17·298	4·023	23·26	6·85	1·27	2·55	4·88	11·87	478·7	196·9	Griffiths's propeller. Wind No. 1.
6	5½	7	10½	1	10	3	0	4	0½	205	15·967	2·738	17·15	6·85	1·22	2·60	4·78	11·69	484·3	198·1	Common propeller cast at Portsmouth in 1850. Wind No. 1 to No. 2.
6	3½	10	0	1	8½	3	0	4	1	202·5	19·975	6·759	33·84	6·85	1·58	2·75	4·84	11·77	477·2	196·0	Lewsey's blades fitted in boss of Griffiths's propeller.
11	0	21	4	3	0	6	10	5	5	83	17·255	5·670	32·86	6·59	1·94	2·86	4·63	12·30	335·5	126·5	Wind No. 3.
13	2	19	11½	3	0	7	4½	5	6½	75	14·765	3·029	20·51	6·59	1·52	2·00	4·29	11·29	376·8	143·1	Wind No. 4 to No. 5. Additional false keel aft.
13	2	19	11½	3	0	7	4½	5	6½	74·5	14·667	3·064	20·89	6·59	1·52	2·03	4·19	11·08	372·8	141·0	Wind No. 3. Sea moderately calm.
12	0	10	0	1	8	7	8	11	1	114	11·245	1·861	16·55	3·77	0·83	4·56	1·62	5·65	511·5	146·3	Wind No. 3 to No. 4.
6	2½	14	0	2	3½	3	6	5	2	127	17·539	13·039	74·35	3·82	2·25	12·48	1·88	4·99	49·8	18·3	Speed by common log.
17	0	12	6	2	1	11	9	8	10	64·87	7·999	0·601	7·51	3·74	0·74	3·42	1·88	4·83	461·4	131·6	Speed by common log. Launching cleets not removed. Negative slip.
12	0½	9	8½	1	8	9	0	8	4	106·74	10·222	0·823	8·05	5·28	0·80	4·17	1·47	4·79	563·0	173·0	
16	1	21	1½	3	2	11	5	12	5	47	9·799	1·990	20·31	3·80	1·31	3·93	0·99	3·77	480·0	126·5	Fully rigged and complete with sea stores.
16	0½	18	9	3	4	11	5	12	5	56	10·357	2·029	19·59	3·80	1·17	3·97	0·99	3·77	563·2	153·4	Fully rigged and complete with sea stores.
14	0	13	0	2	2	10	0	8	8	80·87	10·306	1·451	14·08	3·63	0·93	2·54	1·41	4·97	490·8	139·8	Preliminary trial; vessel not in trim.
16	0	16	0	2	8	10	7	7	8	67·7	0·685	0·012	0·11	4·24	1·00	12·61	2·06	6·34	589·5	191·7	Fresh breeze.
17	0	24	4	3	1	12	2	11	8	51	12·241	2·880	23·53	4·15	1·43	4·58	1·48	5·31	552·7	154·3	Wind No. 4.
11	0	15	7½	2	6	7	1	4	5	185	13·101	2·080	15·88	6·35	1·42	2·53	2·87	8·13	466·2	164·7	Wind No. 2.
19	1	26	9	3	6½	12	8	10	2	59·5	14·117	2·251	15·95	4·01	1·40	3·24	2·89	9·83	577·8	170·0	Wind variable, No. 1 to No. 2.
14	5½	16	0	2	8½	8	7	6	8	74·21	11·711	1·470	12·55	5·47	1·11	2·34	2·42	6·90	444·4	155·7	
6	0	12	6	...		3	6	4	6	39	17·139	11·369	66·36	3·93	2·08	0·96	1·71	4·34	112·4	44·2	Negative slip.
12	0	11	6	1	11	7	3	5	3	87·87	9·968	0·782	7·85	5·77	0·96	2·97	1·82	5·02	680·8	247·5	Speed by patent log. Wind No. 5 abeam. Propeller 11 in. out of the water.
11	1	14	3	2	6½	7	1	4	5	88	12·370	1·649	13·13	6·35	1·29	2·51	2·65	7·54	464·9	163·5	Wind No. 2 to No. 3.
18	0	23	0	3	2	12	3	14	7	62·75	14·236	2·790	19·60	4·27	1·28	3·86	2·37	7·69	632·4	190·1	Wind varying from No. 1 to No. 3.
16	0	23	6	3	0	10	7	9	2	59	13·677	2·364	17·29	4·96	1·47	2·69	2·45	8·04	590·5	180·2	Common screw.
16	0	25	6	...		10	7	9	2	49	12·325	1·656	13·44	4·96	1·59	2·71	2·02	6·63	601·9	183·2	Griffiths's propeller.
11	0	20	6	3	0	6	10	5	2	82	16·582	5·216	31·46	6·59	1·86	2·87	4·87	11·50	336·1	127·7	Wind No. 1.
8	8½	6	0½	0	11½	6	1	4	6½	111	6·627	0·591	8·92	5·09	0·69	3·26	0·70	2·11	540·4	177·8	Wind No. 3 to No. 4 abeam. No guns on board. Negative slip.
17	1	21	6½	3	0	11	10	9	9½	58	12·324	1·293	10·49	3·73	1·26	3·51	1·65	6·59	724·7	203·6	Wind No. 3 to No. 5.
15	9	20	0	3	0	10	2	8	10	62·5	12·330	2·211	17·93	5·02	1·27	2·68	2·12	7·04	489·0	147·2	Wind No. 4.
10	0	11	0	1	3	7	0	5	1½	103·04	11·18	1·410	12·61	5·39	1·10	3·39	1·88	5·61	496·4	160·2	Partly rigged; no yards.
9	0	8	5	1	5½	5	4	6	6	89·64	7·441	0·291	3·91	5·64	0·94	3·66	0·71	2·16	511·5	169·4	Fully rigged and ready for sea.
11	0	15	8½	2	6	7	1	4	2	84	13·016	2·192	16·84	6·35	1·43	2·35	3·04	8·47	417·8	149·7	Wind No. 1.
17	0	19	2	3	2	12	5	14	11	69	13·045	3·045	23·34	3·82	1·13	5·11	1·55	5·73	644·2	174·5	Calm, smooth water. Ship fully rigged and equipped.
17	0	17	0	3	0	11	4	12	6	63	10·897	1·022	9·83	3·77	1·00	4·16	...	...	...	...	Speed could not be accurately ascertained. Mean of two runs. Indicator broken.
18	0	21	8	3	6	11	9	13	3	61	13·037	1·838	14·10	4·30	1·20	4·19	2·00	6·99	701·6	200·9	Wind No. 1. 476 tons of coal on board.
16	0	23	0	3	0	11	5	14	2½	56	13·159	3·859	29·33	3·63	1·44	4·94	1·48	6·04	543·5	133·2	Speed by patent log. Weather calm; water smooth.
16	0	23	6	3	0	10	7	5	9	63	14·604	3·204	21·94	4·96	1·47	2·01	3·37	10·39	439·5	142·5	Upper edge of propeller 2 feet 4 in. out of the water. Wind No. 4; a little swell
12	0	10	0	1	8	7	8	11	1	112·25	11·072	1·774	16·02	3·80	0·83	4·58	1·61	5·63	500·2	142·8	Wind No. 3.
18	1	25	3	3	6	11	8	7	4	56	13·948	2·141	15·35	4·70	1·40	2·44	3·20	9·76	513·7	168·7	Upper edge of propeller 1 foot 8½ inches out of the water. Wind No. 4.
8	10	9	10½	1	5½	5	3½	5	5½	114·75	11·166	1·839	16·47	5·65	1·12	3·88	1·47	4·62	553·7	175·5	
15	11½	16	6	2	7½	9	3	8	7	52·5	8·545	0·202	2·36	6·00	1·03	2·78	0·97	2·78	688·5	240·5	Vacuum imperfect. Negative slip.
15	11	24	7	2	8½	9	3	9	11	55	13·337	2·690	20·17	6·00	1·54	2·90	2·15	6·21	561·7	194·4	Wind No. 4. Speed not considered an average, vessel being so much by the stern.
11	0	14	3	2	7	7	1	4	4	92	12·932	1·867	14·44	6·35	1·30	2·53	3·02	8·56	448·1	158·3	Wind No. 2 to No. 3.
11	0	16	0	2	6	7	1	4	5	88	13·889	2·740	19·73	6·35	1·45	2·57	3·19	9·04	434·5	153·3	Wind No. 2.
15	6½	18	0	3	0	9	6	7	11	69	13·251	3·470	26·32	5·19	1·16	2·97	1·99	6·48	340·0	104·5	Wind No. 2 to No. 5. Variable.
15	7½	24	0	2	10½	11	0	7	8	53	13·547	2·954	23·34	5·19	1·54	2·88	1·96	6·34	450·4	139·3	Wind No. 3.
14	1	17	7	2	10½	9	6	9	10	72·5	12·578	2·157	17·15	4·47	1·25	3·71	1·85	6·26	611·9	180·2	Wind No. 2.
11	0	20	6	3	0	6	9	5	3	82	16·581	4·996	30·14	6·63	1·86	2·78	4·42	11·51	351·9	135·0	Wind No. 1.
11	0½	14	10½	2	6½	7	1	4	11	86·5	12·692	0·832	6·56	6·32	1·35	3·24	3·13	9·46	533·0	176·4	
11	0	16	0	2	6	7	1	4	4	89·25	13·139	2·406	18·31	6·35	1·45	2·43	3·06	8·60	404·1	143·8	Wind No. 4 to No. 5.

TIMBER.

Definition of the term.

The term *Timber* is applied to wood of sufficient size to be adapted for building or engineering purposes, whether it be standing in the forest or after it is felled. While the timber forms part of the growing tree, it is called standing timber; when felled, it is called rough timber. After the rough log is converted—that is, sawn into the various forms for which it appears best adapted—the products are then known as sided timber, balk, thick-stuff, plank, or board, according to the shape and dimensions of the pieces.

It is proposed in the following article to consider this subject in three or four principal lights; as, the growth and cultivation of timber; its use for constructive purposes; the supply of timber from foreign sources; and the most efficacious means for arresting its decay. Under SHIPBUILDING, and in the article STRENGTH OF MATERIALS (*Ency. Brit.*), much additional information regarding timber will be found.

Growth of the tree.

If we examine the cross-section of the trunk of a tree, we shall find it to consist of three principal parts—namely, the pith, the wood, and the bark—the perfect or heart-wood occupying the larger portion. As all timber trees belong to the *exogenous* tribe of plants, which gain their increase by addition to the external surfaces, it therefore follows that the wood of oldest growth is found in the centre of the tree, and that the several concentric layers are younger in proportion as they recede from the centre. Around the perfect wood there is seen a concentric belt of younger growth, which has not yet attained to the maturity of the heart-wood. This belt is called the alburnum or sap-wood; around it is another concentric belt, called the liber or inner bark, surrounded again by the outer bark. The centre of the heart-wood is occupied by the pith; and there is a communication between the pith and the bark that is maintained by what are called the medullary rays, which, as their name expresses, radiate from the pith, in the centre of the perfect wood, to the external coating of the tree, the bark. From their hardness and compactness the medullary rays may serve, in some measure, to resist the pressure of the accumulating annual rings, and to keep open the tubes for the passage of the sap in the interior of the tree. When cut in a sloping direction, they produce the beautifully-varied appearance called *figure* in ornamental woods. The pith, which seems to perform an important part in the growing economy of the tree while it is still young, appears afterwards to lose its utility; for as the central portions of the tree become indurated and formed into heart-wood, the pith is then nearly or altogether obliterated.

Early authorities on timber.

The first English writer on timber was the celebrated Evelyn, who published his *Sylva, or Discourse of Forest Trees*, in 1664. This book still continues one of the standard works on the subject in our language. In 1774 a new edition of it, with most extensive notes, and also engravings of the trees mentioned in the text, was published by the celebrated Dr Alexander Hunter of York. The last edition with these notes was published in 1825. In France the two celebrated philosophers, Buffon and Du Hamel, have each devoted a great portion of their useful lives to the investigation of the physiology of timber, and their writings on the subject have long been the text-books of arborists. In modern times, the phenomena of the growth of plants have occupied the attention of many men, some of whom have eminently distinguished themselves in this particular branch of natural history.

Mr Knight's experiments on the physiology of trees.

The experiments on the physiology of trees so successfully prosecuted by Mr Knight, president of the Horticultural Society, deserve especial notice. He removed a ring of bark, about half an inch in breadth, from a number of trees, and then compared the growth of these trees with that of others not so treated. This was done early in the spring, and in every case he found the result to be the same; namely, that those parts of the stem and branches which were *above* the incision, and had a communication with the leaves through the bark, increased rapidly in size, while those *below* the incision scarcely grew at all, until a new communication was obtained with the leaves through the bark; the increase of the timber thus evidently depending upon the growth of the leaves.

Mode of increase of the timber.

These experiments were so far conclusive as to establish that the current of sap which ran upwards from the roots, was not impeded in its passage by the annular incisions and the removal of the belt of bark; but that it was probably the downward current which was interrupted, and also that it was this downward current by which the annual increase of the tree was effected. By a series of experiments with coloured infusions, Mr Knight traced the upward current through the pores of the wood beyond the annular incisions in the bark, and found that it had neither coloured the bark nor the sap between it and the wood. He traced the coloured infusion along the leaf-stalk into the leaf, through one series of vessels; and he observed another series of vessels which were conveying a colourless fluid in an opposite direction, that is, out of the leaf. He traced this second series of tubes downwards, and found that they entered the inner bark, and, without having any communication with the tubes of the wood, descended through the inner bark from the very extremities of the leaves, apparently to the points of the roots. Mr Knight considers that there are two series of these descending tubes, one of which forms the new annual layer of alburnum, and the other the new annual layer of internal bark. It thus appears that the sap is conveyed upwards, through the pores of some part of the wood, into the leaves, and that when there, probably by its exposure to light and air, and by the evaporation which takes place, it undergoes some peculiar process of elaboration which fits it for contributing to the sustenance and growth of the tree. It also appears that the cause of the growth is the deposition which takes place in the downward passage of this perfected sap. The sap, after this curious preparation in the leaves, is called *cambium*.

The same persevering physiologist then pursued his investigations a step farther. He took trees, and not only removed a ring of bark, but also a ring of the younger wood, to such a depth as to cut through and remove the whole of the alburnum. These trees did not exhibit the slightest symptom of vegetation in the ensuing spring; which fact evidently proved that the ascent of the sap had been prevented by the removal of the alburnum; for the previously-mentioned experiment had shown that the removal of the bark was not attended with such an effect.

Hardening of the sap-wood.

It is the generally-received opinion, that the ascent of the sap through the alburnum is the reason why this gradually becomes perfect wood, in consequence of the deposition of matter which then takes place and fills up its pores; so that the *rationale* of the process seems to be, that the sap of each year deposits a certain amount of nourishment in its upward passage, which goes to strengthen and solidify the sap-wood (or alburnum) of previous years; that then, after being elaborated in the leaves, this same sap becomes *cambium*, and in its decent adds bulk both to the alburnum and the bark. It must, however, be observed, that there is not in timber any appearance of a gradual change from alburnum to perfect wood. On the

Nature of the circulation of the sap.

contrary, in all cases the division is most decided; one concentric layer being perfect wood, and the next in succession being sap-wood. Mr Knight gives it as his opinion, that towards the conclusion of summer, the true sap—that is, the cambium—simply accumulates in the alburnum, and thus adds to the specific gravity of winter-felled timber. He thinks that the true sap descends through the alburnum as well as through the bark—that is, that "the superabundance of true sap is there deposited, and enriches the upward current of aqueous sap, or the sap of the ensuing spring." In confirmation of this, he tested the ascending current of spring sap, extracted from the trunks of trees at various heights, and found that the specific gravity increased with the height, and that the taste also very sensibly altered. He argues from the foregoing facts, that by girdling trees in the spring, and suffering them to grow until the ensuing winter, the wood above the girdling would be increased in specific gravity. In one experiment, in which the belt of bark had been abstracted for several years, he found that the specific gravity of the wood above was 0·590, while below it was only 0·491; and also that the alburnum had acquired a greater degree of hardness, and consequently of durability. This is important, as Du Hamel has very conclusively established by experiment that the strength of timber of the same species varies very nearly as its weight.

Function assigned to the leaves of a tree.

The leaves of a tree perform the important office of inhaling and fixing in a solid form the gaseous food contained in the atmosphere. In the day-time they absorb carbonic acid from the air, which then becomes decomposed, and the oxygen is given off; this process being reversed at night, although in a slower degree. About one-third of the entire carbon of which the tree is composed is believed to be thus extracted from the atmosphere.

Formation of the annual rings.

As the sap descends, it forms a layer or ring of sap-wood and inner bark, by which the circumference of the tree is gradually increased year by year. By counting the number of these so-called "annual" rings, which are very distinct in some species, it is generally supposed that the age of a tree can be ascertained. It is now believed, however, that this is not always a true indication of the age of a tree, a "ring," more or less distinct, being formed in the wood by any sudden augmentation of growth, consequent upon a track of warm weather succeeding a colder season, or a moist period succeeding to extreme drought in summer. It may thus happen that several rings are formed in the wood during one year's growth only. Although the sap of a tree is most active in the spring, and during the season of vegetation, it has been ascertained that it is never altogether stationary, except during severe frosts.

When the tree should be cut down.

When the induration of the sap-wood has reached its extreme limits, the proper time has arrived for the tree to be cut down. This may arise, however, from other causes than mere old age. Ungenial climates and situations check the free circulation of the sap, and the new layers of wood and inner bark are thus imperfectly formed or greatly attenuated in substance, and the tree shows all the symptoms of premature old age at a period of its growth, when, had it been reared under more favourable circumstances, it would have been still young and vigorous. External injury, by which water is admitted into the substance of the tree, will equally induce premature decay in a tree otherwise sound and flourishing. Hedge-row timber is particularly exposed to accidents of this kind, and the practice of planting valuable trees in such situations should either be sparingly adopted, or avoided altogether, more especially as the growing crops are much injured by them. At the same time, waste corners and outlying pieces of ground, perfectly suitable for trees, and indeed only profitable when planted, are too often left vacant in their native barrenness; for a wise Providence has so constituted the majority of trees, that they will flourish upon, and indeed prefer situations which are altogether unfit for the production of corn and other crops. This is chiefly owing to the small proportion of mineral nutriment which trees require in comparison with grain. For several remarks of much practical value occurring in this portion of our article, the author is indebted to the professional knowledge and sagacity of Mr John Blenkarn, who has recently published an excellent treatise on British timber trees. A certain portion of the article TIMBER, written for the preceding edition of the *Encyclopædia Britannica*, has also been incorporated in the present article.

Situations for planting timber.

Mineral constituents of timber.

The mineral constituents of timber vary with the nature of the soil on which it is grown, but these consist chiefly of the carbonates of potash, soda, lime, and magnesia, with generally a small portion of the sulphates, chlorides, and phosphates of the same substances. The following table exhibits the weight of mineral ash remaining after the combustion of 1000 lb. weight of different woods, all equally dry when weighed:—

1000 lb. of	elm	yielded	19 lb.	of ash.
„	poplar	„	20 lb.	„
„	willow	„	4½ lb.	„
„	beech	„	2 to 6 lb.	„
„	birch	„	3½ lb.	„
„	oak	„	2 lb.	„
„	pine	„	1½ to 3 lb.	„
„	ash	„	5 to 6 lb.	„

Influence of soil on the growth of timber.

Although in most parts of England there is soil favourable to the growth of timber, it may well be supposed that all soils are not equally favourable to all kinds of timber, nor will they produce timber of equally good quality. Thus, while England is, *par excellence*, the country of oak timber, the Sussex oak has always been celebrated as superior to all others. In France, the oak of Provence enjoys a similar reputation. Still, an oak-tree grown in a soil but ill adapted for it, as, for instance, a marshy soil, will retain its superiority of species over the inferior timbers, such as willow and poplar, to which such a soil is less unfavourable, although in quality it will fall far short of the standard of perfection for oak timber. In fact, oak grown on such soils will, in some measure, partake of the qualities of the timber to which they are better adapted, and be of more open texture, of softer fibre, and of less durability, than average oak timber. Oaks of slow growth, those for instance from the mountains of Scotland, and from Cumberland and Yorkshire, are proverbially hard and durable. The oak from marshy soils is often of a dull-red colour, or has "foxey" stains in it, as this incipient decay is called. These stains are generally around the heart of the tree. Timber grown in loose soils is often what is termed "quaggy;" that is, the centre of the tree is full of shakes and clefts. Sometimes a shake will extend around a great portion of the trunk, between two of the annual concentric layers, so as to divide them from each other. This is called a cup-shake, and the timber is said to be "cuppy." It is not attributable to the soil, but is supposed to originate in the effect of frosts on the aqueous sap in its ascent. When the alburnum of a tree has been wounded, or a branch improperly lopped or damaged, the subsequent growth of the tree will cover it, and it is then called a rind-gall, which, should the injured part have had time to become decayed, or partially so, or even sodden with the rains, will frequently cause an extensive rottenness in the plant. This is remarkably the case with elm timber. "Doatiness," probably dottiness, which is a spotted or speckled appearance, like small stains in the wood, is most commonly a disease of beech timber; it is, however, occasionally seen in all, and frequently in the American oak. These diseases are in general incidental to the soil.

Diseases and accidents to which growing timber is liable.

In treating of soils in connection with the qualities of the timber which grows upon them, it may be necessary to remember that the object is not to compare various sorts of timber, but to compare the differences in the same species in connection with the soils which produced them. It may also be observed, that as oak is by far the most valuable timber of English growth, the general inquiries we may enter into in the course of this article principally apply to it, unless other species of timber are particularized.

Effects of a marshy soil.

We have already casually adverted to marshy soils, and to the state of the timber grown on them. The grain of such timber is open, its colour of a deep yellow, sometimes with a tinge of red, especially towards the heart; the texture is soft, and the fibre coarse. The quantity of alburnum, and also of bark, is large in comparison with the quantity of perfect wood, and the outer surface of the bark is very coarse and rough. The wood splits easily, and when split it has not the same bright and varnished appearance possessed by the best timber. The chips from the axe do not cling well together, but fall into separate fragments; and a shaving or a small splinter may be easily crumbled between the finger and thumb. When such timber is weighed, although it is far more saturated with moisture, it is of less specific gravity; and when weighed after seasoning, the weight lost will be comparatively greater. Such timber, it is evident, will be more subject to decay, and to become worm-eaten, the softness of its texture inviting the attacks of insects.

The most favourable soil for timber.

These peculiar characteristics attach more or less to timber grown in all soils which are of a moist nature, whether they are marshy, or wet from long continued periodical inundations. They also apply to timber grown in deep sandy soil, in which almost the only nutriment for the roots is the water which percolates downward, and the bottom damps which rise upward through it. In all these soils the timber is of rapid growth, and the trees attain early to a large size. A similar result attends the timber grown in sandy soils on a clay bottom, for the water which falls, not being able to penetrate the clay, cannot escape, and the roots of the trees are therefore virtually in the same circumstances as if they were growing in marshy land. As a general axiom, timber trees have an antipathy to stagnant waters; and, therefore, these observations on marshy soils, and on sandy soils with clayey bottoms, refer themselves to this fact. The soil generally the best adapted for the growth of timber appears to be a rich loam. This may have a considerable admixture of sand, without any apparent detriment to the timber. In such soils roots can penetrate and spread without difficulty, while the loam is capable of retaining sufficient moisture to dissolve and hold in solution the various substances that are found combined with it, so as to fit them to be absorbed as food by the roots of the plants. If the soil be too sandy, it neither retains the moisture sufficiently long in it, nor does it contain adequate nutriment. If, instead of a loam, some of the very stiff clays be mixed with the sand, they do not counteract this quality; for although such clay is capable of combining with a great quantity of water, it will not easily absorb and mix with it; and the tender roots have great difficulty in penetrating the masses of clay. For these reasons, soils composed wholly of stiff clay are not favourable to the growth of good timber, but the lighter clayey earth produces very fine oaks. As has been before stated, sand or gravel, with a large mixture of rich loamy earth, is precisely that sort of dry generous soil which affords ample nourishment to the roots of trees, and allows of their spreading themselves freely in search of it.

Growth of the oak.

Of all timber oak accommodates itself most easily to soil; growing in almost every thing but sterile sand, if there be sufficient depth of stratum. Wherever oak will grow, even in those soils the least genial to its growth, it is a valuable timber. This fact cannot be too often pressed upon the attention of landholders. It is well adapted for planting in hedge-rows between arable fields, because it is found to be less destructive to the undergrowth than almost any other timber; and as its roots seek their nourishment deep in the soil, they not only do not impoverish the ground for the growing crop, but are themselves protected from any injury which they might otherwise sustain from the tillage. Oaks so planted require, however, to be protected during several years, as their early growth is slow. The timber grown in such exposed situations is seldom large; the trees are stunted and crooked; but this rather increases their value for ship-building purposes, as they convert as compass or knee timber. The timber of hedge-row oak is very close grained; that of park-grown oak is more open, and the trees being better protected, spread more freely, and grow to a very large size, with strong lateral branches; while forest-oak will frequently grow to a great height without pushing out any lateral shoots. Forest-oak is invariably inferior in quality to that which grows singly; and in forests the trees that grow on the skirts are always the best timber. The oak flourishes in variable climates, which is probably the cause of the superiority of the English oak. The roots of the oak strike very deep into the soil, at the same time those of no other tree, perhaps, take so wide a range. The top root of an oak has been known to descend to a depth equal to the height of the tree.

Connection between the roots and the branches.

A curious fact has been established in connection with the supply of food for trees, which proves that there is not only a proportion between the spread of the roots and that of the branches of a tree, but that the branches on any one side of the trunk of the tree are dependent for their support on the roots which protrude from the trunk on that same side. Both Buffon and Du Hamel found experimentally, that when the limbs and branches of any part of a tree showed symptoms of decay, the corresponding roots were invariably in a diseased state. They also found, that on that side of a tree from which the roots had pushed most vigorously, the annual concentric layers of wood were thicker, and that, consequently, the form of a section of the tree would be excentric towards that side.

The roots will seek out for themselves the best soil

The determination with which the roots of trees seek out for themselves the best localities is surprising. If trees of different species be growing on the edge of a marshy place, that tree which requires most moisture will push its roots towards the marsh, while that which requires a dry soil will push its roots into the dry firm ground. Du Hamel relates an instance in which he dug two trenches, crossing each other at right angles; he then returned the soil into these trenches, and planted a tree at the point of their intersection. Some years after, upon examining the roots, it was found that they had invariably pushed into the four lines of trenches, leaving the intermediate undisturbed earth wholly untouched.

Depth of soil required.

An equally important consideration with the quality of the soil is its quantity—that is, its depth below the surface. In speaking of soils in connection with the growth of timber trees, it must of course be understood that it is not merely the surface-soil which is meant, but that soil in which the roots of the trees would push and spread, the soil for several feet in depth. It often happens, indeed, that the surface-soil may be well adapted for tillage and for vegetation in general, and yet the sub-soil, that which is essential to the growth of timber trees, may be totally incapable of supplying them with nourishment. Trees which grow singly, as in hedge-rows or in parks, do not require an equal depth of soil with those that grow in forests, because they have facilities for spreading their roots in search of food. But for forest-trees, whether oak, chestnut, or birch, a depth of at least 4 feet of appropriate soil is absolutely necessary for the production of fine timber trees. Elm and ash do not require so great a depth.

The depth of soil determines the age of the tree.

Buffon has given a scale for the ages at which it is desirable to fell timber, dependent upon the depth of soil in which it grows. He says that a depth of from 2 to 3 feet of soil will not support a tree in a thriving condition for a longer period than fifty years. From 3 to 4 feet of soil will enable the tree to go on improving till about seventy years of age; and in soil from 4 to 5 feet deep it will flourish for a century. These periods are for strong and favourable soils. In lighter soils, at least ten years must be taken from each period, and the timber will then also be inferior in quality. As a general rule, the more generous and favourable to the growth of the timber the soil may be, the longer it is advantageous to wait before felling it. Trees should never be allowed to become stag-headed—that is, to have their upper branches bare of leaves. It is in the top branches that the first symptoms of the decline of the tree are to be perceived. The leaves there acquire a faded, weakly appearance, gradually diminish in number, and finally the branches become barren of foliage, and decay. The least appearance of want of vigour in the top of a tree should be the signal for its being cut down; and even then it is a sure token that the timber is past its prime.

How to judge of the goodness of the soil.

The nature of the soil in a track of country may be ascertained either by opening it, or by observing the plants which grow upon its surface. Thus, if plants which flourish only on marshy land are found at all times of the year on any particular track, we may assume that track to be marshy land, whatever its temporary appearance may be. The nature of the subsoil may often be ascertained by examining the ditches. The goodness of earth may be tested, approximately, in the following way. If a hole be dug out, and the whole of the excavated earth can be afterwards returned into the hole, the soil is poor; but if, on the contrary, there is an excess, its quantity is a criterion by which to judge of the richness of the soil.

Deficiency of moisture must be guarded against.

Although, as we have seen, too much moisture is unfavourable to the growth of good timber, a deficiency of it must equally be guarded against, the timber then suffering, not in quality indeed, but in size. Wood grown under such circumstance—as, for instance, the Scotch mountain-oak—is extremely heavy, hard, and dense, and when not "overgrown," or allowed to attain too great an age before being felled, is very durable, and little liable to shrink or warp. Mountain-oak is therefore well adapted for furniture and panelling, &c. As a general rule, the quicker the growth of the tree, the more it will shrink when converted into timber.

Properties of the best oak timber.

These general remarks afford an idea of the difference in the appearance and qualities of timber grown on good soil from that produced on bad soil. It may, however, be desirable to enter a little more into detail. An oak-tree, grown on the soil adapted to the development of its best properties, not only has its concentric rings thin and close together, but they are also of very uniform thickness, and the texture of the grain is fine. When the wood is split, it has a glossy, varnished appearance, and is of a very pale yellow or straw colour. There is sometimes as much as one-fourth difference in weight between samples of oak timber; and the heaviest loses a much less proportion of its weight in drying, and will also, if immersed in water, absorb less than the lightest. The amount of sap-wood in the best timber is comparatively small, and the bark is thin and of a smooth, even texture. In breaking such wood, it produces a sharp, decided noise. Having but little moisture in its composition, and being less hygrometric in its nature than wood of more open texture, it is little subject to decay; and its grain being hard, it is not easily pierced by insects.

The larg oaks on record.

The great size to which oak-trees will attain, when favourably situated as to soil and locality, is truly astonishing. The celebrated Chapel Oak of Allonville, in the Pays de Caux in France (which is still standing, we believe), measures at its base 35 feet in circumference, and at 6 feet above the level of the ground it is 26 feet in girth. It is hollow, the interior having been fitted up as a chapel in 1696, and being still employed in that capacity. The computed age of this tree is between eight and nine centuries. A very large oak was felled in Monmouthshire in 1791; when converted, it produced the following enormous quantity of timber:—

The main stem, 91 feet long, when sided	330	cub. ft.
A branch, 29 feet long, sided 17 inches	58	„
„ 24 „ „ 19 „	60	„
„ 19 „ „ 17 „	38	„
The two main slabs produced 86¼ feet of 3-inch plank, making, with other conversions	216	„
13 sided knees, taken together	217	„
Other minor but useful conversions	276	„
Total	1195	

The weight of useful timber in this tree was nearly 30 tons. The bark weighed 3 tons, 17 cwt., 3 qrs. But the largest oak on record, known as Damory's Oak, grew in Dorsetshire, and was used as an ale-house. It was 68 feet in circumference, and the room formed in it was 16 feet in length. This tree was blown down in 1703. The Cowthorpe Oak, near Wetterby, in Yorkshire, measured (in 1768) 40½ feet in circumference at 4 feet from the ground, the height of the tree being 85 feet. The Bentley Oak measured (in 1759) 34 feet in circumference at 7 feet from the ground. The Boddington Oak, in the Vale of Gloucester, measures, at 3 feet from the ground, 42 feet, and at 6 feet from the ground, 36 feet in circumference.

Different species of oaks.

There are not less than 140 species of oak known, and although there are many sorts cultivated and growing in England, botanists and arborists agree that there are principally two varieties; these are, the Durmast oak, and another, which is commonly called the old English oak, although both are supposed to be indigenous. In the Durmast oak, the *Quercus sessiliflora*, the acorns grow in clusters close to the twig, and the leaves are set on short leaf-stalks, while in the old English oak the *Quercus Robur*, or *Quercus pedunculata*, the acorns grow generally singly, at most two together, on stalks of from 1 to 2 inches in length, and the leaves are close to the twig, without the intervention of any length of leaf-stalk. These are the principal distinguishing marks between the two varieties. Many writers attempt to draw distinctions from the colour and shape of the leaves, and the colour and appearance of the bark; but it is doubtful whether these may be depended upon, as, from a careful examination of the evidence, it is more than probable that the colour and appearance vary much with the soil and locality. There is no doubt, however, as to the comparative inferiority of the timber of the Durmast oak. Almost all the English writers on timber have asserted it, and both Buffon and Du Hamel corroborate their assertions, and give a most decided preference to the oak bearing large acorns on separate stalks over the oak bearing acorns in clusters; which characteristics are just those which distinguish the English from the Durmast oak.

Proportio of sap-wo to heart-wood in different trees.

In favourable soils, the old English oak has seldom more than 12 to 15 concentric rings of sap-wood; but in the Durmast oak there are frequently from 20 to 25, or even 30. This seems to prove the inferiority of the Durmast oak; for it is an established fact, that the best hardwood timber is that in which the proportion of heart-wood to sap is the largest. The Spanish chestnut has usually but 5 or 6 rings of sap-wood, English elm, about 10; white larch, 15; Scotch fir, 30; yellow Canada pine, 42; Memel fir, 44 and red Canada pine as many as 80 to 100.

Size of oak timber.

As a general average of the size of oak timber, 56 cubic feet for each end or log of rough timber, and 30 cubit feet for each end of sided timber, may be assumed as tolerably correct. In order to convert rough timber into sided timber, about two-thirds the diameter of the rough log, in the middle of its length, is assumed as the most advantageous siding; and, on an average, it is estimated that not above one-third of each log or end of rough timber is used in the principal conversion from it, and this principal conversion is estimated to be about three-fourths of the total conversions.

With reference to the size that an oak will attain in a given number of years, much must depend upon the soil and the situation. The plan adopted by the late Duke of Portland of planting tablets of iron or stone with the trees, with the date inscribed upon them, will probably throw much light on this subject. Mr Blenkarn adduces the following case:—Three thriving oaks, growing on a hard, gravelly, and poor soil, were felled in Nottinghamshire, which, on an average, girded 15 feet at 3 feet from the ground, and each tree contained about 430 cubic feet of timber. These trees were known to have been planted in 1692 or 1693, and they were above 149 years old (say 150 years) when they were felled. As they were perfectly sound, and were yearly increasing in size, it is probable that had they been allowed to remain another century, their bulk and cubic contents would have increased at least one-half.

Value of oak timber.

The value of these trees when cut down was more than L.120, a sum equal to 30s. per acre (without taking interest into account) for the land they occupied during the 150 years of the growth,—a reply to those who assert that timber will not pay the rent of the ground it occupies, or injures by its shade. For the first 50 years the land would not be much injured by those trees; and as they grew older the acorns, as food for swine, would compensate for the loss of herbage under the trees. But the land on which these trees grew was not worth 15s. an acre when they were felled, and of course was much less valuable when the trees were planted.

"It frequently happens," says Mr Blenkarn, "that proprietors of large estates have not the slightest idea of the value of the timber growing upon them, regarding the trees on the property as merely an ornamental accessory, little supposing that they may be worth more than half of the value of the estate estimated on the basis of the rental. It may be further affirmed that, on most large estates, a great portion of the timber could be cut down to the benefit of the trees which are left standing. An acre of oak woodland, containing 100 loads of timber (which is a low estimate), is worth L.650 at a moderate computation; and 50 acres of such property would therefore yield L.32,500 worth of timber." This calculation, offered by a professional surveyor, certainly holds out a strong incentive to planting, without taking into account the beauty imparted to the landscape, the shelter obtained for cattle, the cover for game, and other advantages. It is a well-known fact that estates abounding with timber will command a high price in the market, and are eagerly sought after, in preference to others possessing a better soil, but destitute of trees.

Plantations of hard wood.

In making large plantations of hard wood, it is usual in this country to intermix an equal number of birches with the young oaks, for the sake of the shelter they afford, a few beeches, larches, sweet chestnuts, &c., being sprinkled amongst them. It is believed that oaks raised from acorns, which have been sown where the tree is to grow, will ultimately become the largest and finest trees; since, from the great length of its top-root (or *tap-root*), it is almost impossible to transplant an oak without injury to it. They should at any rate be moved while small. Fir-trees make but indifferent nurses for young oaks, as they neither grow so fast on forest land as the birch, nor will the oak thrive under them. A screen of fir-trees is often of great benefit, however, when the young plantation is much exposed. Furze and tall grass also, while useful as a protection for game, will not injure the young trees planted amongst them, as these, though at first overgrown, and apparently choked by the furze, will soon rear their heads above the cover, thankful for the shelter thus afforded them while young.

Time of planting.

It has been found that the best season for planting on light ground is as soon as possible after the beginning of October, and for heavy, moist land, in February and March. When the quality of the ground varies very much, which is almost sure to be the case in extensive plantations, the species of the trees should be varied accordingly, and the appearance of the wood will be much more beautiful than if uniformly planted with trees of one kind. As the oak, however, fortunately thrives on almost any soil, no portion of the wood should be destitute of them.

Artificial drainage.

Where artificial drainage becomes necessary, open drains are preferable to close ones, as being less liable to get choked up with the fibres of the roots. Strong clay soil (of which a great portion of wood-land consists), when so overshadowed by trees that the natural evaporation from the surface is much impeded, becomes almost impervious to water, and the stunted growth of trees, particularly the oak and the ash, and the dead branches in the tops of the oaks, called ***stag-heads***, are mostly attributable to this cause. Good drainage has also the effect of increasing the temperature of the soil.

Open glades should be left.

In large woods which are planted on nearly level ground, it is recommended to leave occasional open spaces or glades, in the thickest parts most remote from the boundaries, unencumbered with brush-wood. These tend greatly to encourage the free circulation of air through the wood, a point of considerable importance in the economy of vegetation. These glades may be rendered very beautiful by planting in them a few choice specimens of ornamental trees, which will generally thrive well in such a situation in consequence of the protection afforded by the surrounding wood.

Thinning woods.

In thinning woods, care should be taken to remove such trees as show any signs of decay, or when one tree interferes with the growth of another, the cleanest, straightest, and those with well-formed compact heads, being alone reserved for timber. The oak and chestnut, as the most enduring trees, should be chiefly left to posterity; the beech, ash, and others, being cut down as they arrive at maturity.

Best season for felling timber.

In consequence of the great value of the bark of oak, it is the practice to fell the timber in the spring of the year, because then the bark is easily detached from the tree, while the bark of winter-felled timber is lost. There can be little doubt, however, that the durability of the wood is much deteriorated by this practice. It was a received opinion among the ancients that timber should be felled in the fall of the year; and not only do modern experiments confirm this opinion, but modern discoveries as to the flow and return of the sap, and its nature at various seasons, tend to show the reason for its correctness. The practice which almost all the eminent arborists have recommended, and supported by their experiments, is to bark trees standing in the spring, and then allow them to remain in this state at least one twelvemonth. This was not an uncommon practice in some of the midland counties of England, and was first strongly recommended in the reign of James the Second by Dr Plott, an arborist of great celebrity at that time. Buffon presented a memoir in 1738 to the Royal Academy of Sciences in Paris, "On increasing the Solidity, Strength, and Durability of Timber;" for which purpose it was recommended to strip the tree of its bark during the season of the rising of the sap, and then to leave it to dry completely before being felled. Du Hamel gives most minute accounts of experiments made by himself, all tending to the same conclusion; and Dr Hunter, in his notes on

Evelyn's *Sylva*, says, "that by stripping off the bark, and allowing the tree to stand and die before it is cut, the sappy part becomes as hard and firm as the heart." Here is a collection of opinions, of such weight, that the general fact which they assert must be considered to be established beyond contradiction. Buffon also says that he caused pines, firs, and other species of evergreens, to be barked standing; and as he found them live longer after the operation than oaks which had been also stripped, he considered their wood acquired proportionately greater hardness, strength, and durability. He recommended the practice for fir-trees destined to be converted into ships' masts.

We shall now notice a few of the peculiarities of other trees most esteemed in this country for their timber.

Elm timber.

The Elm, of which, like oak, there are two principal varieties, will not bear a damp soil with stagnant waters, but it thrives well in moist declivities, provided the land be not too rich. The trees grown on too damp a soil either die prematurely, or their timber is of a soft spongy nature, and prone to decay. There are two British varieties of this timber, the *Ulmus Montana*, or Wych elm, and the *Ulmus Campestris*, or, as they are sometimes called, the Scottish and the English elms. Of these the Wych elm is decidedly the most valuable as timber, and, when used in situations where it is kept constantly moist, is extremely durable; but no elm timber will bear the trials of change of temperature and moisture to which oak in all its varieties is comparatively insensible. The close and interwoven grain of elm, the absence of decided longitudinal fibre, and its power to resist rending from exposure to the heat of the sun, and the alternations of weather, cause its timber to be very useful for small articles, such as the blocks used in the rigging of a ship. It is valuable in many parts of the millwright's machinery, where the wood is subjected to cross strains or great friction. It is also valuable and much used both for the timbers and for the planking of ships below the surface of the water; and the planks of clinker-built boats are very generally of elm. There is one peculiarity about elm timber, namely, that the alburnum or sap-wood is possessed of nearly equal power to resist decay with that which is matured; that is, when both are used in situations where they are not exposed to alternations in moisture. A variety of timber has of late years been introduced into the market under the name of Canada elm, or American rock elm. It is a smooth, even textured, pale-coloured, and strongly fibrous wood, almost devoid of knots, and admirably adapted for boat-building, and all works which require a flexible and close-textured wood. The Canada elm appears to have many of the peculiarities of toughness and flexibility which distinguish the ash. The elm-tree, which is much to be admired for the stateliness of its growth, sometimes arrives at an enormous bulk. King Charles' elm at Hampton Court measures 38 feet in circumference, at the height of 8 feet from the ground. The Wych elm at Field, Staffordshire, is 25 feet in girth.

Chestnut timber.

The Chestnut, *Fagus castanea* (called Spanish, or sweet chestnut), is a very valuable timber tree, its wood being equally durable with that of oak. It was much used for building purposes in former times, both in this country and on the Continent, but its cultivation has been too much neglected of late in England. Chestnut timber may be seen in a state of perfect preservation in many parts of ancient ecclesiastical buildings, Pugin having specially distinguished it by name in the engravings of some of his works.

This tree, as well as the beech, appears to suffer less than any other of the timber trees from being planted in a moist sandy soil; but as the roots of the chestnut extend far downwards, they require a proportionate depth of soil. It grows with frequent twists and contortions of the stem, which, while it adds to its picturesqueness for ornamental purposes, certainly detracts from its value as a timber tree. Some of the largest chestnuts in Europe are found on the flanks of Mount Etna. The largest known in this country is at Tortworth in Gloucestershire. As their shade is detrimental to other trees, they should either be planted in clumps by themselves, or be given full room to spread. When the timber of the chestnut has been some time in use for roofs or joinery, it is difficult to distinguish it from oak.

Beech timber.

The Beech, *Fagus*, is a timber that easily adapts itself to, and flourishes in, almost any soil. Even among rocks its roots will, like those of firs and larches, insinuate themselves into the smallest fissures, and find means to extract sufficient nourishment to produce a useful timber. Beech timber, when used shortly after being felled, and for works where it will always remain in a damp state, is a long-enduring wood. It is largely applied in the mercantile navy for the lower planks of the bottoms of ships. The best variety has its wood of a yellow tinge. It is much used for making cheap furniture; also by railway contractors and others for temporary purposes, and by coopers. The symmetrical shape of the beech, and its bright glossy leaves, render this tree highly ornamental in the park or shrubbery, and the varying hues which its leaves assume as the autumn approaches are a great additional recommendation. As no tree suffers more from injudicious pruning of the roots or branches than the beech, it is better raised from seed in the situation it is intended permanently to occupy.

Ash timber.

The Ash, *Fraxinus Excelsior*, will also accommodate itself to all soils. It will grow in marshy grounds, and in arid land, in deep or in shallow soil. The value of its wood for general purposes is second only to the oak in the list of British timber trees. The ash timber from very poor soils is brittle, wanting the elasticity which is the valuable peculiarity of this wood. It is a very useful timber for carts and implements of husbandry, for machinery, for tools of almost all trades, and it supplies oars to our shipping. When planted in a genial situation, it attains to a very great size, specimens being sometimes found which measure 30 feet in circumference, and 100 feet in height.

Fir timber.

We have hitherto confined our remarks to the hard-wood timber trees, without noticing the numerous Firs which are so valuable to us. Their timber is admirably adapted by its manner of growth, its lightness, and strength, to supply our navies with masts and spars; while from its comparatively small cost, and the ease with which it is worked, it is used very largely for all purposes of building. Indeed, it is questionable whether fir is not more generally useful to us than any other species of timber. Du Hamel, in his treatise *Du Transport et de la conservation des Bois*, has drawn a distinction between firs and pines, although it is usual to designate the timber of both as fir timber. Pines, he says, have the leaves thready and slender, growing in clusters from the same leaf-stalk, while firs have straight leaves, each growing separate, but many growing on the same leaf-stalk like the teeth of a comb. Trees of the pine tribe have one principal root growing straight down like a carrot, with few fibres, while the roots of the fir are more lateral and superficial. The pines grow with their trunks much less tapering towards their tops than the firs; they are, therefore, from shape, more adapted for masts than firs. Their wood is also more resinous, and the resin is of a more glutinous nature, and therefore less easily evaporated. This quality enables the timber to resist better the absorption of water or moisture. The pine is more durable than the fir, and its fracture is, even when partially decayed, much more fibrous, and takes place with more previous warning. The timber of the pine, when healthy, is close-grained, even-textured, and of a bright yellow colour. The fir, although frequently little inferior in appearance in other respects, is always of a much paler shade of colour.

Riga or red pine.

The most valuable of all the varieties of fir timber is that which is called RIGA FIR. It is the red-wood pine of the north of Europe, the *Pinus Silvestris*, which, although spread over a very large portion of the globe, appears to flourish in its greatest perfection in the forests of Lithuania and Poland, where the cold is severe and the soil generous. Riga fir is not only extremely flexible and elastic, but is by far the most durable of all the pine timbers; and as long as it could be procured of sufficient size, it was generally used in the royal navy, not only for topmasts, but also to build the lower or standard masts. At present, from the difficulty of procuring large sticks, the use of it is confined to topsail-yards and the smaller description of spars. The American continent also produces this red pine timber of good quality, although much inferior to that of the north of Europe. It is imported from Canada and from Virginia. The Canadian red pine is of small size, seldom exceeding 14 hands. The Virginian pine is large, sticks of 24 and 25 inches in diameter not being uncommon. It is a resinous and flexible wood; but the sticks are more subject than the Canadian red pine to the defect of large knots, which, from not being firmly united to the surrounding timber (technically, "well-collared"), injure its value. The red pine thrives extremely well in Scotland, where it is called Scotch fir, but is not equal in quality to that imported from the north of Europe. The French dockyards are supplied with mast-timber from the red pine of the Pyrenees and of the island of Corsica, but neither of these is of first-rate quality. Indeed, a climate of low temperature appears to be essential to the growth of superior fir timber. The firs on the northern sides of hills and mountains, in all temperate climates, thrive better than those growing on the southern slope; and even the timber of the northern side of an exposed fir-tree is much superior to that of its southern side.

Scotch fir.

Yellow pine.

YELLOW PINE, the *Pinus Strobus*, which is imported from Canada, is the principal timber now available for large masts and yards, and is very generally used both in the royal and mercantile navies, as well as for building purposes. It has neither the flexibility nor the elasticity of the red pine, nor is it so durable, but it is much lighter. Its great recommendations are its large size and its comparatively small cost. Sticks of this timber run from 16 to 27 or 28 inches in diameter; and for bow-sprits they are sometimes received in the royal yards as large as 29 and 30 inches in diameter; but sticks of these large dimensions are becoming very scarce. This timber grows also in Great Britain, where it was first introduced by an Earl of Weymouth, whence it is called the Weymouth pine; but it does not appear to thrive well in this climate.

Spruce fir.

The SPRUCE FIR, *Pinus Abies*, grows in Scotland, Norway, and other northern countries. It is very generally used in the mercantile navy for yards and top-masts, and also in the royal navy for the smaller description of spars and boats' masts. They are tough, close-grained, and elastic, but are very full of large knots; and care is therefore required in selecting them. The timber also is soft and far from durable, it having very little appearance of resin. The Norwegian spruce grows frequently to a large size.

Cedar.

CEDAR, *Pinus Cedrus*, would be among the most valuable of all timber trees, were it sufficiently common to be available for building purposes. It is almost indestructible from time, and no insects will ever attack it. It thrives well in this climate, but hitherto has only been planted either as an object of curiosity or of ornament. It requires a more generous soil than any other of the tribe of pines, and is considered to be a timber of very slow growth. Pitch-pine is also a very valuable timber for building purposes, but it is too heavy for spars.

Defects in fir timber.

Fir sticks, the Riga hand-masts especially, are very liable to have serious defects in them, which it is often impossible to discover until the stick is worked. They are technically called "upsets." The grain appears to be partly separated, so that a shaving from the stick at that place would bend to a sharp angle at the upset, as if partly broken. There always appears to be a greater or less accumulation of the turpentine about the injury, as if it had originally exuded at the wound, and become congealed around it. These defects are most frequently found in the smaller sticks, those especially that are more resinous and knotty than others; and they sometimes are so numerous as to extend, at very short distances apart, for a great portion of the length of the stick. Mr Cradock, who long superintended the mast-making at Portsmouth dock-yard, considers them to be the effect of violent winds on the more exposed trees of a forest. He founds this opinion on the facts that they are most common in the most flexible timber; that they are not perceived in sticks of large diameter; and that in the firs of little flexibility, as the yellow pine, they are seldom or never found; although the sticks of this fir, from being cut in every variety of direction, to form the components of made-masts, are more searched than any other. The cowdee, a New Zealand timber, lately introduced both in the royal and mercantile navies, is, he says, much subject to this defect; and he has observed it once in a poon topmast. The defect seldom or never appears in the outer layers of the timber, but only after some of these have been removed by the axe, and the older timber laid bare of the sap-wood.

Sap-wood in fir timber.

The sap-wood in all fir timber is useless, and very generally there is a large proportion of it in comparison to the quantity of heart-wood. It is rather a curious fact, that there appears to be a difference between the pines and the generality of the hard-wood timber in this, that a small proportion of sap-wood in fir is indicative of the inferiority of the timber. Thus the red pine of Scotland has fewer layers of sap-wood than either the red pine of Canada or of the Baltic. As a general remark, it may be stated, that the greater the quantity of sap-wood there is about a tree of any description of fir timber, the better will be the quality of the "spine," which is the technical name given to the mature wood.

Cowdee.

The COWDEE, which is now largely imported into this country, is a close and even-grained timber, almost entirely free from knots. It grows to so large a size as to be available for the topmasts and other principal spars of the largest classes of vessels; but from its want of elasticity, and its liability to warp and rend, it is not so suitable for small conversions. It varies greatly in its quality, even so much as often to be of different colours, grain, and texture, in the same stick. It is about the same average weight as Virginia red pine.

Larch timber.

LARCH timber, *Pinus Larix*, formerly unknown in Great Britain, has, within the last century, been very extensively planted. The first plantations of it were made on the vast estates of the Duke of Atholl, in the Highlands of Scotland. The following account, which is extracted from Knowles *On Preserving the Navy*, was, as the author of that work states, furnished to him by the late duke, and it contains, consequently, the results of the longest experience as to the growth of larch timber in Britain which can be obtained. The account is interesting, because plantations of larch are becoming very numerous, as they are found to be very profitable. The returns from a larch plantation during the time the trees are arriving at their full growth, are estimated to be at least double what they would have been from an equal plantation of any other timber. "Seedlings of larch were probably first brought into Scotland in the year 1738 by Mr Menzies; but it has been asserted by some, that they were introduced into that part of this country in 1734 by Lord Kames. Some were left at Dunkeld, and some at Blair-Athole, by the former gentleman; and being exotic plants, were placed by the gardeners in green-houses. Not thriving in those situations, they were planted in the pleasure-grounds, where they grew luxuriantly. When the present duke succeeded to the titles and estates (in 1774), there was a considerable number of trees in a thriving state; and on a general survey of his estates in 1783, there were found to be 900 Scottish acres of plantation, 600 of which were of larch; since which time his grace has planted extensively every year, and in the spring of 1820, 10,820 Scottish, or about 12,984 English acres, were covered with trees. The different species were, of—

	Scotch Acres.
Oak	800
Scottish firs	1500
Spruce firs	500
Mixed plantations in the pleasure-grounds	200
Birch	200
Larch	7620
	10,820

"The larch thrives in very exposed situations. The lower range of the Grampian Hills, which extends to Dunkeld, are at an altitude there of from 1000 to 1700 feet above the level of the sea. The larch-trees are planted as high as 1200 feet up these hills, and grow exceedingly well; a situation where the hardy Scottish firs cannot rear their heads. The spruce fir, however, thrives equally well as the larch on high and exposed hills. The growth of the larch-trees is very rapid, and Scottish fir of the same age will measure only half the quantity; and so much is the wood esteemed in Scotland, that while the former is worth 2s. 6d. per cubic foot, the latter brings only 1s. 3d. The following account of a larch-tree, planted in the year 1738, and measured February 1819, will give some notion of its growth:—1 foot above the ground, girth 17 feet 8 inches; 2 feet, 14 feet 6 inches; 3 feet, 12 feet 7 inches; 5 feet, 11 feet 5 inches; 10 feet, 10 feet 4 inches; 20 feet, 9 feet 7 inches; 50 feet, 6 feet 3 inches; 70 feet, 3 feet 2 inches; 75 feet, 1 foot 10 inches.

"The top was fifteen feet in height, making the whole height 90 feet; and the tree measured 300 feet, or 6 loads, in cubical contents. The white and red larch-trees are those chiefly planted. The duke has made trial of the black or American, and also of the Russian larch, but has found that they do not thrive well. The timber in question has been used for many years in Scotland for almost all local purposes, such as posts, rails, mill-wheels, fishing and ferry boats; and in all these situations has been found to be very durable. The author has seen part of a ferry-boat twenty-three years old, which remained very sound, and the iron nails driven into it as perfect as when they first came from the forge. This, perhaps, was occasioned by their being constantly covered with an insoluble varnish, with which the larch abounds. One of the qualities of larch for building merchant-ships is its great lightness, a cubic foot, weighing, when seasoned (which it does rapidly), only 34 lb. Although it is not so strong as many sorts of wood, it has great resilience. Cabinet-work of great beauty has been made from larch; it polishes well, and when seasoned is not found to warp or shrink. A most important fact in agriculture has arisen from planting larch-trees on rocky ground; the vegetable compost formed thereon by the falling of the leaves has been the cause of producing herbage for feeding cattle, and made that land, which, on the average, did not formerly bring more than 8d. or 9d. per acre, now to be worth from 12s. to 14s. per acre annually."

Cultivation of the larch.

Larch timber, although so generally planted, and so generally thriving, requires considerable attention in the selection of proper soil for it. It is very subject to a heart-rot, which seizes on the roots, and rapidly proceeds up the centre of the stem of the plant, the latter swelling considerably for several feet above the surface of the grou
Larch cannot bear a cold damp soil, or any stagnation
water, or even the moisture of the rich vegetable moul
Nor will it thrive in the light sandy soils; for although
dislikes marshy stagnant waters, its roots require to be pr
served from the droughts of summer. Sandy and gravel
soils, if situated so as to receive from declivities the moi
ture percolating through them, will produce excellent lar
timber; as will also the sides of rocky hills and mountai
in which no moisture can stagnate, and into the fissures a
clefts of which the roots easily penetrate and find am
nourishment. Larch-trees attain to a very great heig
In some of the public buildings of Venice there are s
to be single-pieced beams of larch which are 120 feet
length. It must be very durable, for it is almost the on
wood which was used in the palaces and public buildin
of that city.

The timber imported from Canada under the name
hackmatack is believed to be identical with the Scottis
larch. The timber of America in general is very inferi
to that grown in the north of Europe, being much softe
in its nature, not nearly so durable, and more liable to th
dry-rot. American timber is therefore seldom used i
ship-building, except for deck-deals, and but sparingly als
in the construction of first-class houses.

In consequence of the immense consumption of timber for the maintenance of our fleets, we are obliged to import much from abroad. We obtain oak of excellent quality for planking from Poland and the shores of the Baltic; while from Italy, and from both sides of the Adriatic, sided timber and plank are imported in large quantities. American oak and rock-elm are both valuable timbers, and ar
now coming into very general use in this country, being introduced in considerable quantity. The former is used by cabinet-makers and carriage-builders, principally on account of its great size, uniform texture, straightness of grain, and little tendency to warp. Its specific gravity is somewhat less than that of English oak. Rock-elm is becoming much used for engineering purposes. It is remarkably uniform in texture and growth, and perfectly straight and free from knots. Its great length and uniform siding render it extremely useful for longitudinal ties, piles, and other purposes, which require great length, combined with uniformity in dimension. For example, a baulk of rock-elm, 54 feet long, was found to taper only 1¼ inch, and when slabbed, was 12½ inches square in section, and 5
feet long. A specimen cut from this baulk weighed 3
lb. per cube foot, its specific gravity being equal to that of English oak.

One of the most largely imported woods of tropical countries, and one of the most valuable, is teak. It grows to an enormous size, is particularly straight and free from knots, and has the peculiar property of resisting the attacks of insects. It possesses greater toughness than almost any other wood of equal weight, and is little liable to dry-rot or other disease. The great durability of teak is to be attributed to the large amount of oleaginous matter contained in this timber. Like all other woods, it varies much in quality, according to the locality where it is grown. The finest teak comes from Malabar; then follow the importations from Travancore, Ceylon, Java, the Malay Peninsula, from Pegu and Moulmein. The two last descriptions of teak are very inferior to the Malabar variety, being comparatively coarse, porous, and open-grained; but this inferiority is believed to be due rather to the low swampy locality from which it is cut for the foreign market, than to any inherent bad quality of the timber. Its weight, when moderately seasoned, may be stated to be 42 lb. per cubic foot, while the weight of Malabar teak, on an average, is from 45 to 52 lbs. per cubic foot. The forests of Tonga and Irrawaddy supply the whole of the

Pegu teak. That of the Tonga forests is of the best quality, the country being high, and not flooded during the rainy season; whereas the forests of the Irrawaddy are always in a swampy state, and are part of the year covered with water sufficient to allow of the trees being floated from where they are felled. The Birmans are in the habit of tapping the teak-trees, particularly those which are straight grown, to extract a varnish or oil, which is highly prized by them, and used chiefly for protecting their pagodas or temples from the weather, for which purpose it is very effectual. These edifices are built entirely of untapt teak, as the Birmans consider the timber to be much injured, both in its strength and its durability, by being deprived of this oil. The principal parts of these temples are sunk in the ground, and although so fixed, the timber remains perfectly sound, notwithstanding many of them have stood nearly a century.

Saul.

Inferior as the Pegu and Moulmein teak is to the Malabar or Bombay teak, it is still preferable to the saul, which is now imported to this country in considerable quantity. This is a hard heavy wood, growing in Behar, Oude, and the inexhaustible forests skirting the hills that form the northern boundaries of Bengal. It varies much in quality, the best timber being found occupying the rocky ground at the foot of the hills, while that grown in the alluvial plains is very inferior. As a rule, it deteriorates in quality the further it is produced to the westward. Sauls of large dimensions are now becoming very scarce, as the whole of the forests within a reasonable distance of the navigable streams are quite exhausted; but it is hoped, that as the Indian railways extend into the interior of the country, a further supply of valuable timber will thus become available for exportation. The best description of saul, if well seasoned, may be classed, in point of durability, with the best sort of African timber, now so extensively used by ship-builders in this country. The greatest care is necessary in the selection of saul for immediate use, on account of its requiring a long time to season, and it must not be employed in ship-building for any part exposed to the sun, as it shrinks very much. Saul is used for the frame, beams, shelf-pieces, breast-hooks, and inside planking of ships built in Calcutta.

Indian woods.

The principal woods used in India for ship-building are, besides teak and saul, sissoo, jarrol, poon, and toon, teak being the most durable of them all. Indeed, from the great length of time which several vessels built of Malabar teak have lasted (from thirty to fifty years, and in some particular instances nearly a century), this may be said to be the most valuable timber for ship-building purposes yet known. It is, however, like every other kind of wood, liable to premature decay, if not properly and gradually seasoned by exposure to a moderate current of air, after being felled. Java teak is of very superior quality, little if at all inferior to that from the Malabar coast, and is extensively used for ship-building at Calcutta. "The teak which is grown on high, dry, and open land," says Mr Leonard Wray, in a paper read to the Society of Arts, "is generally of a fine quality, close and compact, and abounding in a mild oil, which exerts no injurious effect upon the iron bolts which may be driven into it. That grown in the dense forests of the wet, low-lying alluvials, on the contrary, is lighter, coarser grained, and contains an acrid oil, which not only affects iron very materially, but even, to a certain extent, poisons and inflames the hand which has been pierced by its splinters."

As a test of the durability of a Calcutta-built ship, we may cite the Hastings, 74 gun frigate, built at Calcutta in 1818. The hull is composed of saul, sissoo, Pegu and Java teak, all of the best kind. So great was the expense incurred in the building of this ship, that when completed, the account, after giving credit for her freight, exhibited the cost of the hull for sea, 1,163,754 Sicca rupees, or, ten rupees to the pound, L.116,375 sterling. It is usual in Calcutta-built ships to convert the frame, with the knees, breast-hooks, &c., from sissoo timber; the beams and inside planking being of saul, and the bottoms, wales, topsides, decks, keels, stem, and stern-post, of the Pegu teak.

Durability of Indian woods.

Mahogany.

Mahogany is the produce of America and the West Indies, being principally imported from Honduras and Campeachy. That imported from the islands is called Spanish mahogany. It differs very much in quality according to soil and locality, the weight of a cubic foot varying from about 53 lb. to 35 lb.

Although mahogany may be stated to be a durable and valuable timber both for ship-building and general purposes, it varies so very much in texture and quality, that the utmost care and judgment are necessary in its selection. There are many well authenticated instances of the extraordinary strength and durability of ships built almost exclusively of mahogany, the most famous being that of the Spanish 80 gun ship Gibraltar, captured by the English in 1757, and broken up at the age of 100 years, when all her timbers were found to be perfectly sound. This, however, only proves the excellent quality of carefully selected Spanish mahogany (the Gibraltar having been built at Havannah), it being equally well known that light, porous, "swamp mahogany," or indeed any of inferior quality, is highly treacherous and unsafe when employed for the timbering of a ship. It is an error to suppose that all Honduras mahogany is light and spongy, the best quality of this timber being as heavy as Malabar teak or English oak, and only the inferior qualities of mahogany being so very light and buoyant. Mahogany is highly prized for the paddle-beams and deck-beams of steam-vessels, in positions where these are exposed to the moist heat of the engine-room, which is very destructive to most other species of timber.

Classification of timbers at Lloyds.

According to "Lloyd's" classification of timbers, those in the first class are the following only:—English oak, African oak, the live oak of America, the morra and greenheart of British Guiana, the teak and saul of India, and the iron bark of Australia. These are all close-grained, compact woods, hard, heavy, strong, and durable, being more or less impregnated with certain oily, resinous, or astringent matters. Mahogany of hard texture, though treated as a second-rate timber, is so far admitted in the construction of A 1 ships, as to include beams and hooks, knees, rudder, and windlass, main-pieces, outside planking to light mark, and the whole of the inside planking.

Greenheart.

Greenheart, the produce of British Guiana, is a very valuable timber. It is a hard, close-grained wood, containing a considerable quantity of oil, like teak. Its specific gravity is about equal to that of African oak, but it is decidedly superior to it in strength, toughness, and durability. These, however, are not its chief advantages, its great value consisting in its complete exemption from the attacks of marine worms. It is therefore an excellent timber for sluice-gates, piles, and all marine engineering works, which would be exposed to their ravages. It is imported in logs of from 12 to 16 inches square, and from 20 to 40 feet in length. It has been used in some instances for the planking of ships. Mr Wray, from whose interesting paper "On Timber for Ship-Building" we have already quoted, says, that greenheart is very abundant within 100 miles of the coast of British Guiana, and can be had almost to any extent.

Morra.

Another excellent timber of British Guiana, still more abundant than the last, is morra. This tree grows to a very great size, often attaining the height of 100 to 150 feet, the lowest branches being 60 feet from the ground. The wood is extremely tough, close, and cross-grained, which properties make it difficult to split, and render it peculiarly applicable to ship-building purposes. It is stated to be little subject to dry-rot. The other British possessions

Supply of colonial timber.

from which we might readily draw a supply of excellent timber are Assam and Tenasserim in the north of India, our settlements in the Straits of Malacca, and Western Australia. From the latter country we have the iron-bark, a first-class timber; the tuart, the jarrah, the blue-gum, and the morell. **Tuart.** The tuart is a noble timber tree, growing in tolerable abundance on the coast. Planks are sometimes obtained of it 10 feet wide; and it is said to be peculiarly adapted to the building of ships of war, as it is difficult to split, and not liable to splinter. In colour it is pale-yellow, or white. Its timber is remarkably cross-grained, hard, and tough, and very strong and durable. **Blue-gum.** The blue-gum is also an enormous tree, "sometimes," says Mr Wray, "yielding planks 14 feet wide, and more than 120 feet long." **Jarrah.** The jarrah of Western Australia is frequently confounded with mahogany, to which some species of it bear a certain resemblance. Mr Reveley, a government engineer in Australia, thus describes the jarrah:—"First, in colour, there is every variety of shade, from almost crimson to reddish brown, and pale brown, inclining to white. In the second place, as to grain, there is almost every variety, from the perfectly straight fibre to every species of curl, including the zebra and satin specimens. The length of the stem of this tree, taking the average, may be 65 feet (many being much longer), without a branch or a knot in all that length, and very nearly equal in size all the way up. It is not attacked by insects of any kind, nor has it any tendency to dry-rot, and is scarcely affected in any way by damp or moisture." There are forests of this wood in Western Australia of more than 4 miles in depth, and which are known to extend for a length of 150 miles. Here, then, is timber enough to maintain our navy for a hundred years to come, if we would only avail ourselves of the resources of this valuable colony, and encourage the exportation of its timber, by providing a ready means of access to a shipping port.

We shall now mention a few other species of timber trees, of minor importance to the preceding, but still useful for many purposes of construction.

Acacia, is of small dimensions, seldom exceeding two feet in diameter; but when used in house-carpentry is very durable. It is harder, tougher, and more elastic than the best oak. It is a valuable timber for tree-nails for ship-building; also, for posts and rails for fences, in which capacity it is very enduring.

Alder.—The wood of this tree lasts a long time under water, which renders it valuable for piles, water-pipes, &c. It has a close texture, a fine colour, and works well under the plane, which makes it a favourite with the cabinet-maker. The best charcoal for gunpowder is made from this wood. When burned in the open air, 1000 lbs. of the ashes yield 65 lbs. of potash.

Birch.—This wood is hard, but not very durable. It is chiefly used for making cheap furniture, and for firewood.

Box is a valuable wood, being very close-grained, hard, and heavy, and cuts very clean under the chisel or graving-tool, being therefore used almost exclusively by the wood-engraver. Being susceptible of a fine polish, it is much used by the turner, mathematical instrument-maker, &c. It is also very durable.

Cedar (Cedrus pinus) grows to a great size; the timber is resinous, of a reddish-white colour, light and spongy in its texture, easily worked, but apt to shrink and warp if great attention be not paid to the seasoning. It was much valued by the ancients for its durability and preservative properties. The wood is odoriferous, and admirably adapted for joiner-work, being light and easily worked. Although a resinous wood, it contains but a small quantity of that substance. It resists the attacks of insects.

Cedar, Indian (Cedrus deodara), is also a very large tree. The wood is very compact, highly impregnated with resin, and possessed of a hard and fine grain. Its durability when exposed to the weather is very great, some bridges constructed of it in India having lasted for five hundred years. It is much used by the Hindoos in their buildings.

Chestnut (Castanea) has been already mentioned as a very excellent timber for building purposes. The *Horse Chestnut*, on the other hand, is a soft, inferior wood of but little strength or durability. It resists moisture, however, and may be advantageously used for water-pipes under ground.

Cypress is a fine-grained wood, remarkable for its great durability, and its freedom from injury by worms or insects. Owing to this property, it was employed in Egypt for mummy-cases.

Hornbeam is a hard, heavy, tenacious wood, very close grained. It is much used for cogs of wheels and other engineering purposes, where the material is exposed to friction.

Lignum vitæ is a very hard, dense wood, much used by millwrights and turners; its chief use, however, is for the sheaves of blocks. It is also employed by the engineer for lining the sockets of shafts, which are found to revolve in it with little friction and wear.

Lime, though a highly ornamental tree, and growing to a great size, is not of much value for its timber, which is soft and light, and deficient in strength and durability. Being close grained and smooth in its texture, however, it is well adapted for carving and cabinet-work.

Maple is a clean, white wood, prized for its lightness, and is used by the turner for making dishes, bowls, and trenchers; and by the joiner for common furniture. As it is not liable to warp or split, it is readily stained to imitate mahogany and other woods.

Plane.—The wood of this tree much resembles the beech. It is used by the joiner and cabinet-maker, but is not remarkable for strength or endurance. It keeps best under water, and is used in America for quays and other marine works.

Poplar.—The wood of this tree (of which several kinds are grown in this country) is much used by builders for floors, especially, as it does not easily split by driving nails into it, and it has the property of not readily catching fire. When used for this purpose, however, it requires from two to three years' seasoning, as it shrinks much in drying.

Sycamore, when kept dry, is durable; but is readily attacked by the worm. It is a species of maple, and is possessed of similar qualities.

Walnut is one of the most valuable of English timbers. The wood is solid and compact, easy to work, not liable to crack or warp, and handsome in appearance; it is therefore much used for the better class of furniture. The screws of presses and gun-stocks are generally made of it. The black Virginia walnut is the most prized. It prefers hilly, calcareous soils.

Willow is a soft, smooth, light wood, of little value; but, if kept dry, it will last a long time in situations where much strength is not required.

Yew was principally used of old for the making of bows, and is now a favourite wood with turners from the smoothness and toughness of its grain, and from its taking a high polish. It sometimes attains an extraordinary bulk. At Gresford, near Wrexham, there is a yew 29 feet in circumference at a little distance below the branches; and in Dibdin churchyard, New Forest, there is a yew-tree measuring 30 feet in girth at the ground; while others, of large size, occur at Iffley, Hampton Court, Dorly-in-the-Dale, Tisbury, and other places. When found growing in churchyards, they may be generally reckoned as coeval with the church itself.

As the strength of timber has been already treated of in the articles, STRENGTH OF MATERIALS, and SHIP-BUILDING,

Timber.

Strength of timber is as the density.

we have little to add here upon this important subject. It may be observed, however, that the weight or density of a timber is in general a sure index to its strength, the densest wood being at the same time the strongest and the most durable. The oak, as well as all other timbers, varies in its specific gravity according to the soil which produces it, the density mainly depending upon the length of time occupied in the formation of the wood. Those trees which grow fast from being located on moist, sandy soils, never produce such strong timber as others of slower growth.

Position of the strongest wood.

It has been found by experiment, that the bottom part of the trunk, with the corresponding branches, is denser and stronger than the upper part of the same tree. Those trees which are suffered to complete their full term of growth before being cut down, have their heart-wood throughout of the same weight and strength, taking a cross section of the trunk at any one place, whilst those that are felled prematurely are found to possess these qualifications in the central portion of the wood only, which is then considerably harder than that immediately surrounding the sap-wood.

Over-grown timber.

In trees which have been over-grown, on the other hand, the central portion of the wood is the weakest, the process of natural decay always commencing in the heart of the tree. It is a common thing to see the heart of some fine tree (blown over by the wind, perhaps), which, to an untrained eye, looks perfectly sound and flourishing, to be already disintegrated by the spreading filaments of dry-rot, which have attacked it so soon as its vigour began to flag. The age at which oak timber is at its prime, is generally supposed to be from eighty to a hundred years, although this depends, as we have before explained, upon the nature of the soil on which it is grown. The weight of good oak timber is about 60 lbs. in the green state; and, when seasoned, about 50 lbs. If the seasoning is carried beyond this by artificial desiccation, the strength of the timber is impaired.

Dry-rot.

The decay of wood by the growth of fungus, denominated dry-rot, may be traced to the putrifying of the sap, when this has been left within the pores of the timber in the same condition as it exists in the living tree.

Preservation of timber;

The various means which are employed to arrest this destructive fermentation are, either to wash out the sap by long soaking in water, aided by the action of the sun; to dry up the sap, either naturally by exposure to the sun and wind, or artificially by *baking*, or by heated currents of air; or else by injecting into the pores of the wood some metallic salt to combine with the albumen and render it insoluble, or some antiseptic substance to preserve the vegetable tissue. The processes of natural seasoning and artificial desiccation, being those most in use for the preservation of ship-timber, will be found amply described in the article SHIP-BUILDING; also, the best mode of *creosoting*, although the latter process, from the increased inflammability and the strong smell it imparts to timber, is scarcely applicable to the building either of ships or houses.

by creosoting;

For the preservation of railway-sleepers, and other wood-work out of doors, which is not particularly liable to danger from fire, the creosoting process has been proved to be most valuable. Its efficiency depends, in a great measure, upon the mode of operation, and the quantity of creosote injected into the timber, which should be done under pressure in a closed cylinder. The process is most applicable to fir and other soft woods, which should imbibe, at least, 7 lbs. of the creosote oil per cubic foot, oak imbibing not more than 2 or 3 lbs., even under a pressure of 120 lbs. per square inch. This substance seems to act, *firstly*, by coagulating the albumen; *secondly*, by furnishing a water-proof covering to the fibre of the wood; and, *thirdly*, by preventing the putrefaction of the sap by its antiseptic properties.

Timber.

by absorption of metallic salts.

The various processes for the preservation of timber by the absorption of metallic salts, have all more or less failed in practice, and are now very generally abandoned. These are known by the names of the inventors, as Kyan's, Margary's, Burnett's, and Payne's processes. The object sought by each of the three first of these methods was to coagulate the albumen in the capillary tubes of the timber, and thus prevent, or retard, the putrefaction of the sap.

Kyan's process.

Kyan used chloride of mercury for this purpose, dissolving, at first, 1 lb. of the salt in 4 gallons of water; but as it was found that the wood absorbed about 6 or 7 lb. of this costly salt per load, more water was added to lessen the expense, until the solution became so weak as, in a great measure, to lose its effect. This process has, therefore, been entirely abandoned.

Margary's.

The salt employed by Margary was sulphate of copper, which, being much cheaper than chloride of mercury, could be used as a stronger solution. Its efficacy, however, has proved doubtful in many cases, while in not a few instances it has failed altogether.

Burnett's.

Better than either of the preceding is Sir William Burnett's plan of injecting a solution of chloride of zinc, in the proportion of about 1 lb. of the salt to 4 or 5 gallons of water. This process is still in use, and has certainly proved beneficial in a great many cases, but it cannot always be relied upon. Payne's process consisted in the successive injection of two substances in solution—the first, a metallic or earthy solution, and the second a decomposing fluid—the consequence being that the capillary tubes of the timber became filled with an insoluble substance.

Superiority of creosoted timber.

The process of creosoting timber, already referred to, was first patented by Mr Bethell in the year 1848. One great advantage of creosoted timber is, that it perfectly resists the attacks of marine worms and insects, as well as the white ant of India, which is more than can be said for timber prepared with solutions of metallic salts. Even that prepared with corrosive sublimate (as in Kyan's patent) has no immunity in this respect, the albumen appearing to neutralize the poisonous property of the salt.

Artificially prepared timber not suitable to ship-building.

For ship-building purposes such chemically prepared, or "salted," timber is scarcely to be recommended, as it attracts much moisture, and is very destructive to the metal fastenings. Empyreumatic oils and resinous solutions, although these certainly render the wood impervious to moisture, and preserve the iron or metal bolts from oxidation, are still very objectionable from the increased inflammability which they impart to the structure. The time necessarily required in preparing the wood with the preservative substance is also a great drawback to its employment in ship-building, where a delay of even two or three days, more especially in repairing, is often of serious consequence; and it should be remembered, the timber must be operated upon after it has been shaped or "converted."

Soaking timber.

Timber may be very perfectly preserved from subsequent decay by long submergence in shallow salt water, or, which is still better, in salt mud. When thus treated for a period of from ten to twenty years, the sap gets thoroughly washed out of the pores of the wood by the alternate absorption and expulsion of air or other gases, caused by successive variations of temperature. It need scarcely be hinted, however, that such a mode of procedure, though sometimes adopted in government dockyards, would be ruinously expensive to the private ship-builder.

Importance of good ventilation for preserving timber.

Having pointed out the fatal objections generally attending the use of chemically-prepared timber for ships or houses, it remains to show what means can be employed (and that with tolerable certainty) for preserving the timber of these structures from premature decay. The means at our command for this purpose are summed up in the two words, "seasoning" and "ventilation:" namely, thorough seasoning or drying of the timber on shore, when this is practicable; but, by all means, good ventilation on board. If these well-known and universally approved principles were but carried out in an honest and common-sense fashion, we should hear but little of rotten gun-boats, or heavy repairs to frigates after a first commission. Though it is undoubtedly true that the closely-packed timbers and double planking of a vessel of war present great obstacles to a thorough ventilation of the bottom, much may still be done by conducting currents of air down into the hold, and between the timbers, by means of wind-sails, or, if necessary, by fanners worked either by steam or hand, and by so arranging the internal accommodation that there may be as little stagnation of air as possible. However well seasoned and dry the timber may be when the ship is launched, it will rapidly absorb moisture from the damp atmosphere of the hold, unless evaporation from its surface be kept up by a forced circulation of air.

Cheaply-built ships often last the longest.

It is certainly unbecoming the scientific character of the age that ships built hurriedly and cheaply, and of very inferior timber, by what are contemptuously called "slop" builders, are known to resist the ravages of dry-rot much better than the expensively and elaborately-constructed ships of Her Majesty's dockyards; nay, more, that these same "slop-built" ships, even when constructed entirely of green timber (as they frequently are), will last longer than a government ship built with the best seasoned oak! The whole secret is, of course, the internal ventilation of the holds and frame of the ship. In a cheaply-built merchant-ship the timbers are spaced at some distance apart, and the ceiling planks are not placed so close together as hermetically to seal the spaces between the timbers, the consequence being that good ventilation is maintained amongst the planks and timbers of the bottom and sides. Even when such a ship is built of green wood, the circulation of air is generally sufficient to season the timber in its place and prevent its decay, for the dry-rot fungus will not thrive in an atmosphere less moist and stagnant than that of an underground cellar. The shrinkage of green timber in such a case would also conduce to its preservation by admitting the air between the ceiling planks.

Necessity for systematic ventilation.

These remarks are not intended to excuse the use of unseasoned timber in ship-building, a practice which should be resorted to only from dire necessity, but rather to show that if ships built of green timber can be preserved by what may be termed accidental ventilation, those built of seasoned timber should, *à fortiori*, be still more easily preserved by systematic ventilation. The action of heat in causing an upward current of air naturally suggests itself as a ready means of effecting this object on board ship. The dry-rot has been frequently arrested in a ship by thoroughly drying the timbers, holes having been previously cut in the ceiling planks to promote circulation. Yachts and other small vessels, when not in use, may be preserved from dry-rot by hauling them up out of the water in an exposed situation where the wind will get to them, keeping skylights and hatches open, and if a plank be removed from the bottom they will be all the safer. Should they be entirely closed up, on the other hand, the dry-rot will flourish within like mushrooms on a hot-bed.

Sap-wood should be removed

Sap-wood should always be removed from the timbers and planks of a ship, as from its spongy texture and imperfect development, it is more liable to dry-rot than the heart-wood (besides being much weaker); and when the dry-rot has once commenced either in a ship or a house, it is rapidly propagated by contagion. The process of seasoning timber quickly by a current of heated air will be found amply detailed in the article SHIP-BUILDING.

Measurement of timber.

Timber is bought and sold by solid measure, according to the number of cubic feet in the tree or log. The measurement of timber is therefore the operation by which these cubic contents are determined; that is, multiplying together the three dimensions, or the mean length, the breadth, and the depth, of each log. If the log should vary much in size in different parts, then the length, breadth, and depth of each of these parts must be multiplied together, and the contents of the log will be the sum of the products. When the log tapers, a mean breadth or depth is taken; the object in every case being to attain the most correct approximation to the contents of the log. In measuring rough logs, it is however usual to gird the log at the measuring place with a string, and then, folding the string into four equal parts, to assume this fourth part of the girth to be one side of the square area at the measuring place; which area, when multiplied by the length, will give the solid contents of the log. The arithmetical operation, simple as it is, is universally superseded by the more simple and far more correct plan of referring to published tables of contents, calculated for every foot in length of a log, and every quarter of an inch in the side of the square. Those most generally used for this purpose are in Hoppus's *Practical Measurer*.

In measuring standing timber, the length is taken as high as the tree will measure 24 inches in circumference, less than which measurement is not considered as timber. At half this height, the measurement for the mean girth of the timber in the stem of the tree is taken; one-fourth of this girth is assumed to be the side of the equivalent square area. The buyer has in general the option of choosing any spot between the but-end and the half height of the stem as the girding place. All branches, as far as they measure 24 inches in girth, are measured in with the tree as timber. An allowance, which varies according to circumstances, is generally deducted for the bark. In oak it is from about one-tenth to one-twelfth of the circumference at the girding place; in other sorts of timber it is less. In all, however, this allowance depends much upon special agreement.

It is usual to speak of timber by the load, which means 50 cubic feet of squared timber, or 40 cubic feet of rough timber. A load of plank is dependent upon its thickness. Thus it will require 200 square feet of 3-inch plank to make the load of 50 cubic feet; therefore the load of plank is the number of square feet of its respective thickness, which is necessary to make the load of 50 cubic feet. Deals are measured, according to their thickness and lengths, by the hundred, reckoning 120 to the hundred. (R. M—Y.)

TONNAGE.

Signification of the term.

Importance of good rules for tonnage.

THE term *tonnage*, as applied to shipping, was originally intended to express the actual burthen that any ship could carry, in order that the various dues and customs which are, and always have been, levied upon ships might be proportioned to their carrying powers. To avoid cavilling and uncertainty as to the real tonnage of a vessel (which, it is evident, depends upon the draught of water at which she can safely swim), it must have been soon found necessary to establish one universal mode of calculating the tonnage of merchant-shipping, depending on certain fixed and definite measurements of the hull. A fixed rule, strictly enforced by law, has consequently been adopted by all maritime nations for this purpose. Upon the principles recognised in framing these rules depends, in a great measure, the preponderance of good or bad qualities in the ships themselves, the body of shipowners in general being found unequal to the temptation of sacrificing the prospective safety, and the weatherly qualities, of their ships to the present sure gain arising from a low rate of register tonnage, when this can be compassed by any peculiarity of build, however extravagant. Legislation on this subject requires, therefore, to be conducted with the utmost caution and circumspection, an irreparable injury having been already done to the merchant-shipping of this country from the erroneous principles on which the measurement for tonnage used to be made.

Tonnage used for fiscal and commercial purposes.

Not only are all dues and customs levied according to tonnage, but ships are also built, bought, and sold for a certain price per ton of their admeasurement; and by the conditions of Lloyd's classification-list of shipping, they must be timbered and fastened, and must have their anchors, cables, and boats, all in proportion to the same datum. The *tonnage* of a ship, therefore, in so far as these considerations are involved, is virtually assumed to be a correct representation of her *size*.

The true principles on which tonnage should be computed.

Mr Moorsom, surveyor-general for tonnage.

On scales of displacement.

The true principles upon which the register tonnage of shipping should be computed appear to be the following:—1st, It should afford a practically correct measurement of all space eligible for stowage or passenger accommodation; 2d, The measurements and dimensions involved should be such, both as regards their number and position, as to effectually prevent even our most ingenious builders from escaping the due influence of the rules, whatever form or dimensions of vessel may be resorted to; and, 3d, It should be such as to ensure the dues levied being justly proportional for all classes of vessels. The question has been raised whether the legal tonnage of a ship should not represent numerically the commercial tons actually carried either of measurement or dead-weight cargoes, or both of them, rather than merely express, as at present, the relative capacity of ships. On this subject it was remarked by Mr G. Moorsom, surveyor-general for tonnage to the Board of Trade, at a meeting of the Institution of Naval Architects (as reported in the *Mechanic's Magazine* of 6th April 1860), "that the preservation of the expression of the present aggregate tonnage of the kingdom has been the *sine quâ non* with all the public commissions on the question, and is upheld also by the shipping community, as constituting a fairer standard of capacity, under general circumstances, than the estimated cargoes carried, whether of measurement or weight, which must necessarily vary with the ever-varying circumstances of longer or shorter voyages—to say nothing of the acknowledged almost impossibility of satisfactorily arriving, by any general rule, at the proper positions of the load and light draughts of water, on which the calculation of the weights carried solely depends." In regard to the question of weight-cargoes, Mr Moorsom observed that "parties were agitating as to the desirableness of placing a scale of tonnage (or displacement) on a ship certificate of registry, to show the weight of cargo carried at different lines of flotation, for the convenience of ship owners, brokers, and masters. He questioned, however, if the utility of that object was at all commensurate with the labour and difficulty of its production, and he had yet to learn that the parties themselves, for whose interest it was proposed, desired such a document. But, if needed, it could be furnished to the ship owner or broker by any respectable builder or surveyor of shipping, and ought not to be prepared at the public expense. It would require ten or twelve practised draughtsmen for a period of nine or ten years to prepare such scales for the existing commercial navy, and two or three others in addition for the ships annually building. Tables had been prepared at the Board of Trade by which it appeared that the weights due to one inch of immersion at the two different draughts of the load and the light lines varied, on an average, to the extent of about 10 per cent. only, so that, for all commercial purposes, it would be sufficient to know what weight of cargo corresponded to an inch of depression."

Old rule for tonnage, called "Builders' Old Measurement."

Until January 1836, the rule for computing the tonnage of ships was as follows:—The length was taken on a straight line along the rabbet of the keel of the ship, from the back of the main sternpost to a perpendicular line from the fore part of the main stem under the bowsprit. The breadth was taken from the outside of the outside plank in the broadest part of the ship, either above or below the main wales, exclusively of all manner of doubling planks that might be wrought upon the sides of the ship. If the ship to be measured was afloat, a plumb-line was dropped over the stern, and the distance between such line and the after part of the stern-post, at the load water-mark, was measured; then was taken the length from the top of this plumb-line, in a direction parallel with the water, to a perpendicular immediately over the load water-mark, at the fore part of the main stem. Subtracting from this length the before-mentioned distance between the plumb-line and the after part of the stern-post, the remainder was reckoned to be the ship's extreme length, from which three inches were deducted for every foot of the load draught of water. With the dimensions thus obtained, the rule then was:—"From the length taken in either of the ways above mentioned, subtract three-fifths of the breadth taken as above; the remainder is esteemed the just length of the keel to find the tonnage; then multiply this length by the breadth, and that product by half the breadth, and dividing by 94, the quotient is deemed the true contents of the tonnage."

This rule (called "builders' old measurement," or when contracted, B.O.M.) is still much in vogue as a guide for the purchase and sale of ships. It is evident that the tonnage as determined by it was intended to express the size or bulk of the ship, the half-breadth being an assumed equivalent for a mean depth. The evils which arose out of this assumption were very great. As the depth was not at all involved, it might be increased to any extent without increasing the tonnage; while, on the contrary, as the square of the breadth was involved, an undue preponderance was given to this dimension, and it became necessary, on the part of shipowners, to restrict it within the least possible limits. The effect of such a law was obvious. The British merchant ships, in order to profit by its inconsistencies, were built exceedingly narrow and deep in proportion to the length, so that, according to parliamentary returns, we find, on an average, the mercantile navy would carry a third more weight than its legally registered tonnage. In fact, the ships became little more than oblong boxes, most dangerous as sea-boats, and, from their want of stability, not capable of carrying sufficient sail to insure their safety on lee shores. Hence, after every gale of wind, the leeward coasts were covered with their wrecks; and hence Lloyd's books registered annually the average loss of six ships in four days. This tonnage law, as we have said, was happily altered in January 1836, when the following rule for calculating the tonnage of vessels was substituted for it:—

Tonnage law of 1836.

"The tonnage of every ship or vessel required by law to be registered shall, previously to her being registered, be measured and ascertained while her hold is clear, and according to the following rule: (that is to say), divide the length of the upper deck between the after part of the stem and the fore part of the sternpost into six equal parts. Depths—at the foremost, the middle, and the aftermost of those points of division, measure in feet and decimal parts of a foot the depths from the under side of the upper deck to the ceiling at the limber-strake. In the case of a break in the upper deck, the depths are to be measured from a line stretched in a continuation of the deck. Breadths—divide each of those three depths into five equal parts, and measure the inside breadths at the following points: *videlicet*, at one-fifth and four-fifths from the upper deck to the foremost and aftermost depths, and at two-fifths and four-fifths from the upper deck of the midship depth. Length—at half the midship depth measure the length of the vessel from the after part of the stem to the fore part of the sternpost; then to twice the midship depth add the foremost and the aftermost depths for the sum of the depths; add together the upper and lower breadths at the foremost division, three times the upper breadth, and the lower breadth at the midship division, and the upper and twice the lower breadth at the after division, for the sum of the breadths; then multiply the sum of the depths by the sum of the breadths, and this product by the length, and divide the final product by 3500, which will give the number of tons for register. If the vessel have a poop or half-deck, or a break in the upper deck, measure the inside mean length, breadth, and height, of such part thereof as may be included within the bulkhead; multiply these three measurements together, and dividing the product by 92·4, the quotient will be the number of tons to be added to the result as above found. In order to ascertain the tonnage of open vessels, the depths are to be measured from the upper edge of the upper strake."

Mode of ascertaining the Tonnage of Steam-Vessels.

"In each of the several rules hereinbefore prescribed, when applied for the purpose of ascertaining the tonnage of any ship or vessel propelled by steam, the tonnage due to the cubical contents of the engine-room shall be deducted from the total tonnage of the vessel, as determined by either of the rules aforesaid, and the remainder shall be deemed the true register tonnage of the said ship or vessel. The tonnage due to the cubical contents of the engine-room shall be determined in the following manner: that is to say, measure the inside length of the engine-room in feet and decimal parts of a foot, from the foremost to the aftermost bulkhead; then multiply the said length by the depth of ship or vessel at the midship division, as aforesaid, and the product by the inside breadth at the same division, at two-fifths of the depth from the deck, taken as aforesaid, and divide the last product by 92·4, and the quotient shall be deemed the tonnage due to the cubical contents of the engine-room."

For ascertaining the Tonnage of Vessels when laden.

"And be it further enacted, that for the purpose of ascertaining the tonnage of all such ships, whether belonging to the United Kingdom or otherwise, as there shall be occasion to measure while their cargoes are on board, the following rule shall be observed and is hereby established: that is to say, measure, first, the length on the upper deck, between the after part of the stem and the fore part of the sternpost; secondly, the inside breadth on the under side of the upper deck, at the middle point of the length; and, thirdly, the depth from the under side of the upper deck, down the pump-well, to the skin; multiply these three dimensions together, and divide the product by 130, and the quotient will be the amount of register tonnage of those ships."

Objections to it.

It was soon found that this rule was somewhat partial in its operation in different classes of vessels, and that it could be, within certain limits, evaded by an ingenious builder; but still the evasions were not so destructive to the good qualities of ships as those which were commonly practised during the continuance of the old law.

Difficulty of framing a perfect tonnage law.

It is exceedingly difficult, probably even impossible, to frame a rule for computing the tonnage which shall be at once of practical application, and yet not have in some degree the effect of restricting improvement in the qualities of merchant-ships. It is difficult to induce a man to forego a constant and positive gain for one that is only prospective and uncertain. We have seen that the obstacles which oppose themselves to correctly and satisfactorily determining either the light or the load draughts of water, are sufficient to prevent the difference between the light and load displacements from being taken to represent the tonnage. This is, however, the only correct measure of a ship's power to carry cargo; the difference being, of course, exactly equal in weight to the cargo which either has caused or may cause it. All other quantities which can be taken as measures of that power are little more than assumptions, and whether they represent the external dimensions of a ship, or her internal capacity, they scarcely give an approximation even to the power which she may possess of carrying burthen; while, in either of the above cases, the fact that these quantities must be determined by measurements at fixed measuring places, affords opportunity for evasion, and indeed invites it. For if, by any arrangement of the dimensions, or by any peculiarity of the shape, a ship can be enabled to carry a greater burthen than her registered tonnage, the freight of that greater burthen is a premium which is offered to that one proportion between her dimensions, or that one peculiar form for her body, and a restriction is, to a certain extent, placed upon improvement; because the shipowner will content himself with the best ships that he can obtain possessing the advantages of those dimensions or of that form.

The rule last quoted for computing the tonnage assumes it to be the space for stowage, and the internal capacity of the vessel is calculated in order to determine it. As there are necessarily fixed measuring places, the rule may, as we have said, be evaded by a certain build. Its phraseology might also be easily evaded by building accommodations on deck, which would not come within the meaning of the terms that are used in it—"poop," "half-deck," or "break in the deck." Under its operation, vessels might also be advantageously built of very small register tonnage to carry cargoes of heavy goods; for which purpose they should be of the lightest materials, but with very large scantlings, that the internal capacity may bear but a small proportion to the load displacement of the vessel. This rule, however, was far less injurious to the mercantile navy of Great Britain than that which had preceded it.

New tonnage law of 1854; its advantages.

The present rule for tonnage was introduced in the year 1854, constituting one of the most important sections of the Merchant Shipping Act of that year. It is universally admitted to be a vast improvement upon all that had gone before, and indeed to be one of the greatest benefits ever conferred by the Legislature upon naval architecture, tending, as it does, to advance the character of the merchant marine of this country. The builder is at length free to construct his ship in the way he thinks best for the requirements of her particular trade; the very impossibility of evading the law by any alterations in the dimensions or form making shipowners content to have good trustworthy ships, in place of the dangerous abortions of twenty years since. It is found that the vessels built since the new law came into operation have an average length of 5 times their breadth, in place of 3½ times as formerly, and that their average depth has decreased from above ⅘ths of the breadth to ⅔ds ditto, their speed and weatherly qualities being improved in like proportion.

The following is the present law for measurement of tonnage (introduced 1854):—

Tonnage deck.

"Throughout the following rules, the tonnage-deck shall be taken to be the upper-deck in ships which have less than three decks, and to be the second deck from below in all other ships; and, in carrying such rules into effect, all measurements shall be taken in feet, and fractions of feet, and all fractions of feet shall be expressed in decimals.

Rule I., for ships where the hold is clear.

"The tonnage of every ship to be registered, with the exceptions mentioned in the next section, shall, previously to her being registered, be ascertained by the following rule, hereinafter called Rule I.; and the tonnage of every ship to which such rule can be applied, whether she is about to be registered or not, shall be ascertained by the same rule.

"(1.) Measure the LENGTH of the ship in a straight line above the upper side of the tonnage-deck from the inside of the inner plank (average thickness) at the side of the stem, to the inside of the midship stern timber or plank there, as the case may be (average thickness), deducting from this length what is due to the rake of the bow in the thickness of the deck, and what is due to the rake of the stern timber in the thickness of the deck, and also what is due to the rake of the stern timber in one-third of the round of the beam; divide the length so taken into the number of equal parts required by the following table, according to the class in such table to which the ship belongs.

Table of classes.

"TABLE.—Class 1. Ships of which the tonnage-deck is (according to the above measurement) 50 feet long or under, into 4 equal parts. 2. Ships of which the tonnage-deck is (according to the above measurement) above 50 feet long, and not exceeding 120, into 6 equal parts. 3. Ships of which the tonnage-deck is (according to the above measurement) above 120 feet long, and not exceeding 180, into 8 equal parts. 4. Ships of which the tonnage-deck is (according to the above measurement) above 180 feet long, and not exceeding 225, into 10 equal parts. 5. Ships of which the tonnage-deck is (according to the above measurement) above 225 feet, into 12 equal parts.

Transverse areas.

"(2.) Then, the hold being first sufficiently cleared to admit of the required depths and breadths being properly taken, find the TRANSVERSE AREA of such ship, at each point of division of the length, as follows:—Measure the depth at each point of division from a point at a distance of one-third of the round of the beam below such deck; or, in case of a break, below a line stretched in continuation thereof, to the upper side of the floor-timber at the inside of the limber-strake, after deducting the average thickness of the ceiling which is between the bilge-planks and limber-strake; then, if the depth at the midship division of the length do not exceed 16 feet, divide each depth into four equal parts; then measure the inside horizontal breadths at each of the three points of division, and also at the upper and lower points of the depth, extending each measurement to the average thickness of that part of the ceiling which is between the points of measurement; number these breadths from above (*i.e.*, number the upper breadth *one*, and so on down to the lowest breadth); multiply the second and fourth by 4, and the third by 2; add these products together, and to the sum add the first breadth and the fifth; multiply the quantity thus obtained by one-third of the common interval between the breadths, and the product shall be deemed the transverse area; but if the midship depth exceed 16 feet, divide each depth into 6 equal parts instead of 4, and measure, as before directed, the horizontal breadths at the five points of division, and also at the upper and lower points of the depth; number them from above as before; multiply the second, fourth, and sixth by 4, and the third and fifth by 2; add these products together, and to the sum add the first breadth and the seventh; multiply the quantity thus obtained by one-third of the common interval between the breadths, and the product shall be deemed the transverse area.

Computation from areas.

"(3.) Having thus ascertained the transverse area at each point of division of the length of the ship, as required by the above table, proceed to ascertain the REGISTER TONNAGE of the ship in the following manner:—Number the areas successively 1, 2, 3, &c., No. 1 being at the extreme limit of the length at the bow, and the last number at the extreme limit of the length at the stern; then, whether the length be divided according to the table into 4 or 12 parts, as in classes 1 and 5, or any intermediate number, as in classes 2, 3, and 4, multiply the second and every even-numbered area by 4, and the third and every odd-numbered area (except the first and last) by 2; add these products together, and to the sum add the first and last if they yield anything; multiply the quantity thus obtained by one-third of the common interval between the areas, and the product will be the cubical contents of the space under the tonnage-deck; divide this product by 100, and the quotient being the tonnage under the tonnage-deck shall be deemed to be the REGISTER TONNAGE of the ship, subject to the additions and deductions hereinafter mentioned.

Poop and any other closed-in space.

"(4.) If there be a break, a poop, or any other permanent closed-in space on the upper-deck, available for cargo or stores, or for the berthing or accommodation of passengers or crew, the tonnage of such space shall be ascertained as follows:—Measure the internal mean length of such space in feet, and divide it into two equal parts; measure at the middle of its height three inside breadths—namely, one at each end, and the other at the middle of the length; then to the sum of the end-breadths add four times the middle breadth, and multiply the whole sum by one-third of the common interval between the breadths, the product will give the mean horizontal area of such space; then measure the mean height, and multiply by it the mean horizontal area; divide the product by 100, and the quotient shall be deemed to be the tonnage of such space, and shall be added to the tonnage under the tonnage-deck, ascertained as aforesaid, subject to the following provisos:—*First*, That nothing shall be added for a closed-in space solely appropriated to the berthing of the crew, unless such space exceeds one-twentieth of the remaining tonnage of the ship,—and in case of such excess, the excess only shall be added; and, *secondly*, that nothing shall be added in respect of any building erected for the shelter of deck-passengers and approved by the Board of Trade.

In case of two or more decks.

"(5.) If the ship has a third deck, commonly called a spar-deck, the tonnage of the space between it and the tonnage-deck shall be ascertained as follows:—Measure in feet the inside length of the space at the middle of its height from the plank at the side of the stem to the lining on the timbers at the stern, and divide the length into the same number of equal parts into which the length of the tonnage-deck is divided as above directed; measure (also at the middle of its height) the inside breadth of the space at each of the points of division, also the breadth of the stem and the breadth at the stern; number them successively, 1, 2, 3, &c., commencing at the stem; multiply the second, and all the other even-numbered breadths by four, and the third and all the other odd-numbered breadths (except the first and last) by two; to the sum of these products add the first and last breadths; multiply the whole sum by one-third of the common interval between the breadths, and the result will give, in superficial feet, the mean horizontal area of such space; measure the mean height of such space, and multiply by it the mean horizontal area, and the product will be the cubical contents of the space; divide this product by 100, and the quotient shall be deemed to be the tonnage of such space, and shall be added to the other tonnage of the ship, ascertained as aforesaid; and if the ship has more than three decks, the tonnage of each space between decks above the tonnage-deck shall be severally ascertained in manner above described, and shall be added to the tonnage of the ship ascertained as aforesaid.

Allowance for engine-room in steamers.

To be rateable in ordinary steamers.

May be measured where the space is unusually large or small.

"In every ship propelled by steam, or other power requiring engine-room, an allowance shall be made for the space occupied by the propelling power, and the amount so allowed shall be deducted from the gross tonnage of the ship, ascertained as aforesaid, and the remainder shall be deemed to be the register tonnage of such ship; and such deduction shall be estimated as follows (that is to say): (*a*) As regards ships propelled by paddle-wheels, in which the tonnage of the space solely occupied by and necessary for the proper working of the boilers and machinery is above 20 per cent. of the gross tonnage of the ship, such deduction shall be 37 hundredths of such gross tonnage; and in ships propelled by screws, in which the tonnage of such space is above 13 per cent. and under 20 per cent. of such gross tonnage, such deduction shall be 32 hundredths of such gross tonnage. (*b*) As regards all other ships, the deduction shall, if the Commissioners of Customs and the owner both agree thereto, be estimated in the same manner, but either they or he may, in their or his discretion, require the space to be measured, and the deduction estimated accordingly; and whenever such measurement is so required, the deduction shall consist of the tonnage of the space actually occupied by, or required to be enclosed for the proper working of the boilers and machinery, with the addition in the case of ships propelled by paddle-wheels of one-half, and in the case of ships propelled by screws of three-fourths, of the tonnage of such space. In the case of screw-steamers, the contents of the shaft-trunk shall be added to and deemed to form part of such space.

Tonnage, &c., to be carved on main beam.

"In every registered British ship the number denoting the register tonnage, ascertained as hereinbefore directed, and the number of her certificate of registry, shall be deeply carved, or otherwise permanently marked, on her main beam, and shall be so continued; and if it at any time cease to be so continued, such ship shall no longer be recognised as a British ship."

Practical working of the rules.

Allowance to steamers not satisfactory.

These rules have now been in operation for a period of five years, during which about 16,000 British, and a much greater number of foreign ships, have been measured by them. The experience of their operation thus afforded has proved highly satisfactory, with the single exception of the method of estimating the allowance made to steamers for their propelling power, by the plan of percentages on their gross tonnage. After explaining certain abuses under the old law, which led to the adoption of this mode of allowance, Mr Moorsom, in the paper before alluded to, stated, that "it had been found practically to admit of the intended allowance being anomalously increased by other means, and had given dissatisfaction even to the owners themselves, by its unjust action between steamer and steamer." In illustration of this, Mr Moorsom gave a paper of examples, by which it was seen that, in two paddle-ships of about the same gross tonnage and power, there could be, and frequently was, a difference in their allowances to the extent of 20 per cent.; and that in a similar case of screw-vessels, the difference was to the still greater extent of about 40 per cent. He likewise found that "the system of percentages frequently gave to large-powered coasting steamers undue allowances; to extreme-power tugs to within 1 per cent. of a negative tonnage; and to long-voyage auxiliary-power vessels, on the contrary, a less allowance than the old system." Steam-vessels seem to have gained by the new law, as regards their register tonnage, an average advantage over sailing vessels of a decrease of about 6¼ per cent., which is very unequally and unjustly distributed between steamer and steamer. To give an example, the steam-tug United States, of Cardiff, 60 horse-power, is but 4 tons register. This anomaly will probably be soon remedied, such an alteration in the law being already provided for, without further legislative interference, under the provisions of the 29th section of the Merchant Shipping Act of 1854.

Alteratio in the measurement of steamers.

The following alteration in the mode of measuring steamers for tonnage has been recently introduced, with the view of making a more equitable allowance than heretofore for the space occupied by their propelling power;—

Copy of Minute of the Board of Customs, dated 23d October 1860.

"In pursuance of the powers granted by the 29th section of 'The Merchant Shipping Act, 1854,' the Board, with the approval of the Board of Trade, direct, with a view to the more accurate and uniform application of the principle of granting a certain allowance to steamers for their propelling power, that, in lieu of the rules set forth in sec. 23 of the Merchant Shipping Act, the following rule be adopted in future, viz.:—

"Rule.—In every ship propelled by steam, or other power, requiring engine-room, an allowance of space or tonnage shall be made for the space occupied by the propelling power, and the amount so allowed shall be deducted from the gross tonnage of the ship; and such deduction shall be estimated as follows; that is to say:—

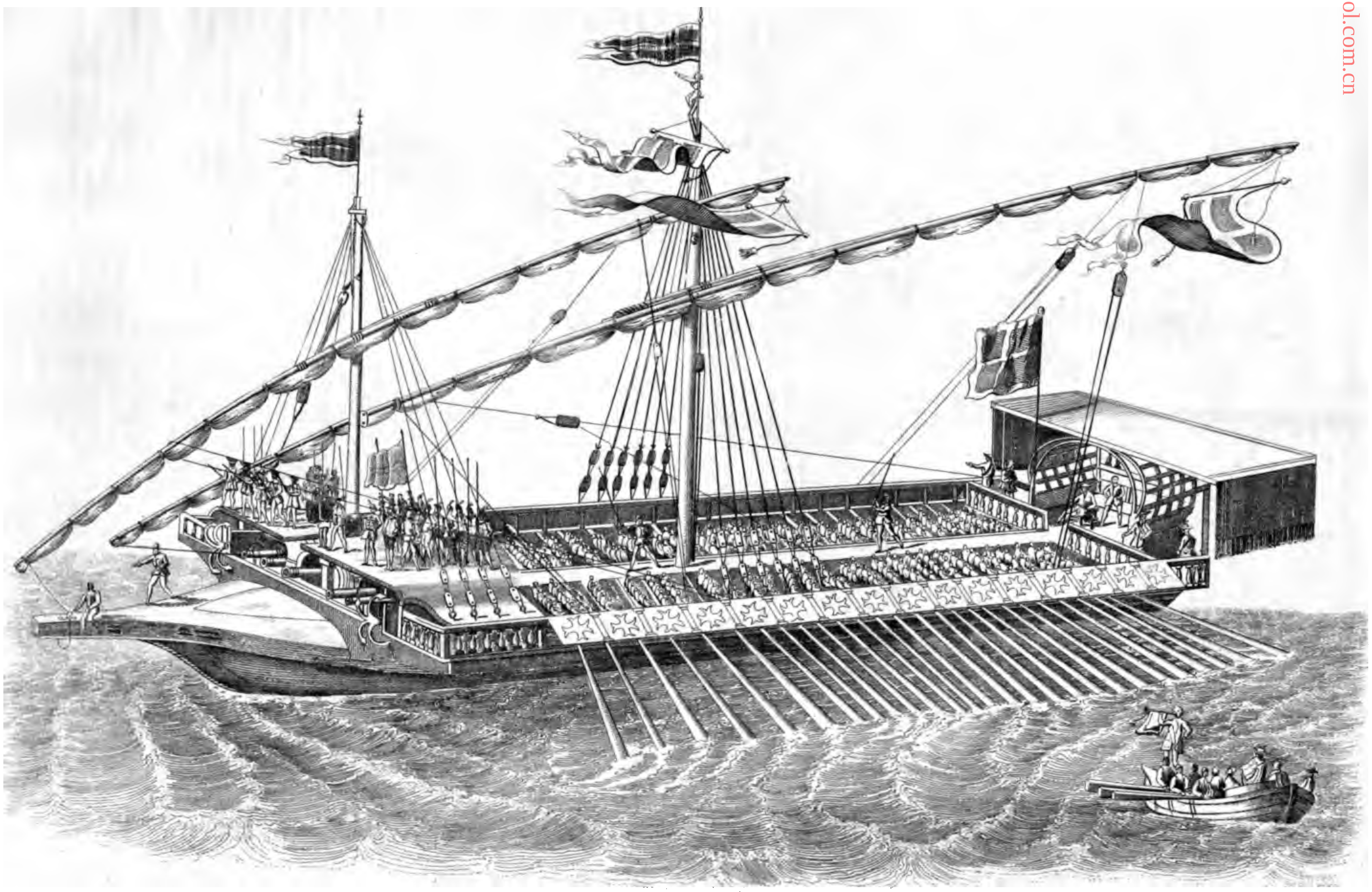
"1. Measure the mean length of the engine-room between the foremost and aftermost bulkheads, or limits of its length, excluding such parts, if any, as are not actually occupied by, or required for, the proper working of the machinery;—then measure the depth of the ship at the middle point of this length, from the ceiling at the limber strake to the upper deck in ships of three decks and under, and to the third deck, or deck above the tonnage-deck, in all other ships;—also the inside breadth of the ship clear of sponsing, if any, at the middle of the depth; multiply together these dimensions of length, depth, and breadth for the cubical contents;—divide this product by 100, and the quotient shall be deemed to be the tonnage of the engine-room, or allowance to be deducted from the gross tonnage on account of the propelling power.

"2. In the case of ships having more than three decks, the tonnage of the space or spaces betwixt decks, if any, above the third deck, which are framed in for the machinery, or for the admission of light and air, found by multiplying together the length, breadth, and depth thereof, and dividing the product by 100, shall be added to the tonnage of such space.

3. "In the case of screw-steamers, the tonnage of the shaft trunk shall be deemed to form part of, and added to, such space, and shall be ascertained by multiplying together the length, breadth, and depth of the trunk, and dividing the product by 100.

"4. In any ship in which the machinery may be fitted in separate compartments, the tonnage of each such compartment shall be measured severally in like manner, according to the above rules, and the sum of their results shall be deemed to be the tonnage of the said space."

(R. M—Y.)

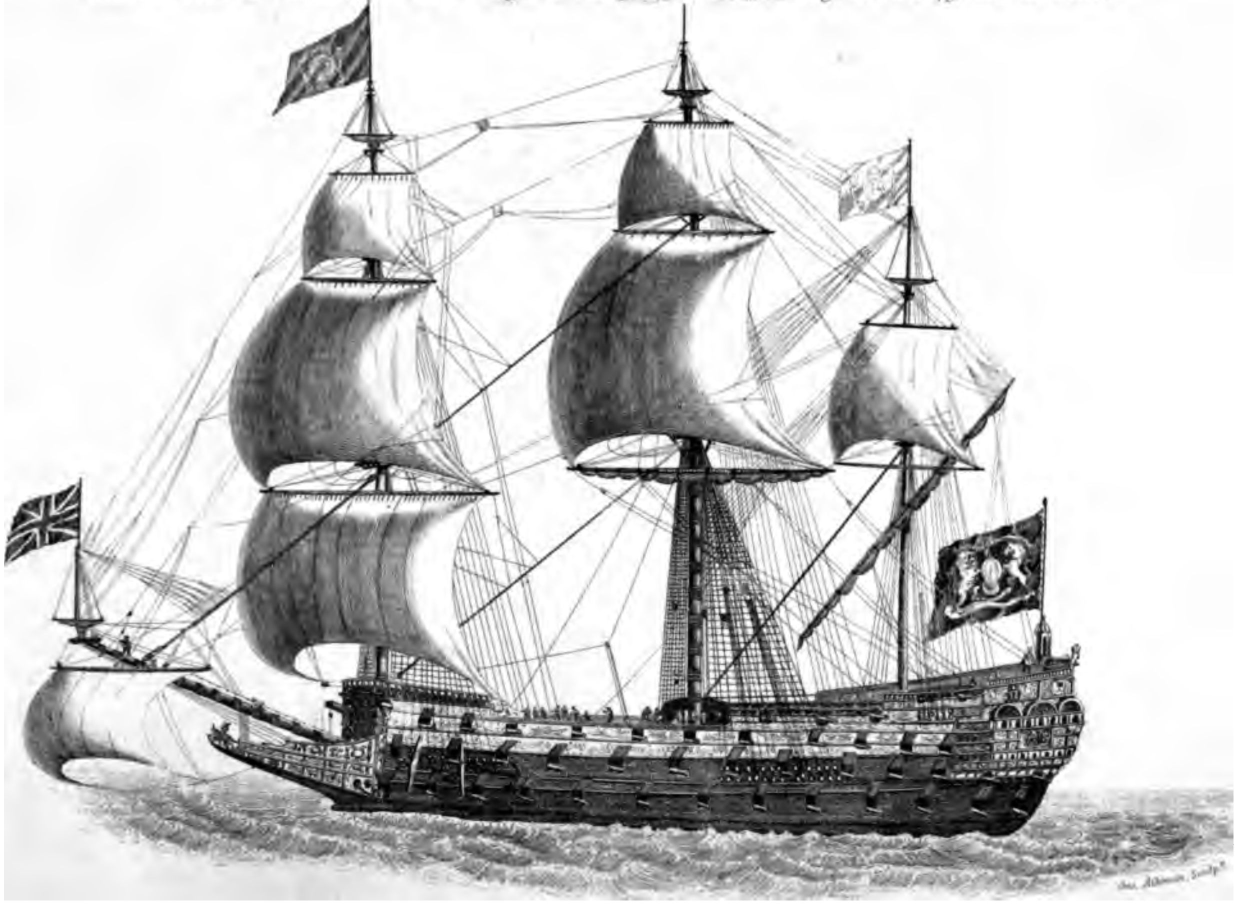


Geo. Aikman, Sculpt.

Galley of the Seventeenth Century, from Van Yk.

SHIP-BUILDING. ***PLATE II.***

The Henri Grace à Dieu, built in the reign of Henry 7th from a drawing in the Pepysian Collection.

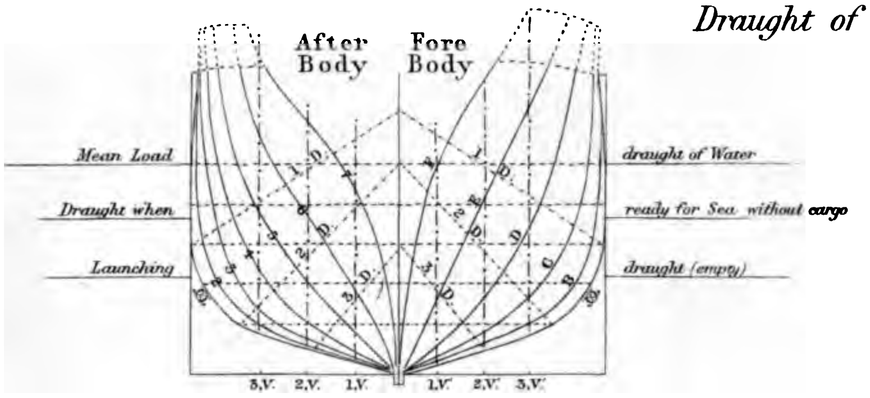


The Sovereign of the Seas, built 1637. From a Painting by Vandevelde.

Published by A. & C. Black. Edinburgh.

SH

Draught of the Wooden CLIPPER SHI

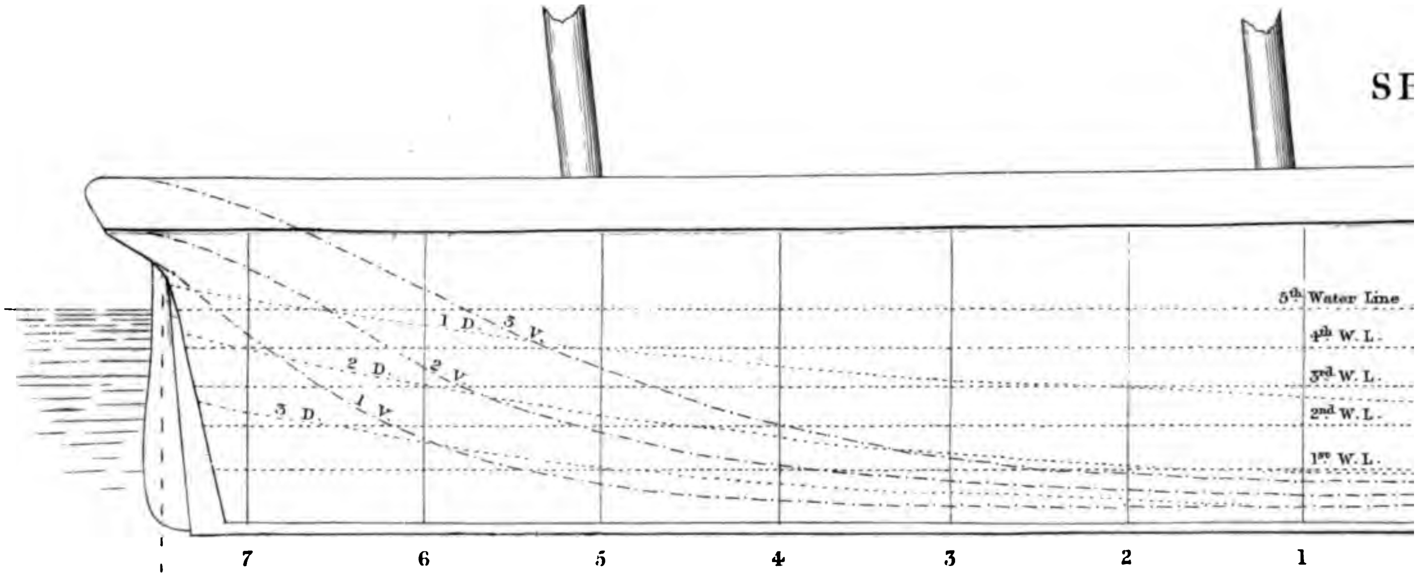


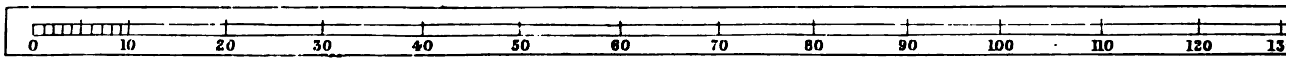
BODY PLAN

Pri

Length between
Length of Keel
Breadth Extrem
Breadth of Fran
Depth of Hold
Burthen in Tons,

SI





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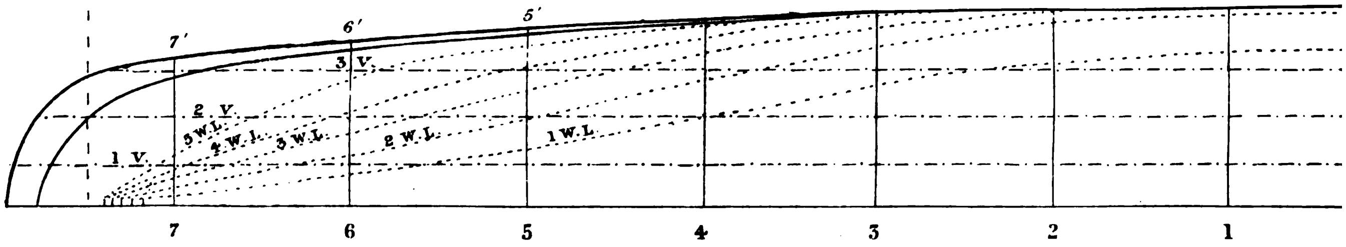
HALF B



Pub

UILDING.

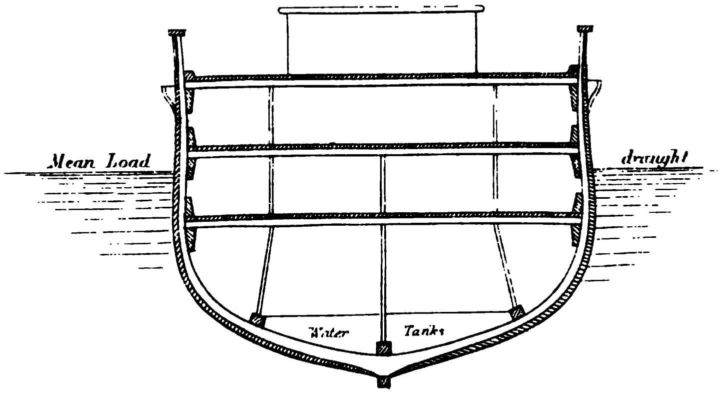
PLATE

MBERG", Built by Messʳˢ A Hall & Cº of Aberdeen.

Dimensions.

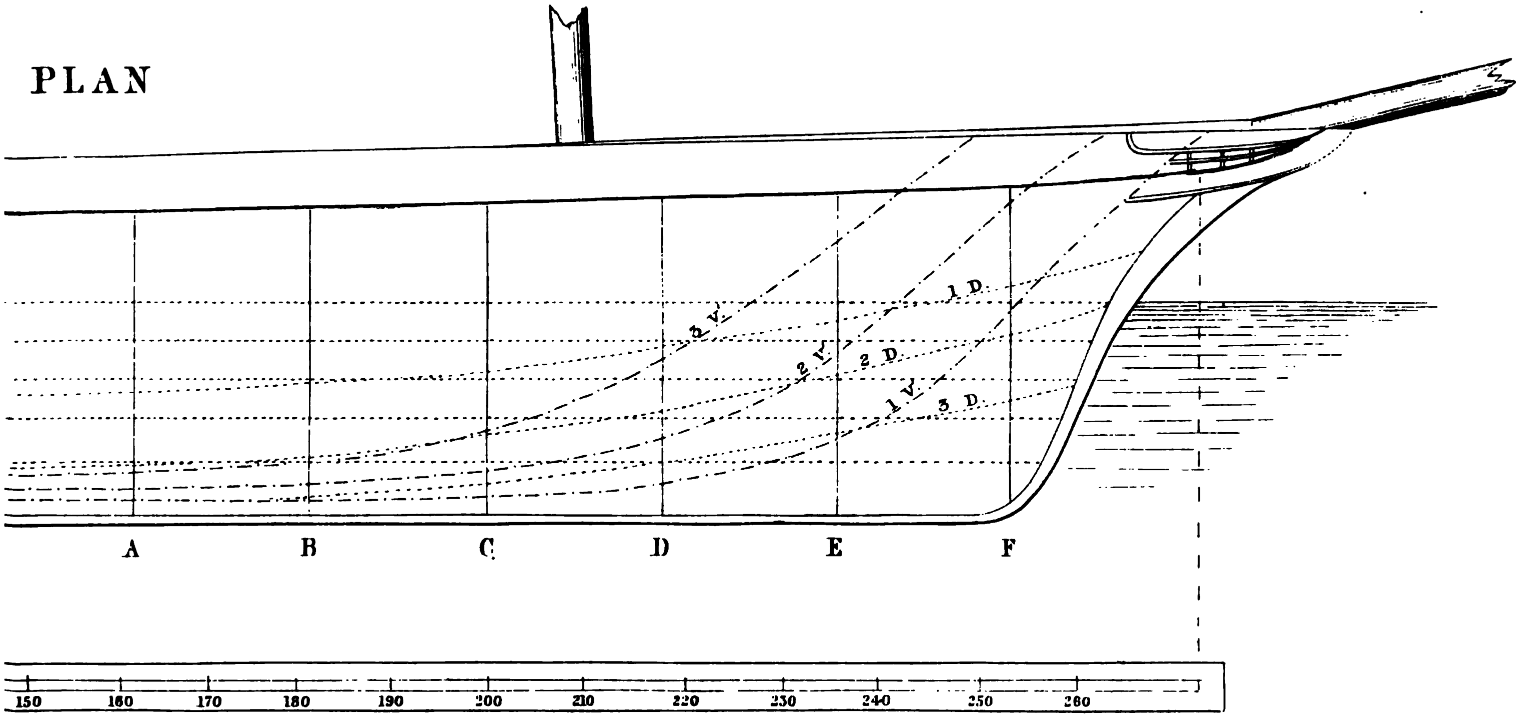
	Feet	Inˢ
iculars	262	6
	245	"
	45	"
	42	"
	29	9

Old Measurement. 2600 Tons



MIDSHIP SECTION

PLAN



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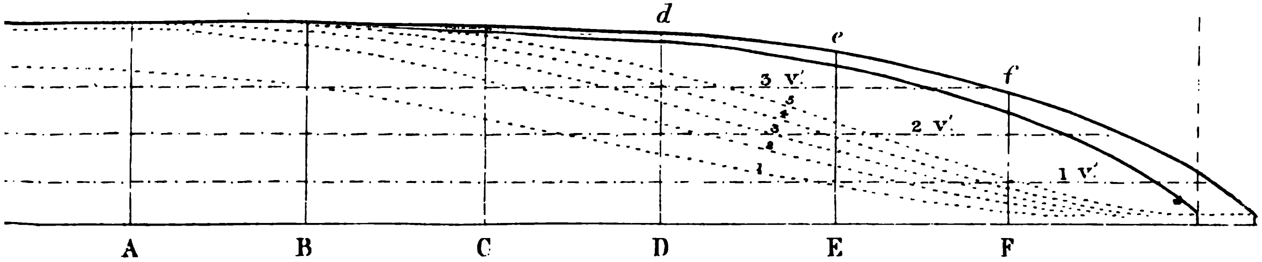
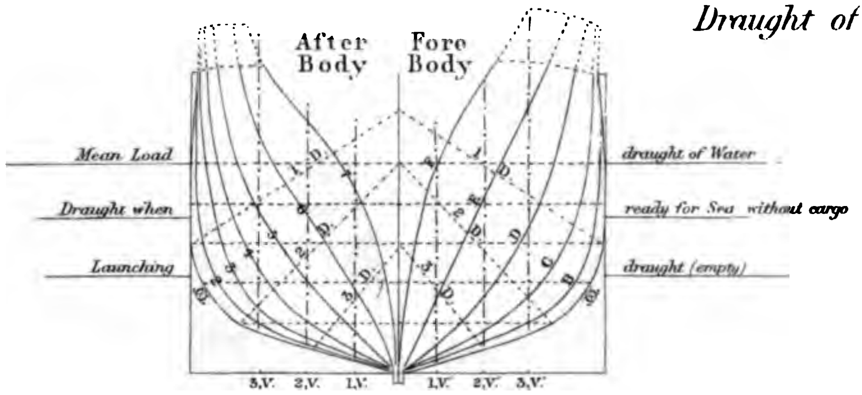


A. Black, Edinburgh.

G. Aikman sc. Edinʳ

SHIP

Draught of the Wooden CLIPPER SHIP "S



BODY PLAN

Princi

Length between the l
Length of Keel . _
Breadth Extreme
Breadth of Frame _
Depth of Hold . .
Burthen in Tons, Bui

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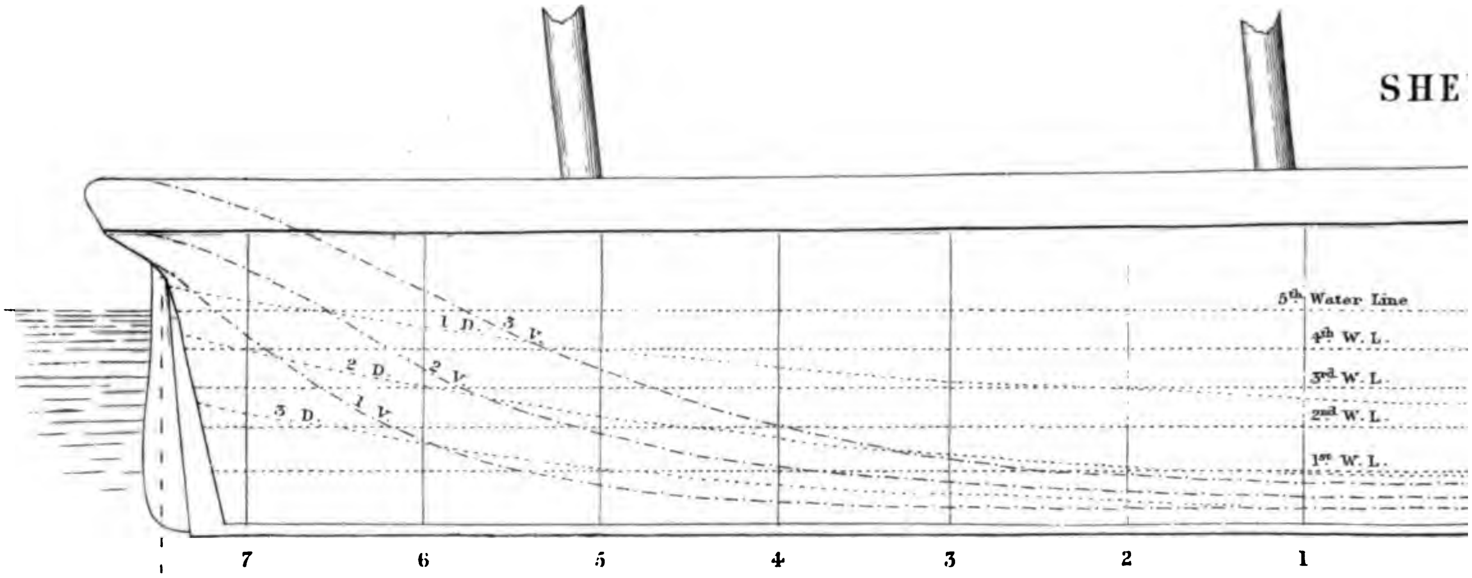
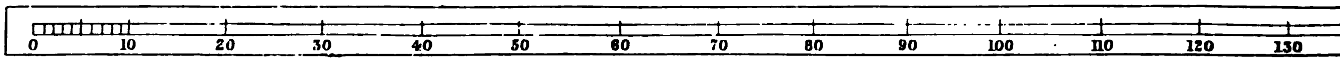
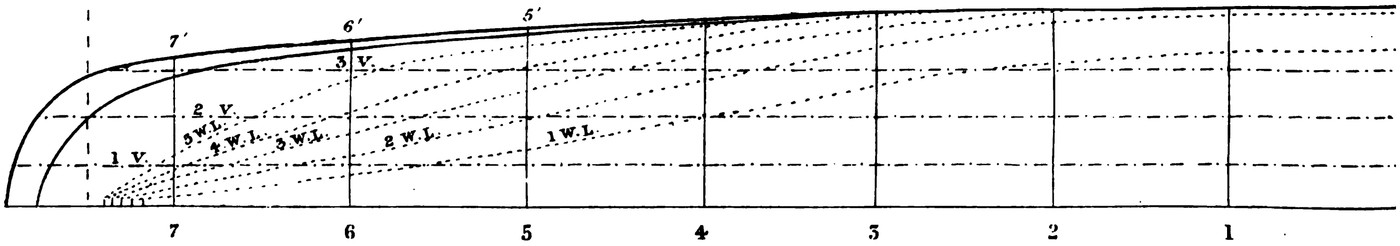




Scale

HALF BRE



Published

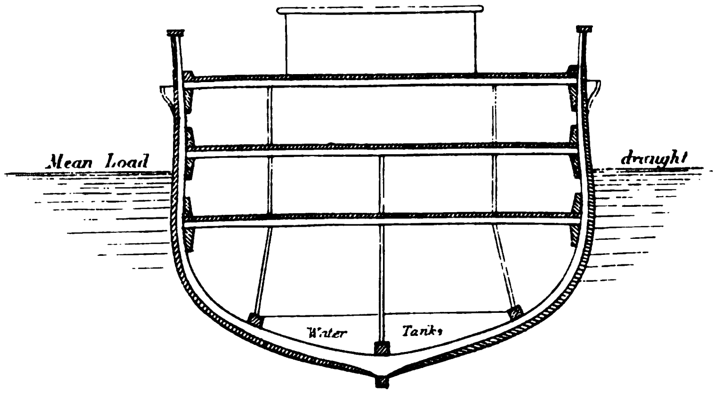
UILDING.

MBERG", Built by Mess^{rs} A Hall & C^{o} of Aberdeen.

imensions.

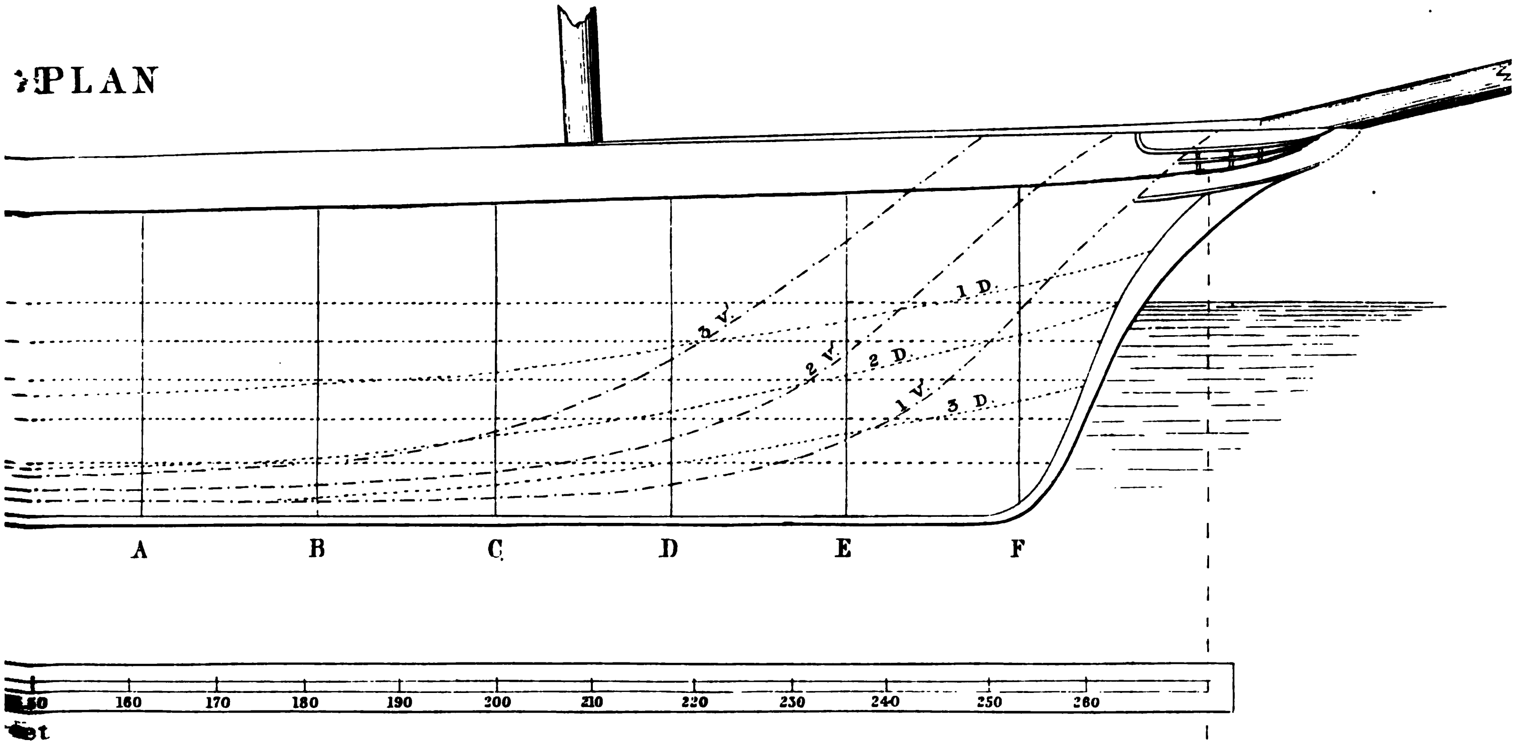
	Feet	In^{s}
iculars	262	6
	245	"
	45	"
	42	"
	29	9

ld Measurement, 2600 Tons



MIDSHIP SECTION

PLAN



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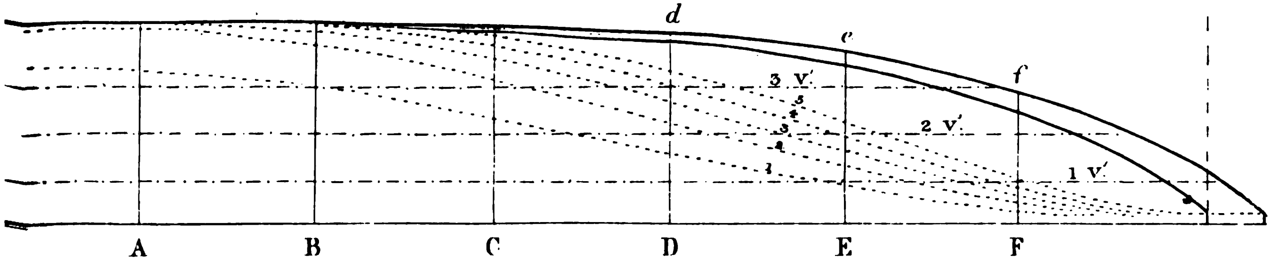


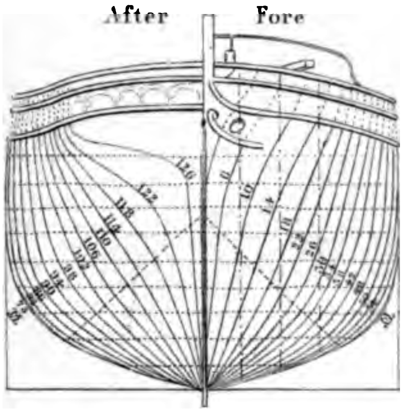
Black, Edinburgh

Allen sc Edin

SHIP BUI

DRAUGHT OF THE IRON CLIPPER SAIL

BODY PLAN

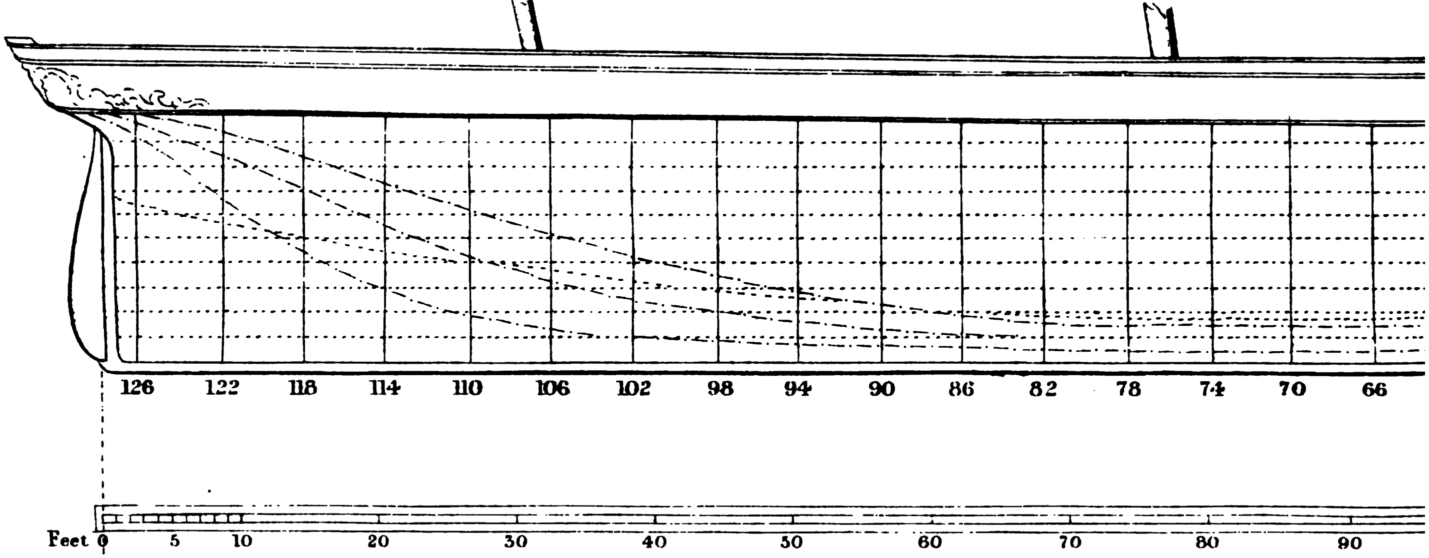


Dimensions

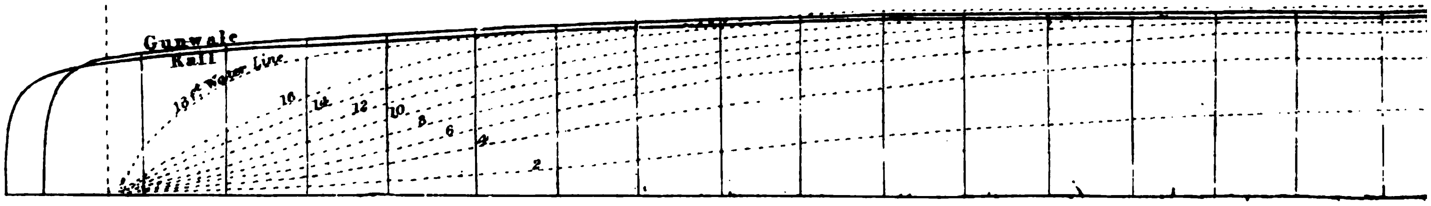
	Ft.	In.
Length between Perpendiculars	185	0
Breadth extreme	29	0
Depth in Hold	18	0

Builders, Scott & C°, Greenock.

SHEER P



HALF-BREADTH I



Published by A & C Black Ed

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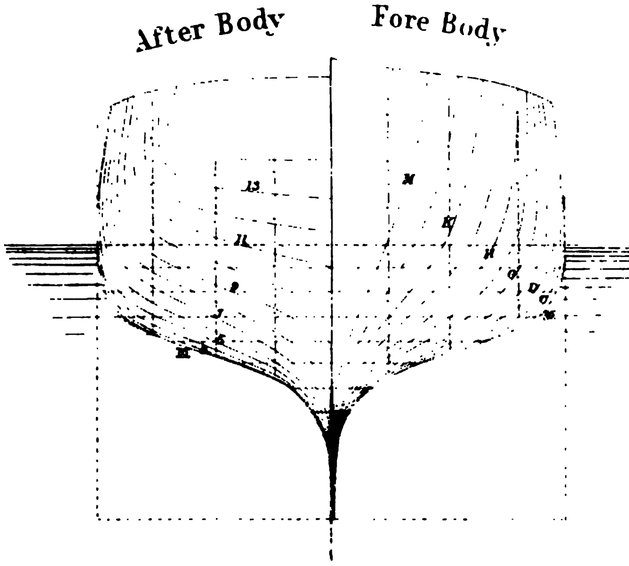
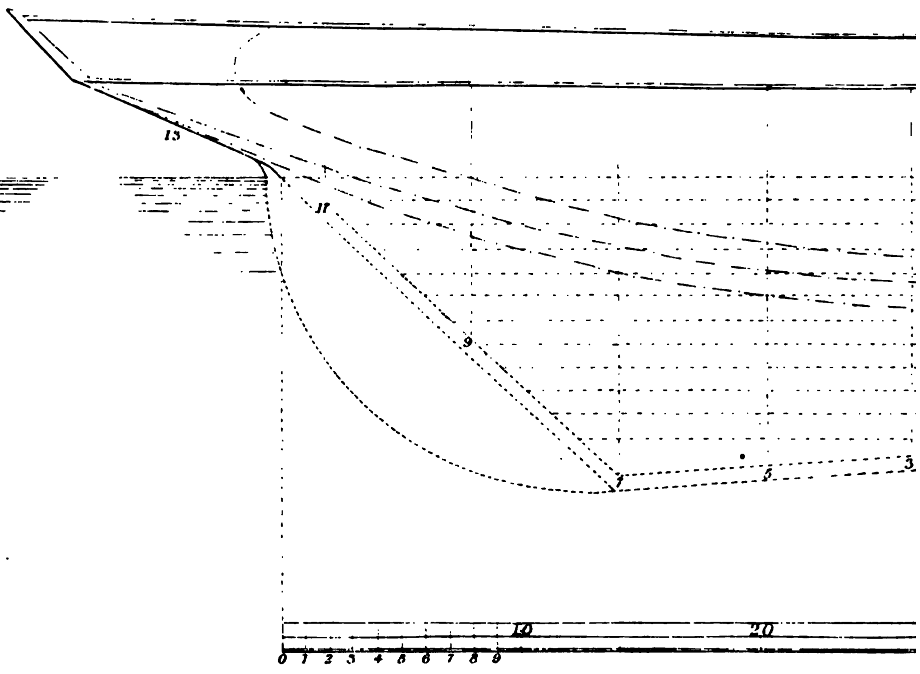
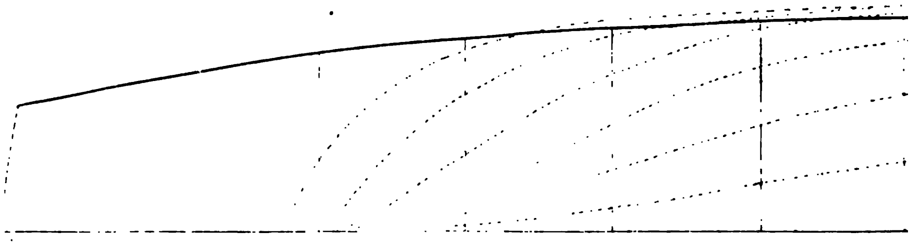




Principal Dimensions

Length in Load water line	*82' 6"*
Breadth Extreme	*19'*
Depth at the Side	*14' 6"*
Tonnage O.M.	*99 Tons*



Published l

BUILDING.

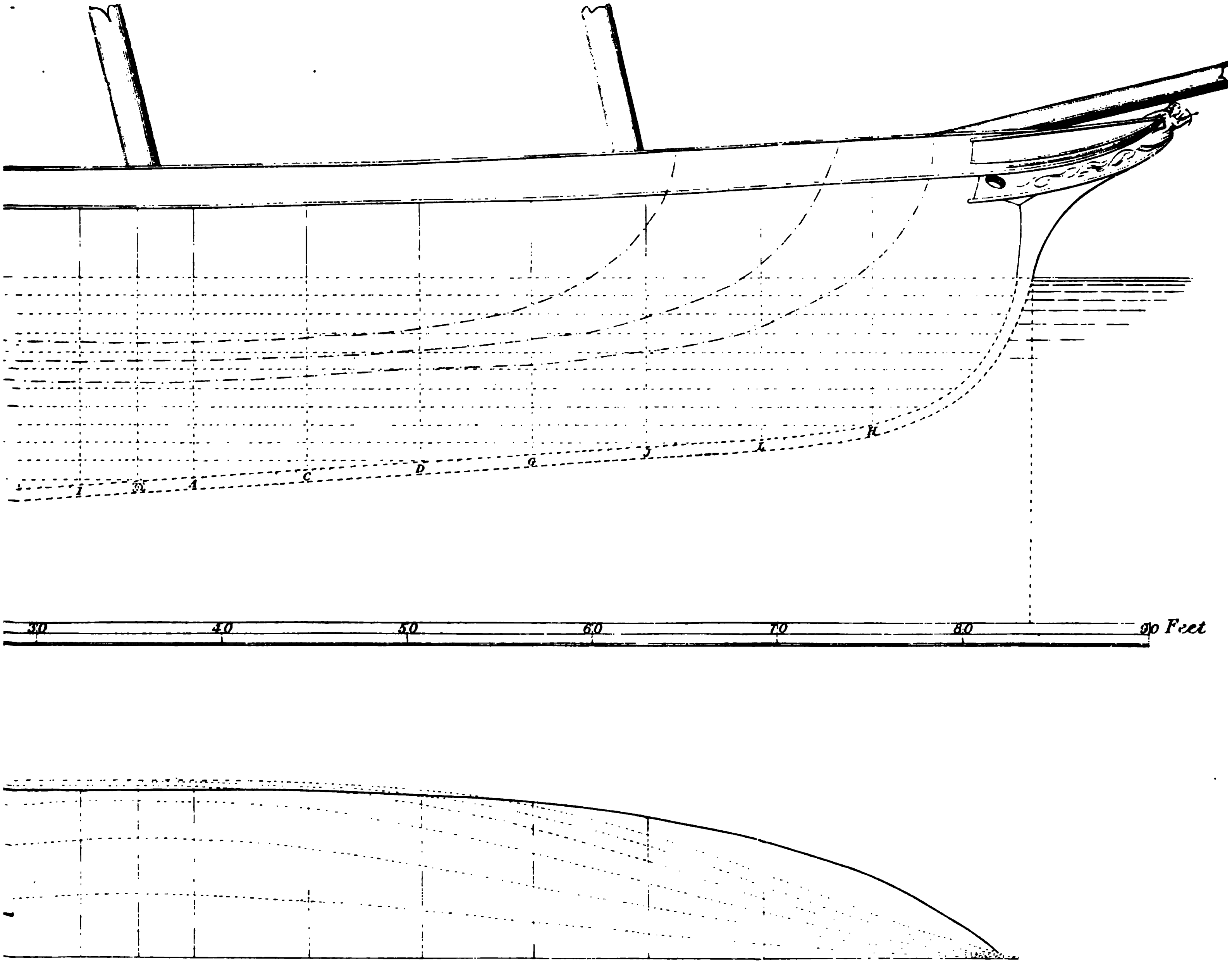
PLATE V

EMIS,

LY TITANIA)

Sailing Yacht.

Russell F.R.S.



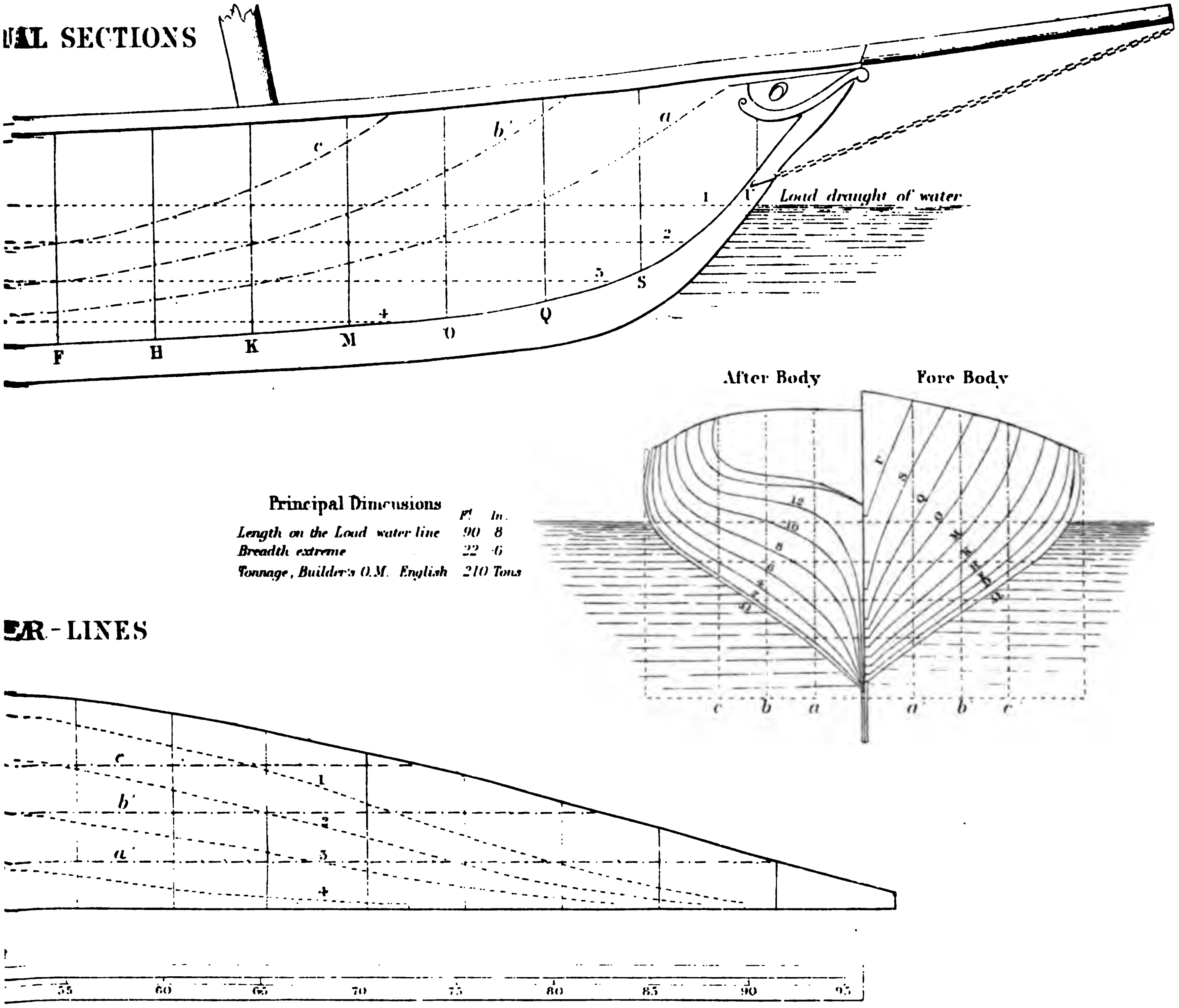
C. Black. Edinburgh.

Aikman.

ILDING.

NG-YACHT "AMERICA"

PLATE VI.



Principal Dimensions

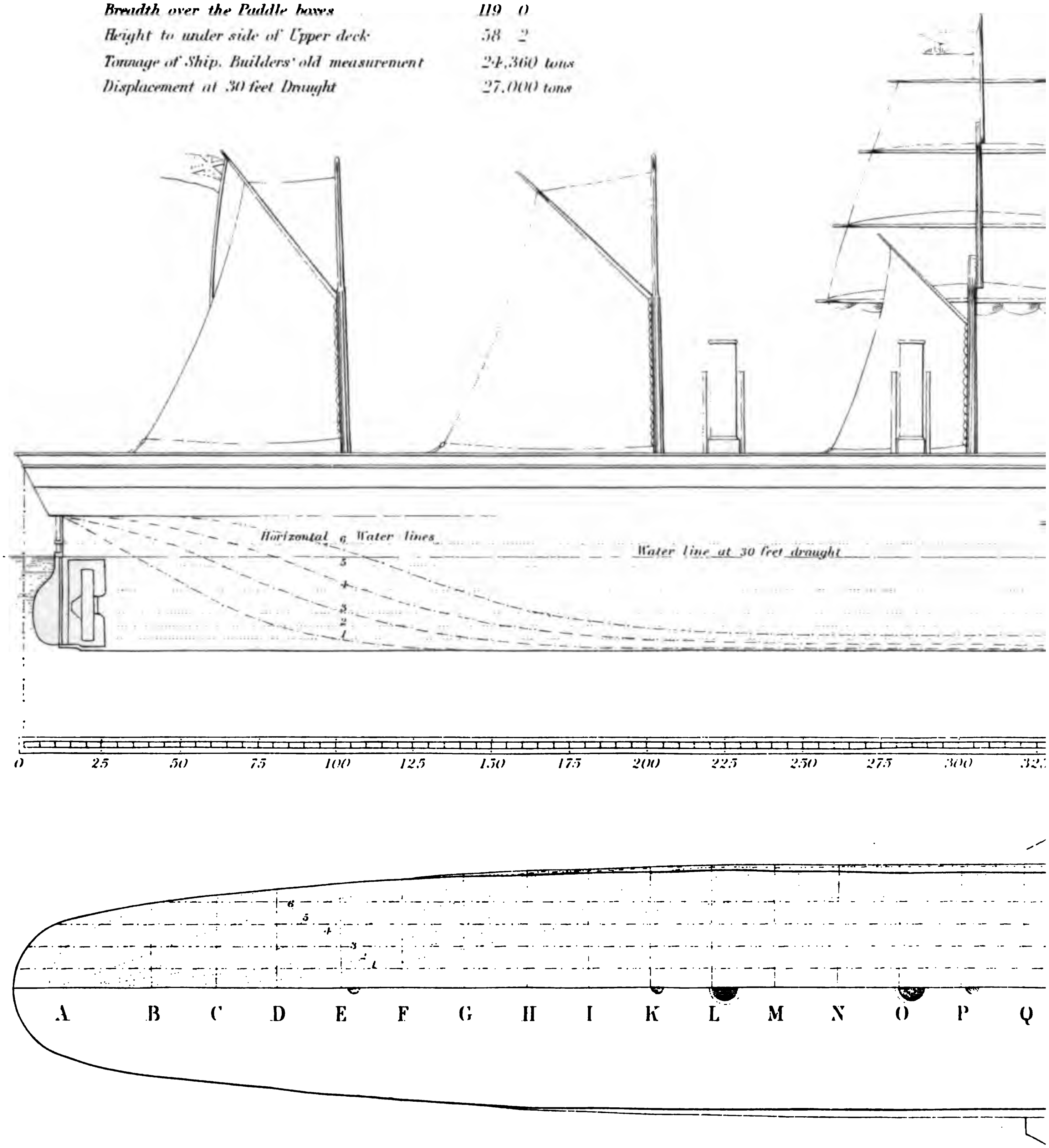
	Ft	In.
Length on the Load water line	90	8
Breadth extreme	22	6
Tonnage, Builder's O.M. English	210 Tons	

SHI

"GREAT EA

Dimensions of the Hull.

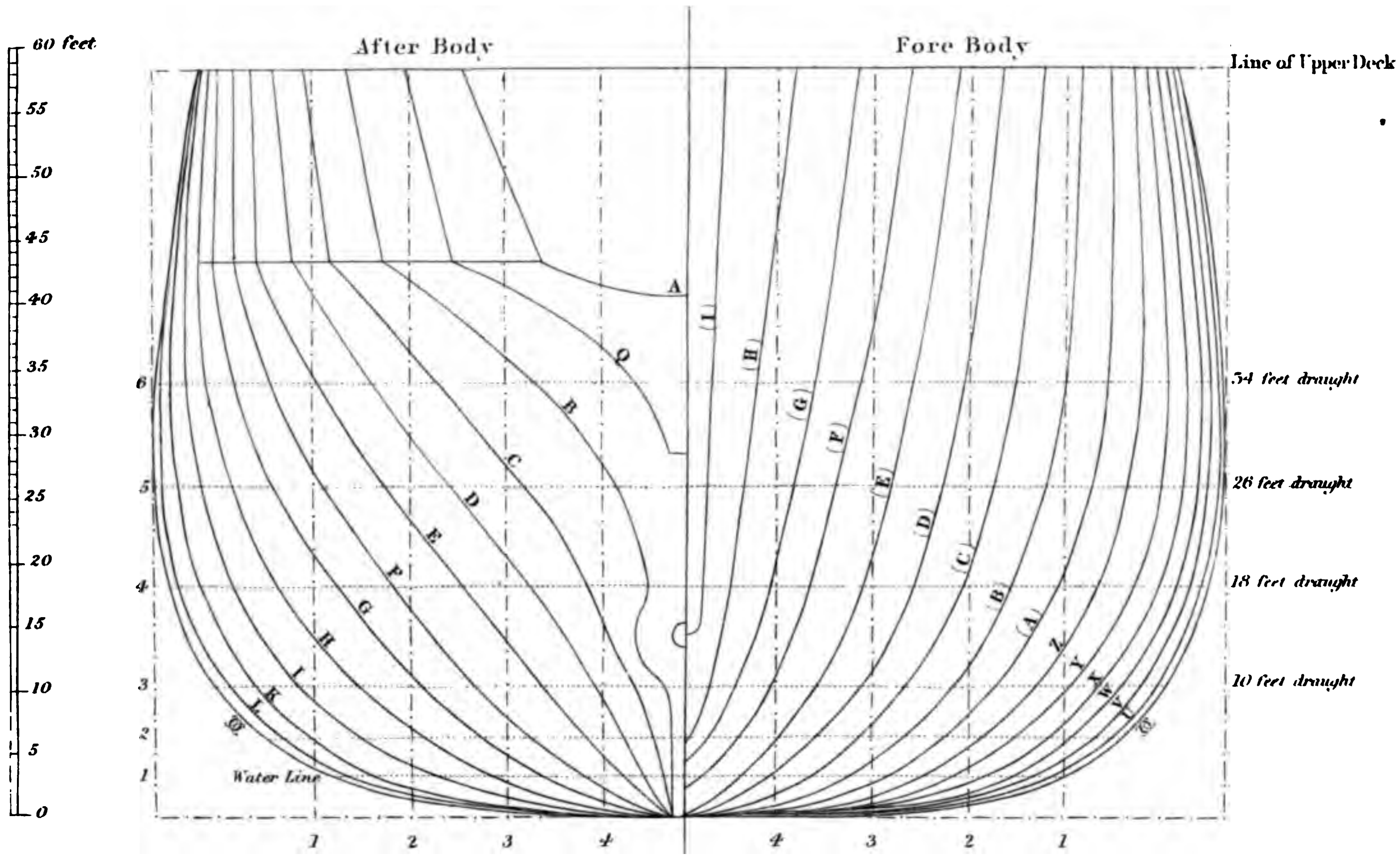
	ft.	in.
Length from centre of rudder post to stem	680	0
Length on the Upper deck	692	0
Breadth of Hull	82	6
Breadth over the Paddle boxes	119	0
Height to under side of Upper deck	58	2
Tonnage of Ship. Builders' old measurement	24,360 tons	
Displacement at 30 feet Draught	27,000 tons	



SHIP BUILDING.

PLATE IX.

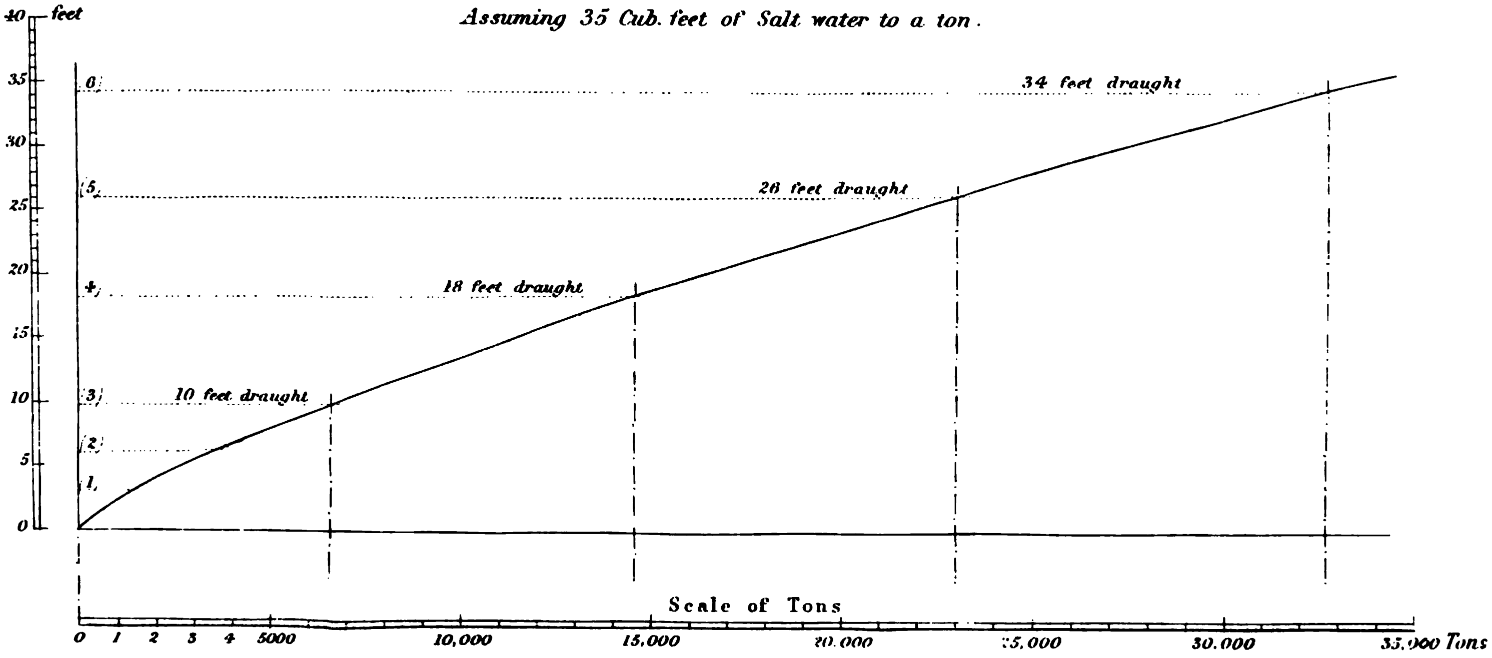
"GREAT EASTERN" STEAM SHIP.



VERTICAL SECTIONS.

SCALE OF DISPLACEMENT,

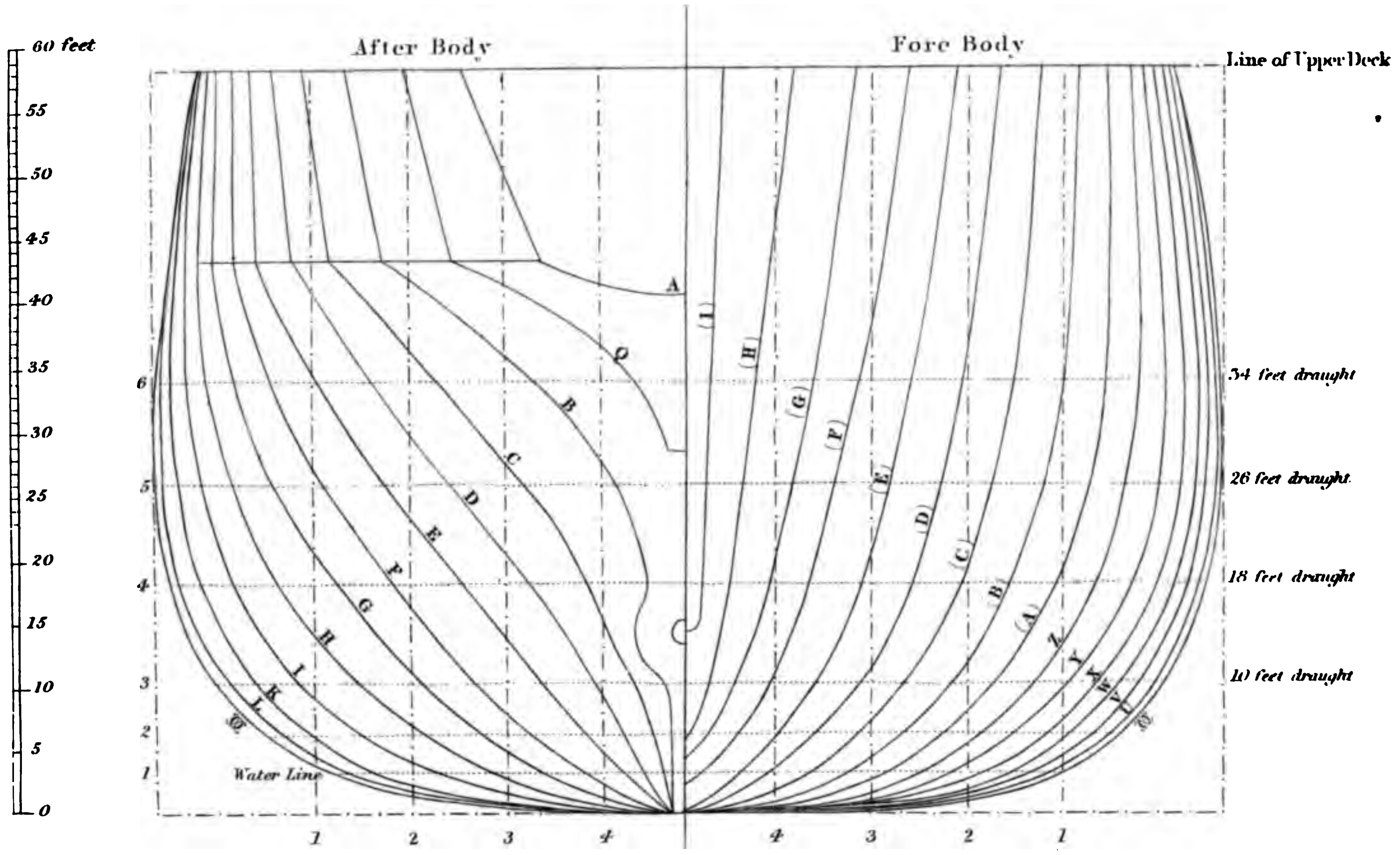
Assuming 35 Cub. feet of Salt water to a ton.



Published by A. & C. Black, Edinburgh.

SHIP BUILDING.

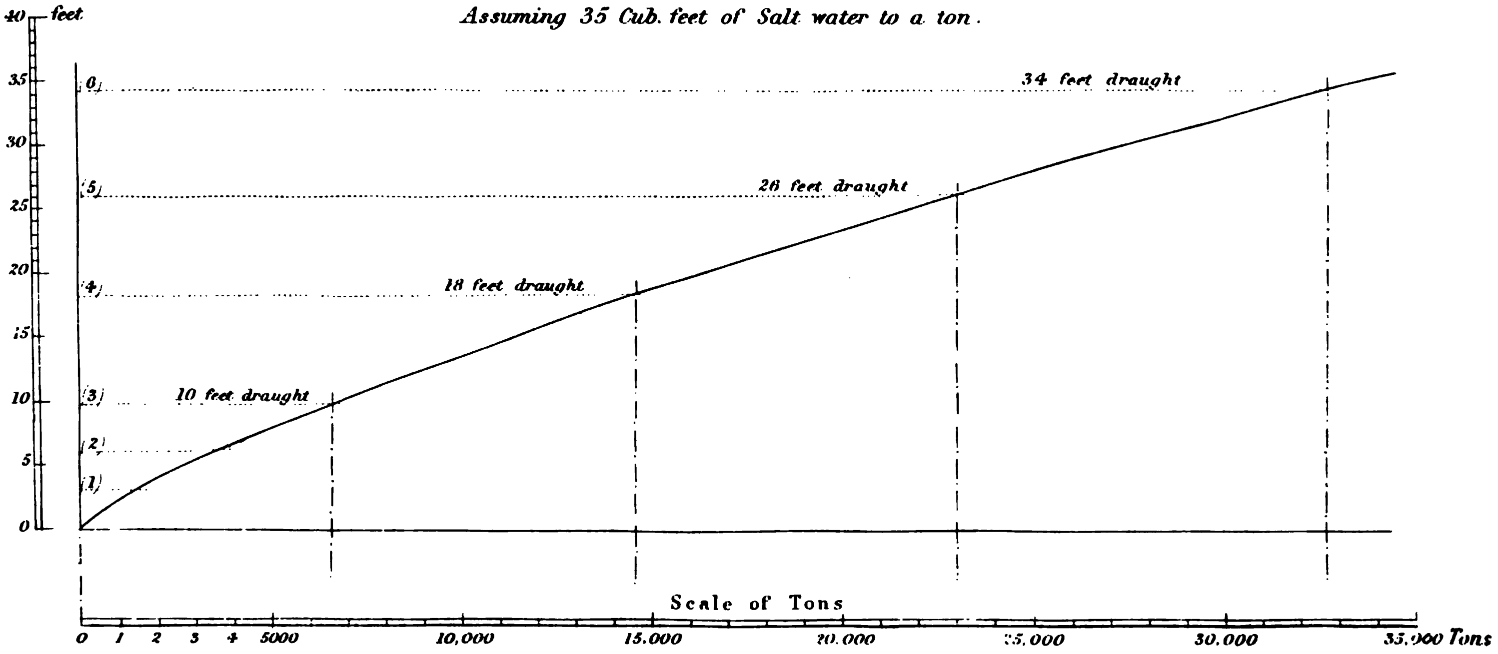
"GREAT EASTERN" STEAM SHIP.



VERTICAL SECTIONS.

SCALE OF DISPLACEMENT.

Assuming 35 Cub. feet of Salt water to a ton.



Published by A & C. Black, Edinburgh.

ING .

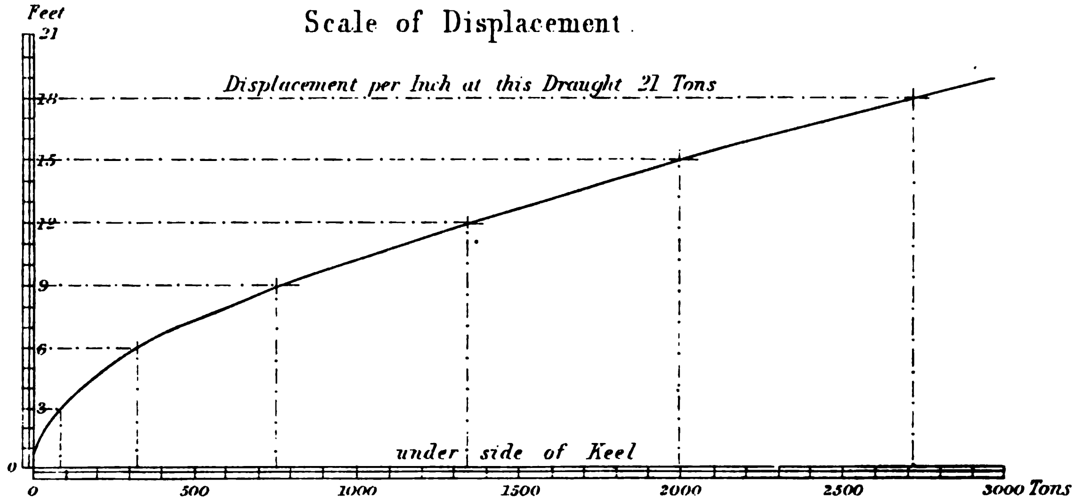
PLATE XI.

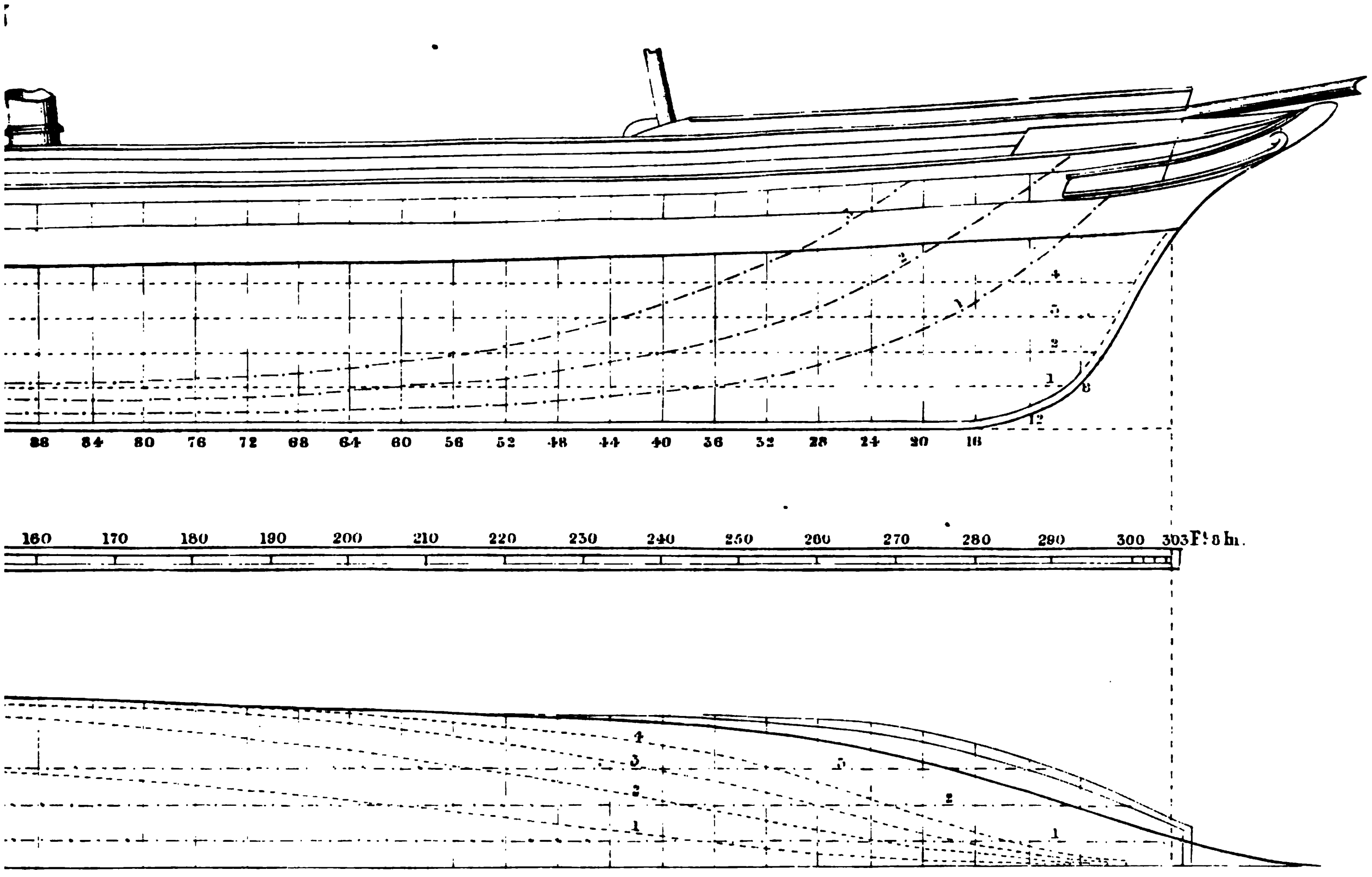
EAM SHIP "PERA."

Steam Nav. C°

In.s
8
4¾
1
2½

Scale of Displacement.





urgh.

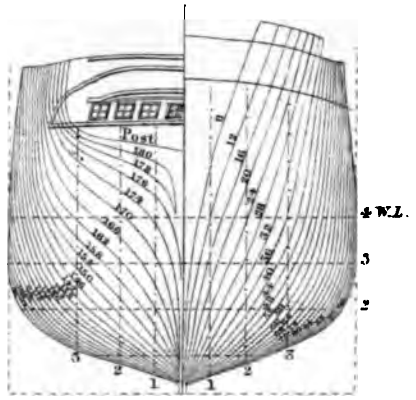
G. Aikman sc. Edin.

SHIP BUILD

DRAUGHT OF THE SCREW ST

Belonging to the Pen. & Oriental

BODY PLAN



Principal Dimensions.

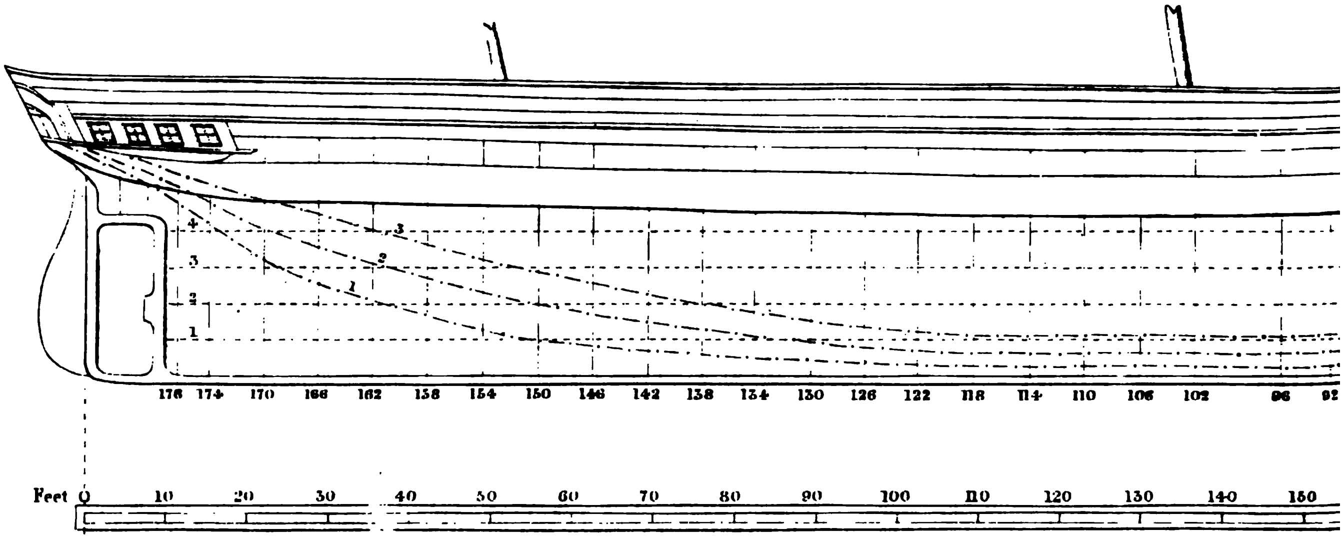
	Fe
Length between Perpendiculars	30
D°. of Keel for Tonnage	27
Breadth for Tonnage	4
Depth in Midships from top of Keel	2

Burthen in Tons N°.s $2622\frac{66}{94}$ O.M.

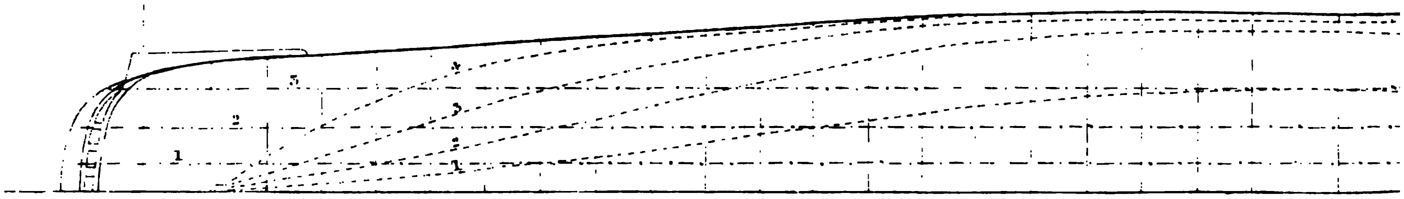
Builders of the Ship. Mare & C°.

Makers of the Machinery. G. & J. Rennie.

SHEER PLA



HALF BREADTH PLA



Published by A. & C. Black. Edin

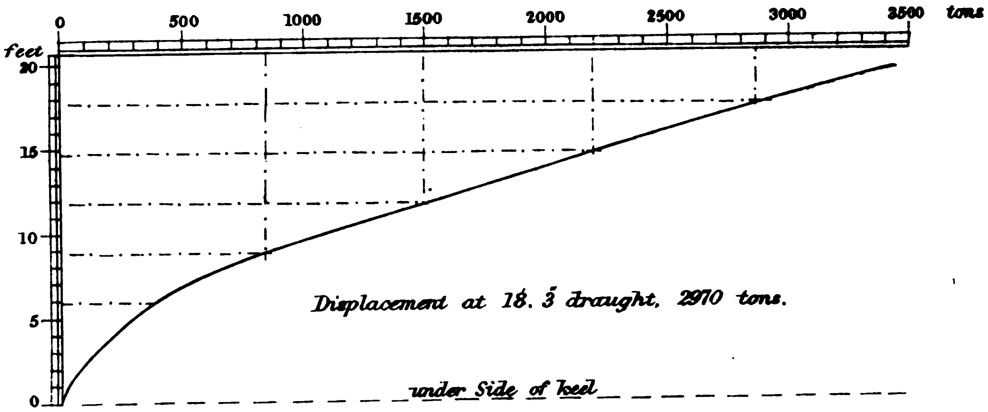
EW STEAM SHIP "CEYLON"

riental Steam Nav. Co.

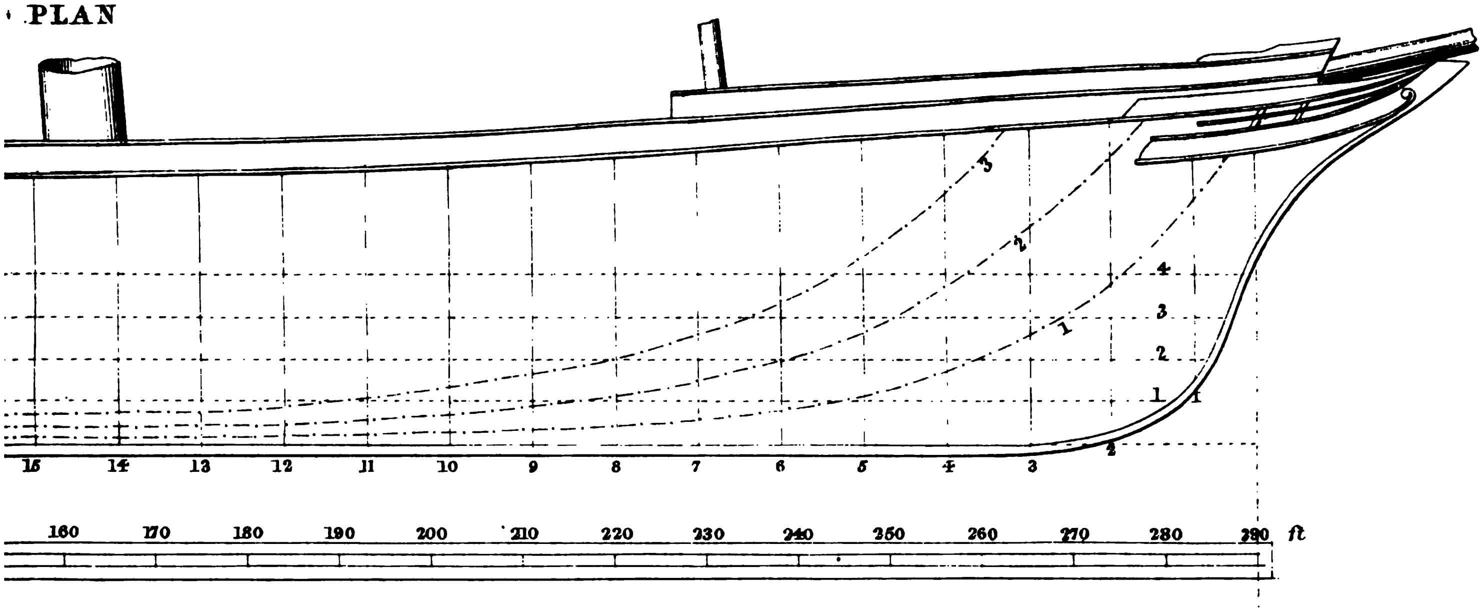
feet
... 290.
... 41.
... 29.

mant.

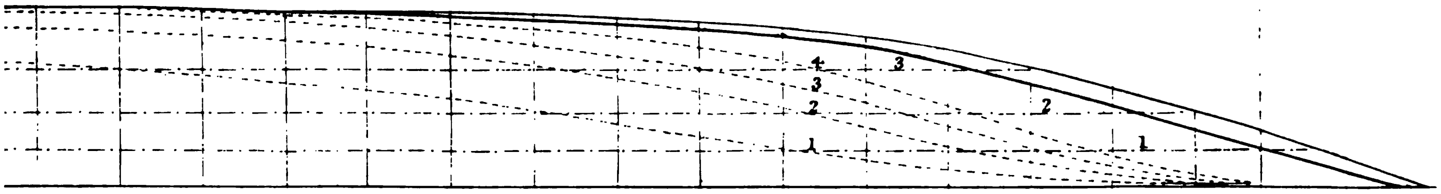
Scale of Displacement



PLAN

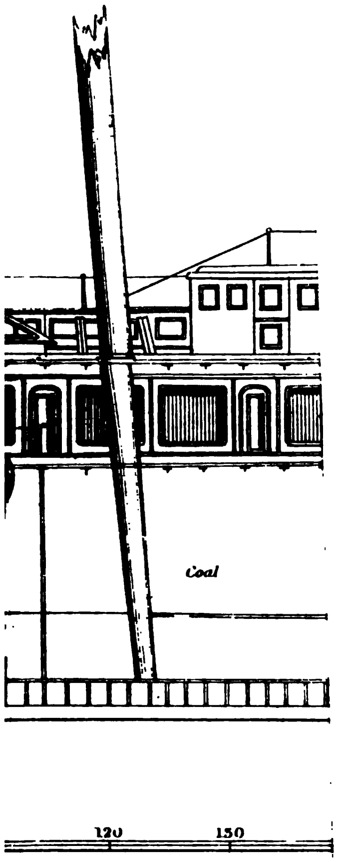


ADTH PLAN



c Edinburgh.

G. Aikman Sc. Edinr.

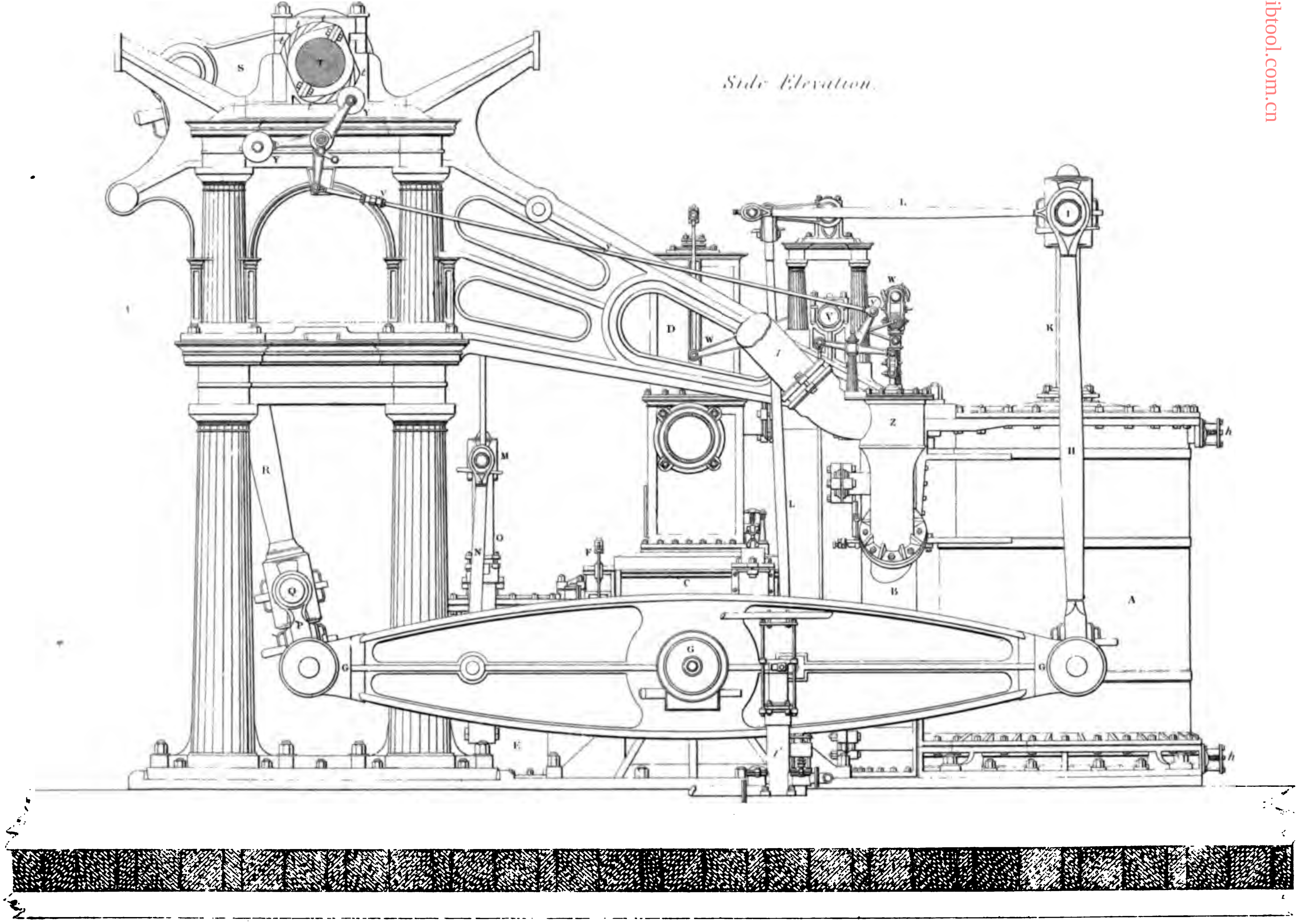


Publis

STEAM NAVIGATION.

SIDE LEVER MARINE ENGINE.

Side Elevation.

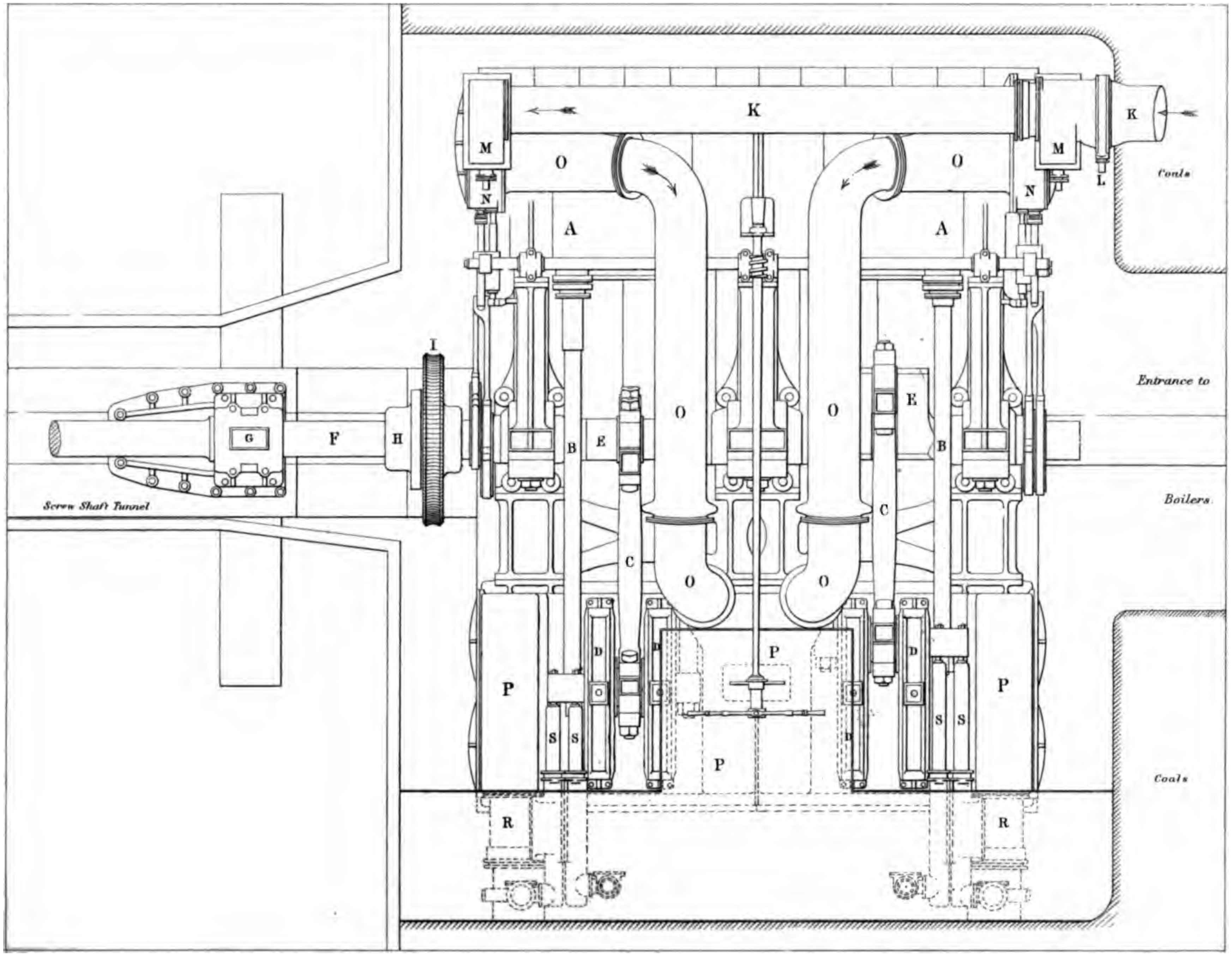


Published by A.&C.Black, Edinburgh

Geo Aikman Sculpt

PLAN OF A PAIR OF DIRECT ACTION SCREW ENGINES OF 500 HORSE POWER.

By Ravenhill, Salkeld & C° 1859.



Scale ⅛ Inch – 1 Foot

Published by A.&C. Black. Edinburgh.

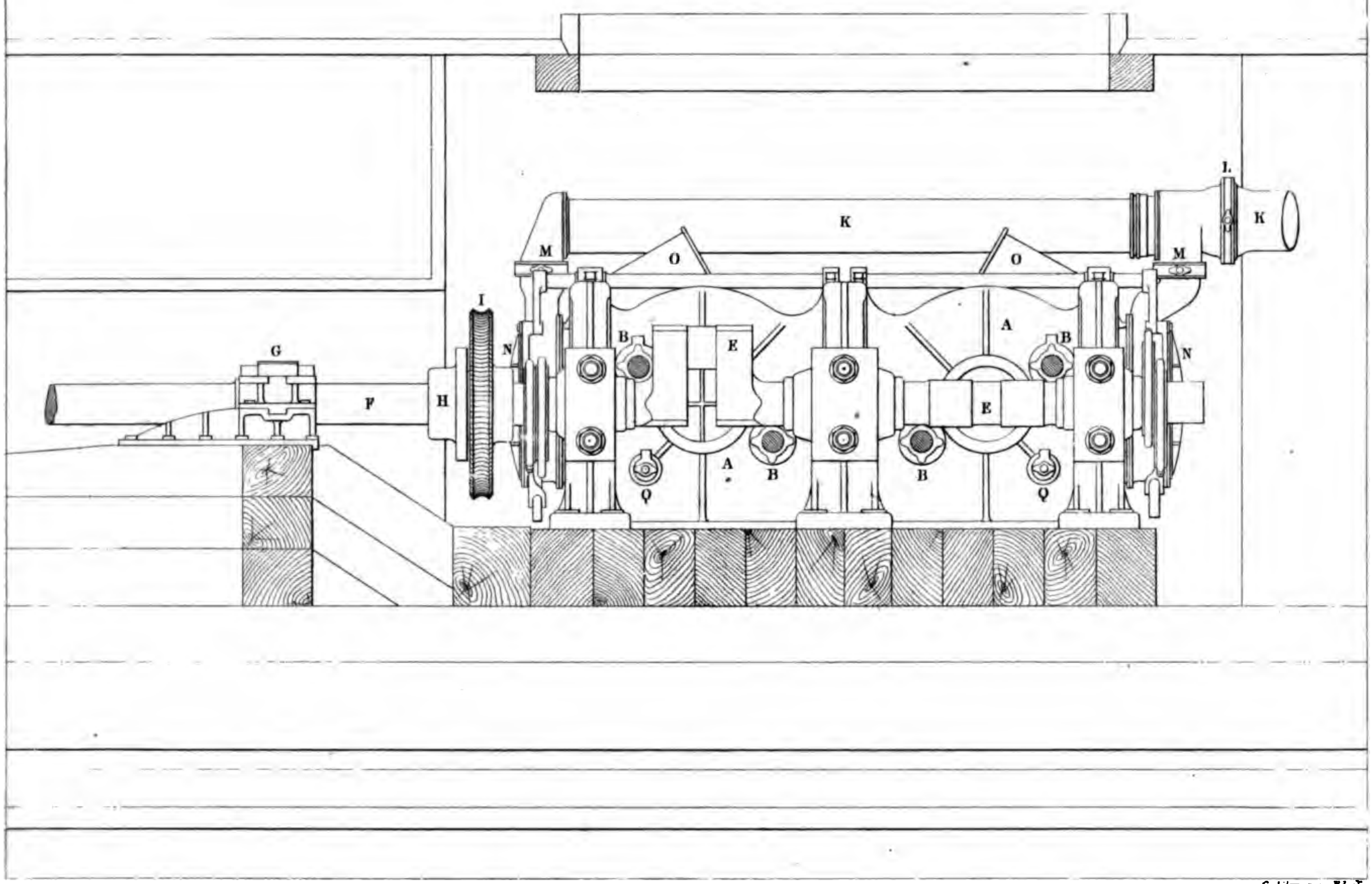
G. Aikman sc.

FORE AND AFT ELEVATION OF A PAIR OF DIRECT ACTION SCREW ENGINES OF 500 HORSE POWER

By Ravenhill, Salkeld & C^o 1859.

As fitted on board H.M. S.s. "Waterloo," "Nelson" &c.

Scale, ¼ inch = 1 Foot.

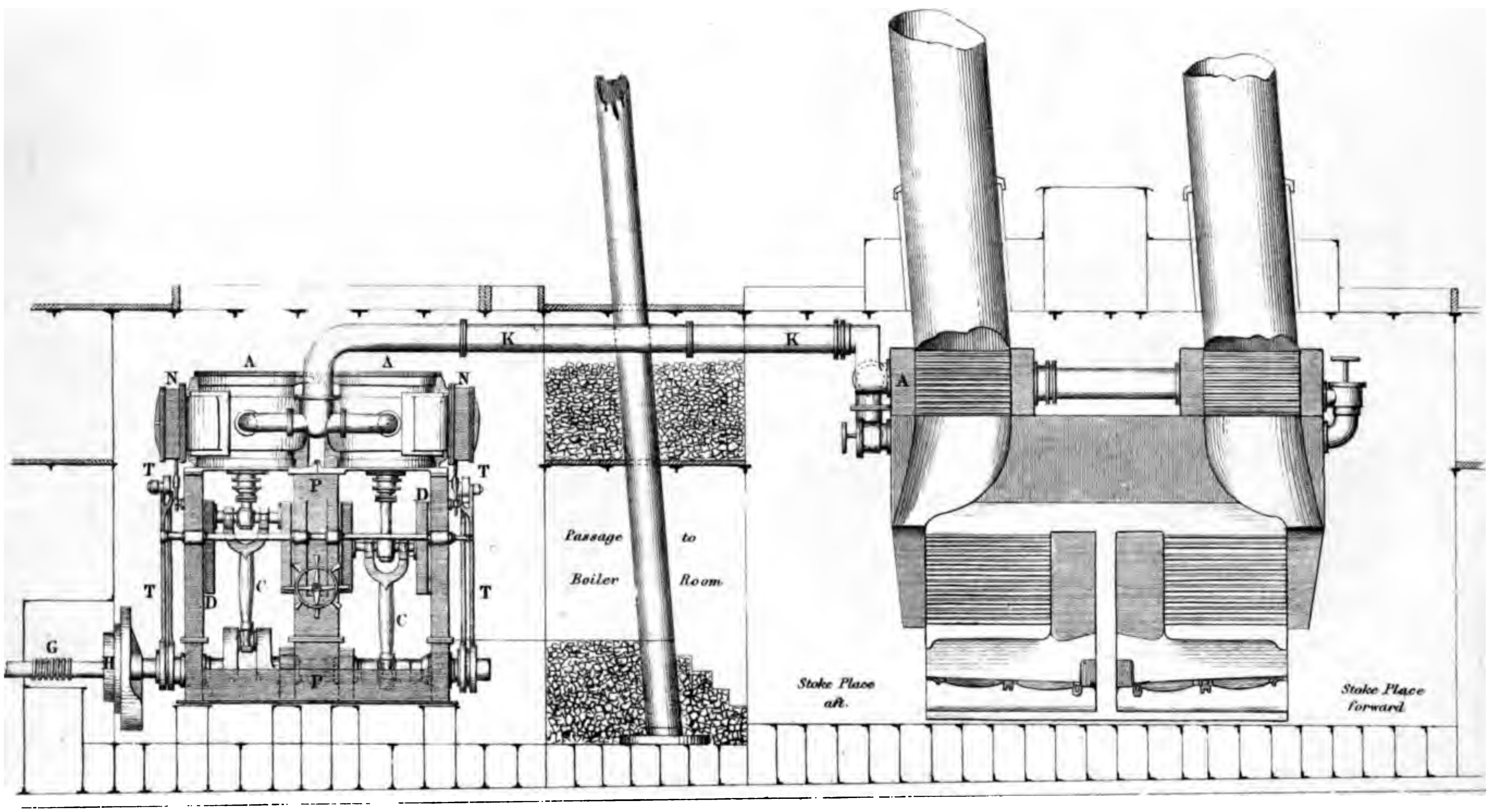


Published by A. & C. Black, Edinburgh.

G. Aikman sc. Edin^r.

ENGINES AND BOILERS OF THE SCREW STEAM SHIP "THUNDER".

J. & W. Dudgeon, Millwall, London.



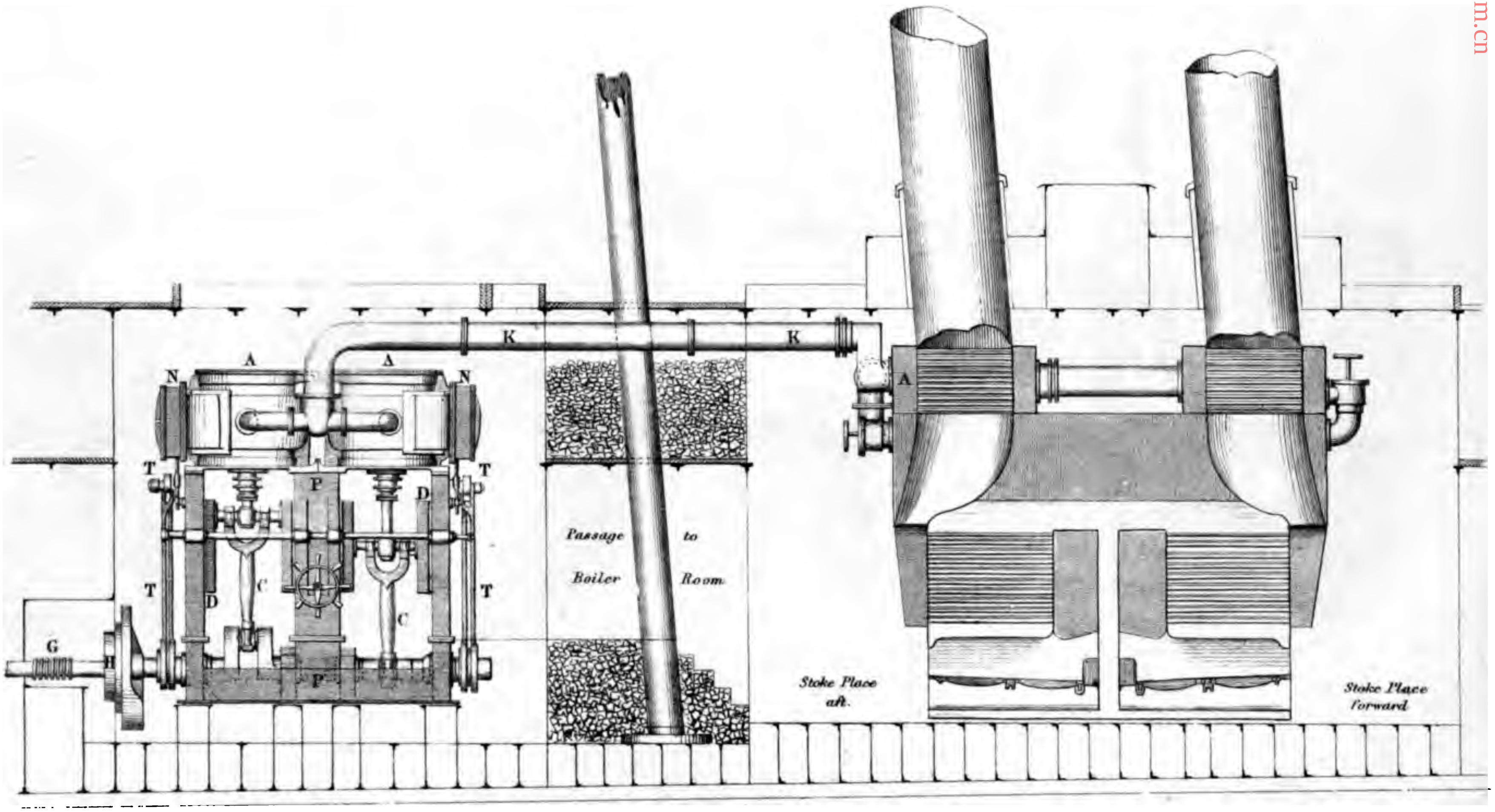
Scale ⅛ Inch = 1 Foot

G. Aikman sc.

Published by A&C Black, Edinburgh.

ENGINES AND BOILERS OF THE SCREW STEAM SHIP "THUNDER".

J. & W. Dudgeon, Millwall, London.



Scale ⅛ Inch = 1 Foot

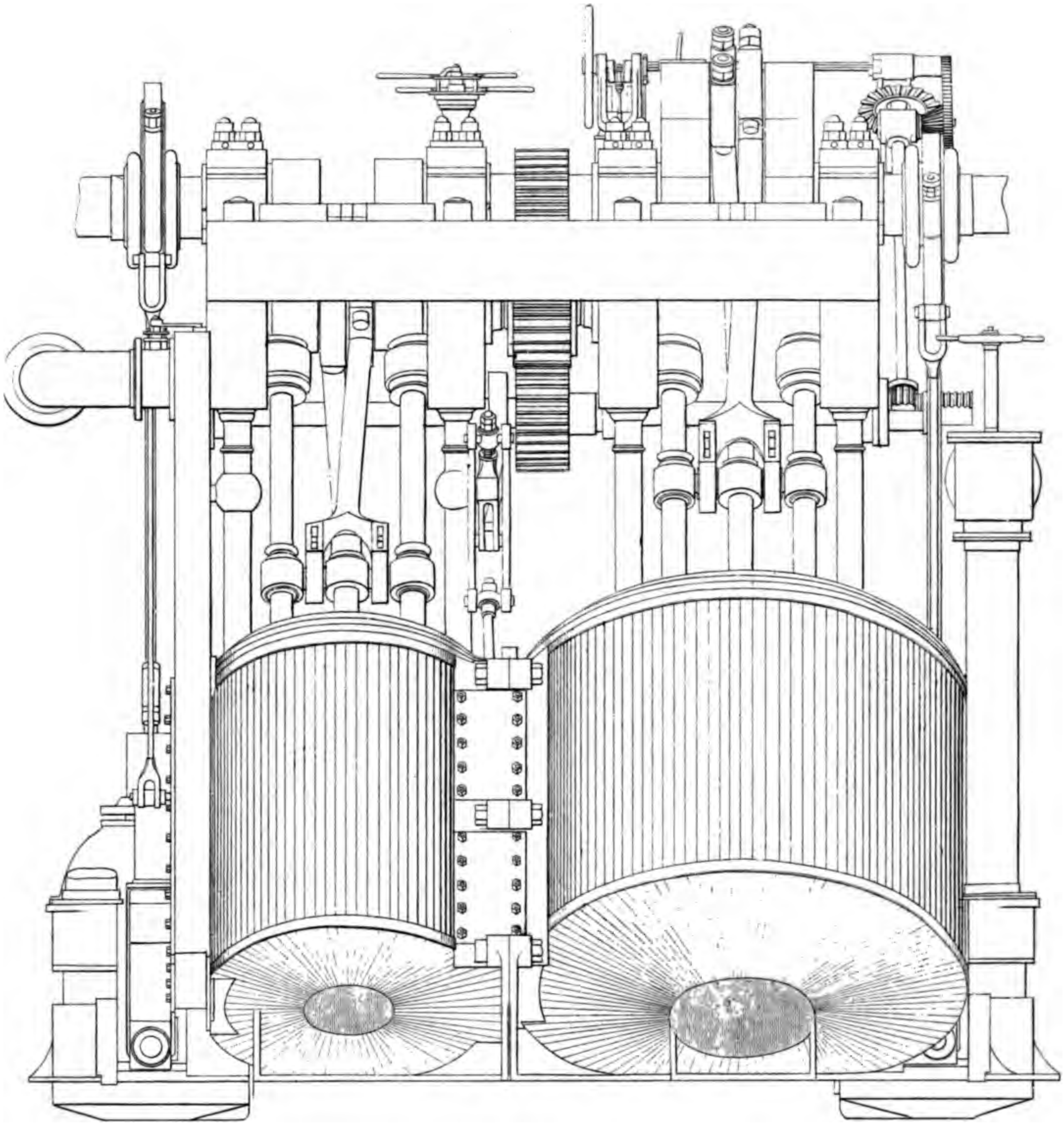
G. Aikman sc.

Published by A.&C. Black, Edinburgh.

STEAM NAVIGATION.

ENGINES OF STEAMERS CALLAO, LIMA & BOGOTA.

320 Horse Power.



FRONT ELEVATION.

G. Aikman sc.

Published by A. & C. Black, Edinburgh.

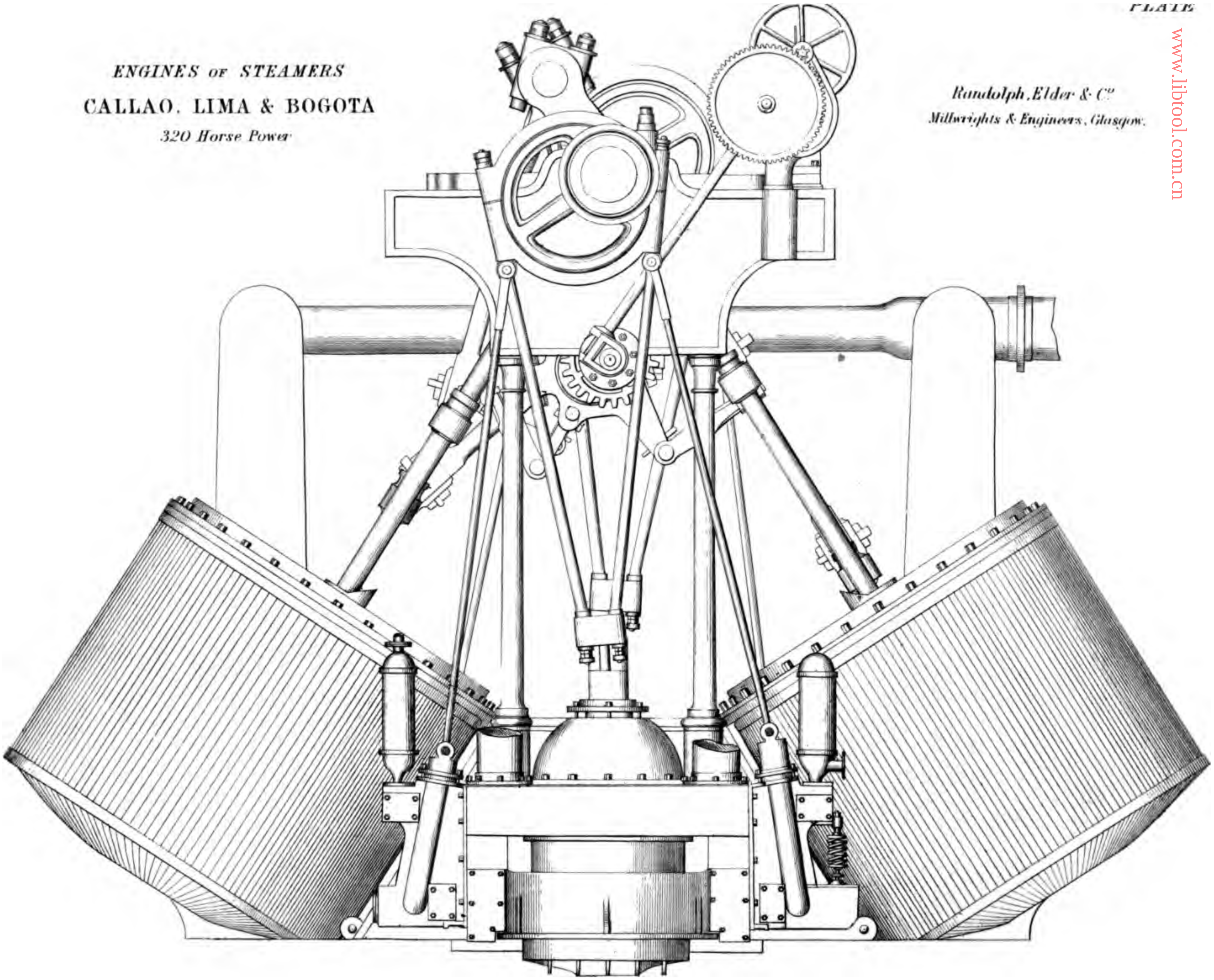
ENGINES OF STEAMERS

CALLAO, LIMA & BOGOTA

320 Horse Power

Randolph, Elder & C^o

Millwrights & Engineers, Glasgow.



SIDE ELEVATION

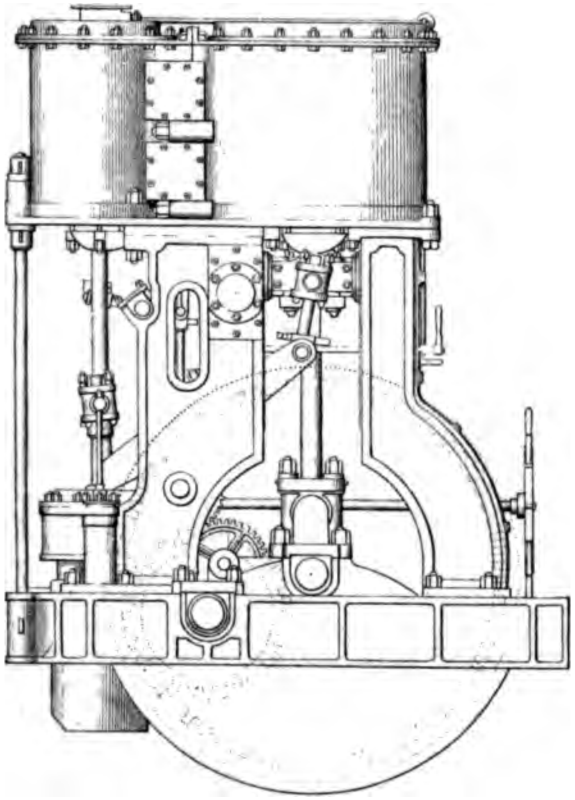
G. Aikman sc. Edin.^{r}

PLATE XXIII

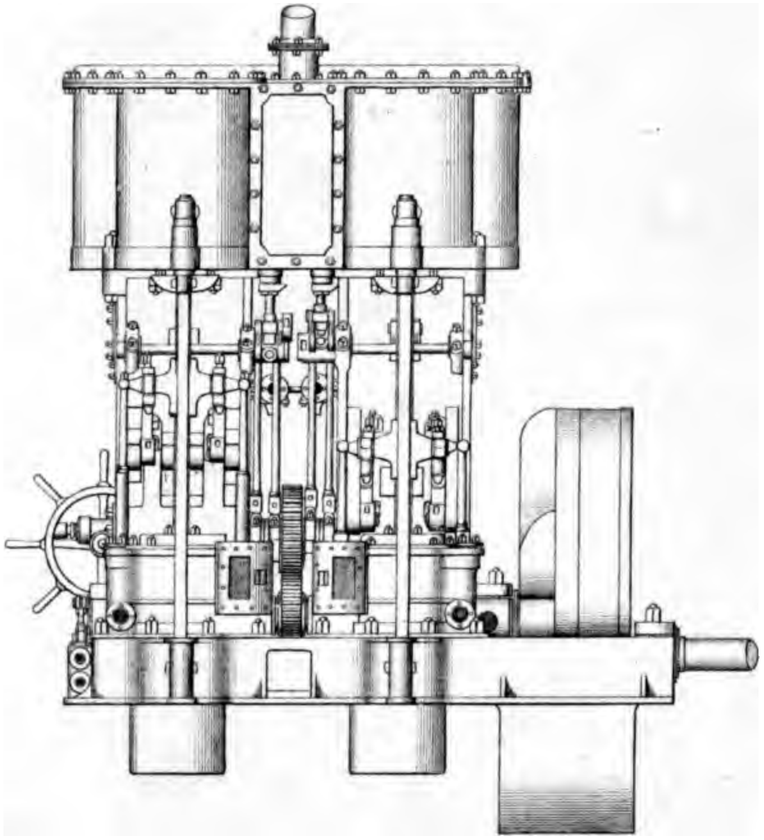
STEAM NAVIGATION.

INVERTED DOUBLE CYLINDER ENGINES.

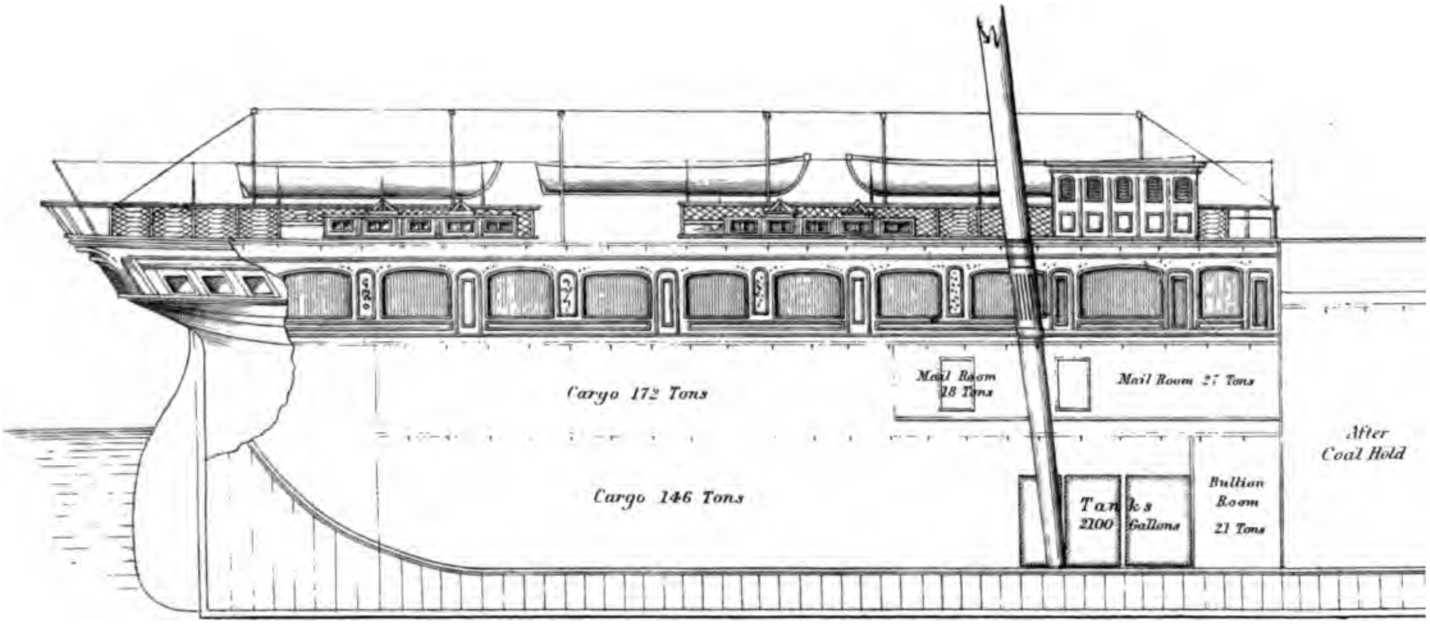
End Elevation



Side Elevation



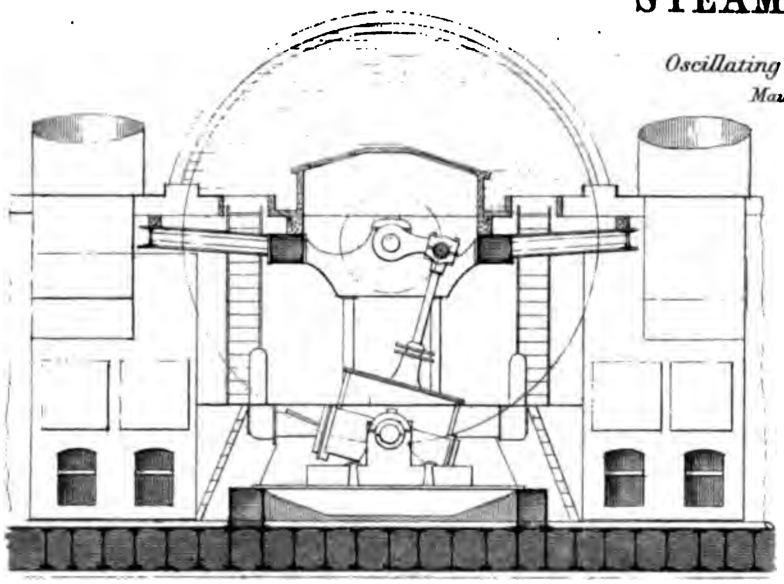
Published by A. & C. Black, Edinburgh.


Cargo 172 Tons
Mail Room
28 Tons
Mail Room 27 Tons
After
Coal Hold
Cargo 146 Tons
Tanks
2100 Gallons
Bullion
Room
21 Tons

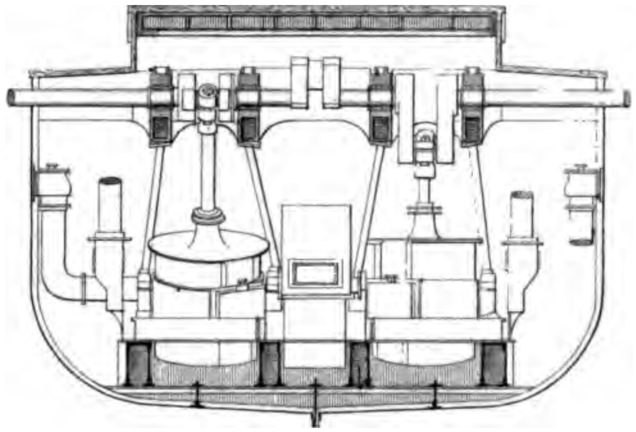
of I

STEAM NAVIGATION.

Oscillating Cylinder Marine Engines.
Maudslay Sons & Field.

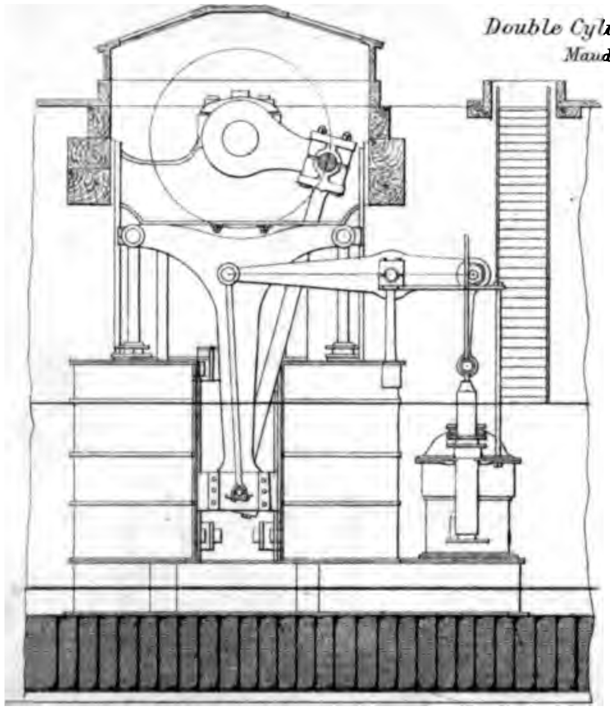


Side Elevation.

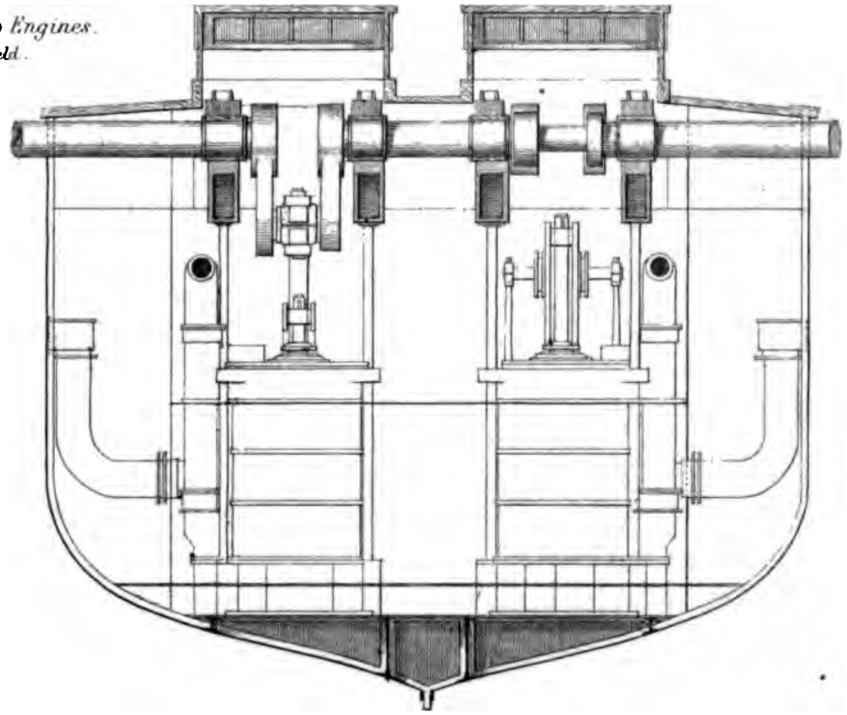


Cross Section.

Double Cylinder Marine Engines.
Maudslay Sons & Field.



Side Elevation.



Cross Section.

G. Aikman sc. Edinr.

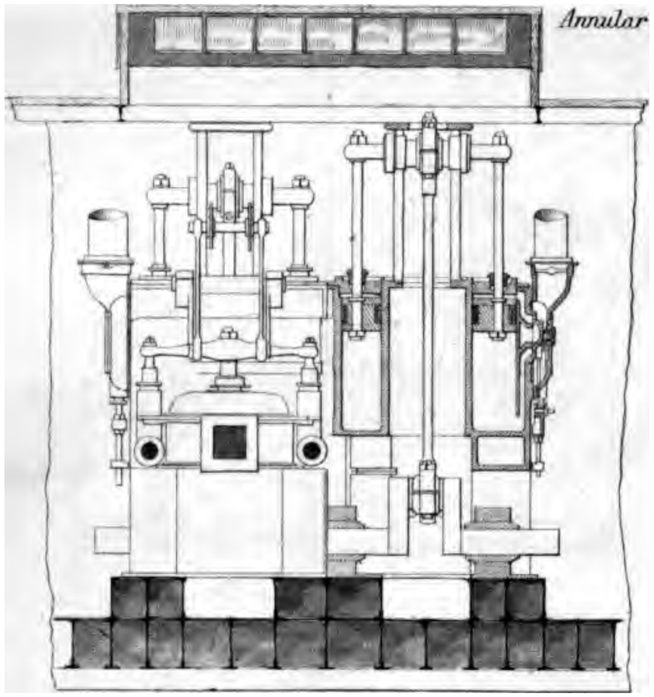
Published by A & C. Black, Edinburgh.

STEAM NAVIGATION.

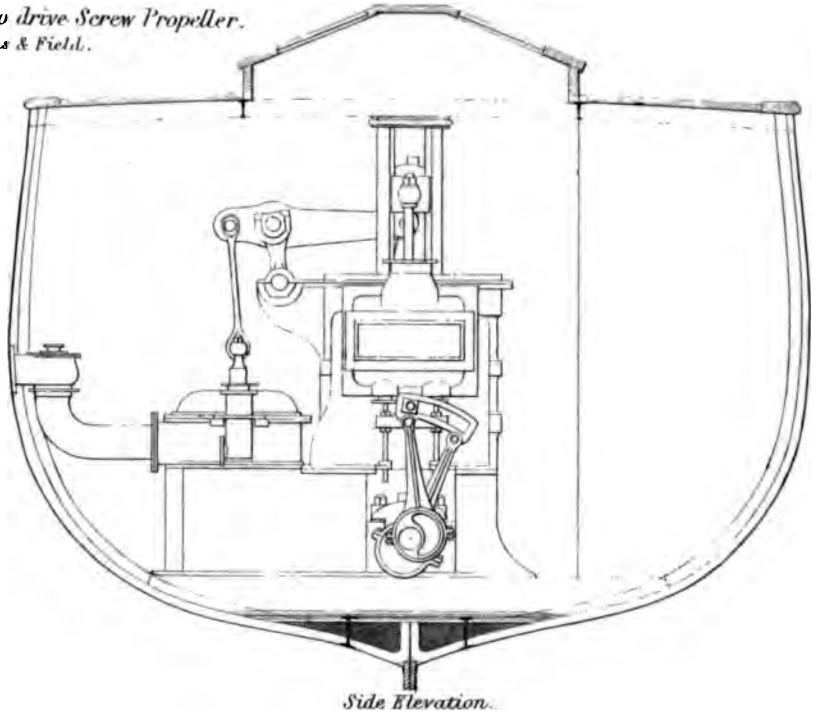
PLATE XXVI.

Annular Cylinder Engines to drive Screw Propeller.

Maudslay Sons & Field.



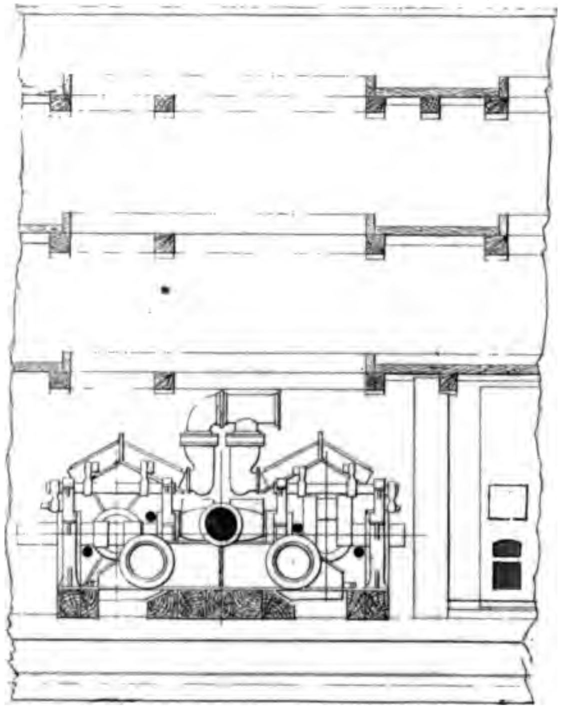
End Elevation & Section through Centre.



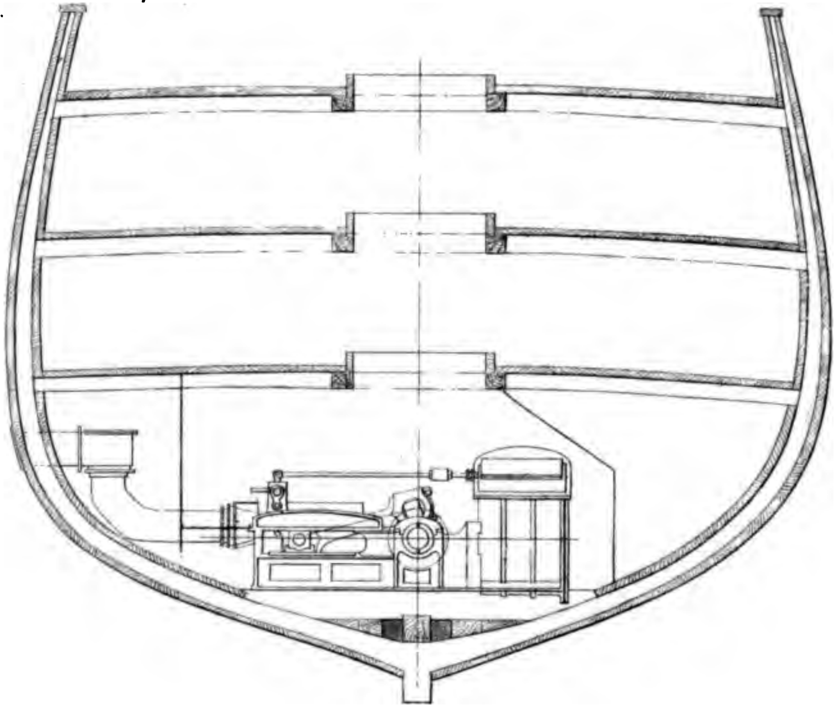
Side Elevation.

Horizontal Direct-acting Engines to drive Screw Propeller.

Maudslay Sons & Field.



Front Elevation.



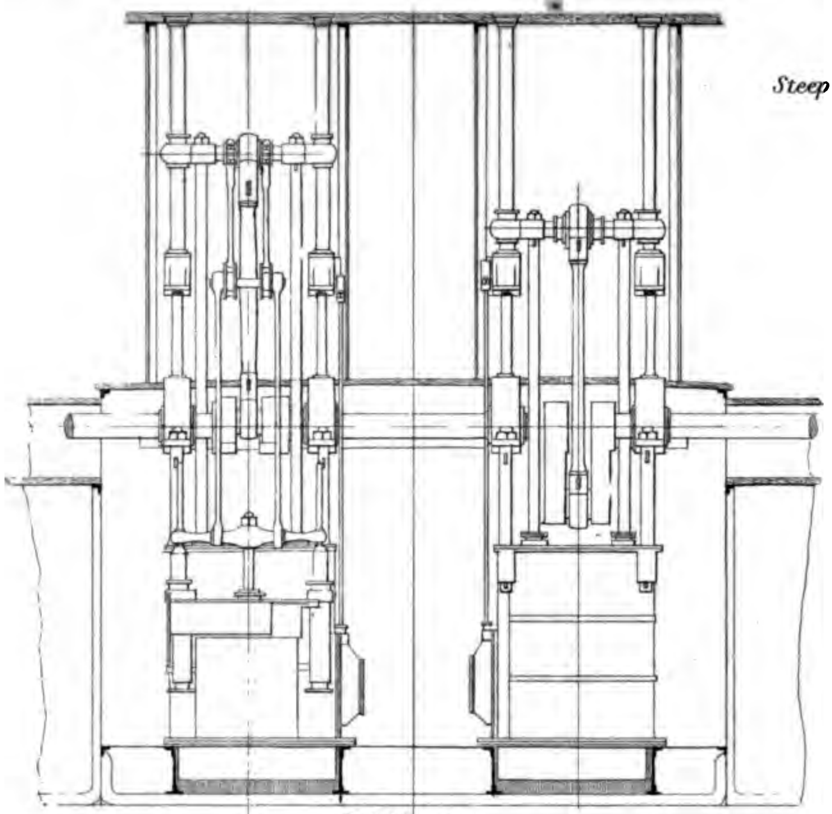
Side Elevation.

G. Aikman sc. Edin.

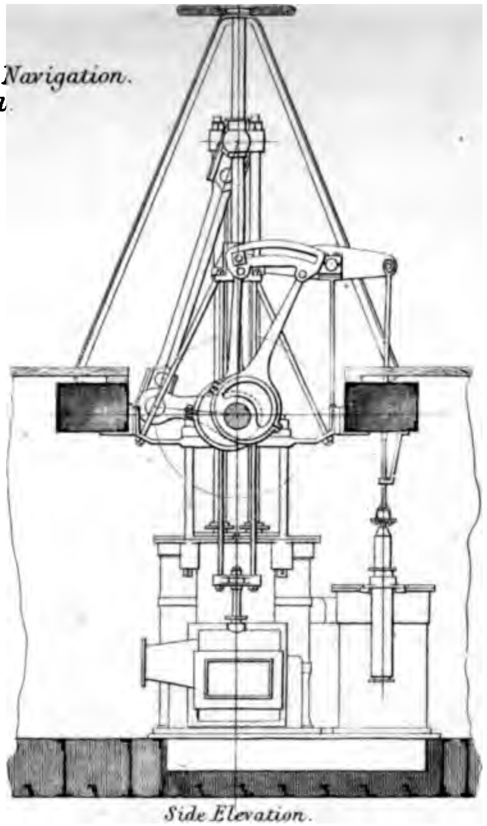
Published by A. & C. Black Edinburgh.

Steeple Engines for River Navigation.

Maudslay Sons & Field.



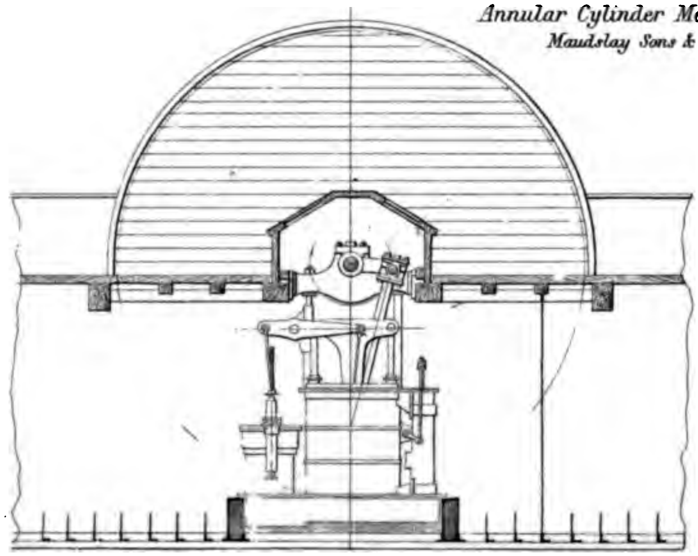
End Elevation.



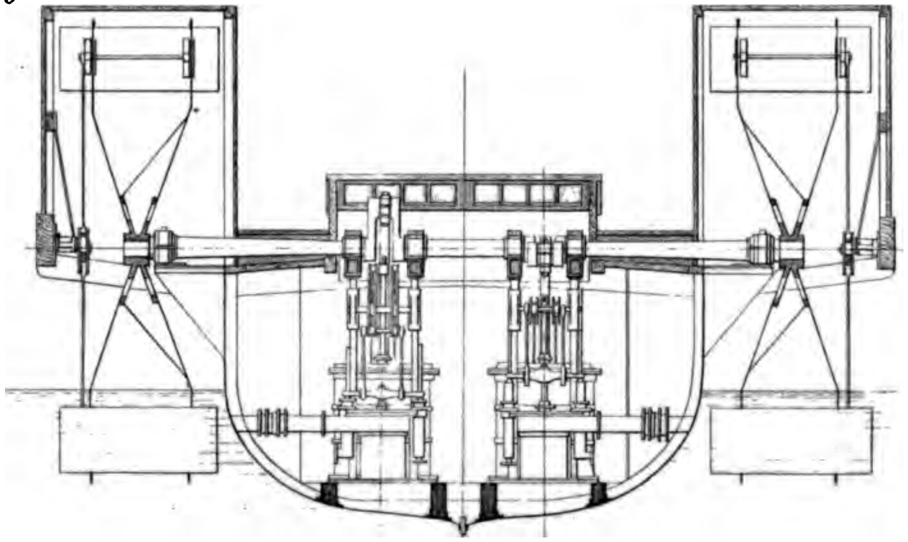
Side Elevation.

Annular Cylinder Marine Engines.

Maudslay Sons & Field.



Side Elevation.



Cross Section.

J. Aikman sc. Edin.r

Published by A. & C. Black, Edinburgh.