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.

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, 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 wooden 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.

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 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 contribute to produce this lateral curvature.

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 other parts of the ship.

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 connexion 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 connexion 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" are in constant operation from the moment of launching the ship. 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, 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.

In his *Manual of Naval Architecture*. Mr W. H. White gives illustrations of the still-water strains upon two armoured ships in the British navy the "Minotaur" and the "Devastation."

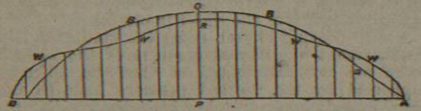

Fig. 9.

In these diagrams the curves B represent the distribution of the buoyancy. The ordinates of the curve are proportionate to the displacement of adjacent transverse sections of the ships. The curves W represent the distribution of the weight of the ships and their lading. The curves L represent the excesses and defects of buoyancy obtained from the two curves B and W and set off from a new base line. The excess of buoyancy above the line is exactly equal to the defect of buoyancy below it. The curves M indicate the bending moments. The ordinates of the curve lying above the base are obtained by summing all the moments, whether upwards or downwards, about the point in the length of the ship where the ordinate is taken. It may happen, as in the case of the "Devastation," that the moments will tend to cause hogging for a portion of the length and will then change their character, and at other portions of the length will tend to cause sagging. Where the curve M crosses the base line there is no strain of either hogging or sagging tending to bend the ship there. In the "Minotaur" there is a hogging tendency throughout. The amount at the midship section is very great, being represented by the moment 4·5 feet × 10·690 tons. After Sir Edward Reed left the Admiralty he strongly expressed his fears that this strain was too considerable for safety in the "Minotaur" and "Agincourt."

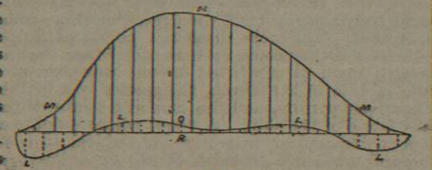

Fig. 10.

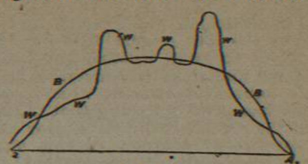

Fig. 11.

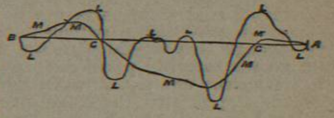

Fig. 12.

Designing.

The principal plans of a ship are the "sheer" plan, giving in outline the longitudinal elevation of the ship; the "body" plan, giving the shape of the vertical transverse sections; and the "half-breadth" plan, giving the projections of transverse longitudinal sections. In addition to these the builder is furnished by the designer with elevations, plans, and sections of the interior parts of the ship, and of the framing and plating or planking.

The thicknesses or weights of all the component parts are specified in a detailed specification, in order that the ship when completed may have the precise weight and position of centre of gravity contemplated by the designer. In the case of ships built for the British navy all the building materials are carefully weighed by an agent of the designer before they are put into place by the builder. As each section of the work is completed, the weight is compared with the designer's estimate in the designing office. As soon as the incomplete hull is floated the actual displacement is measured, and compared with the weights recorded as having gone into the ship. It is also the practice in the Royal Navy to calculate the position of the centre of gravity of the incomplete hull, and its draught of water before it is floated, in order to avoid all risk of upsetting from deficiency in stability at that stage of construction. The ship is usually found to float in precise accordance with the estimate. When completed ships float at a deeper draught than was intended, or are found to be more or less stable than was wished, this is nearly always due to additions and alterations made after the completion of the design. Where the designer is at liberty to complete the ship in accordance with the original intention there ought to be precise correspondence between the design and the ship.

In designing a ship of novel type the designer has to pass all the building details through his mind and assign them their just weights and proportions and positions. Every plate and angle bar and plank, every bar and rod and casting and forging, and every article of equipment has to be conceived in detail and its effect estimated.

Building.

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 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.

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. 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.

Those portions of a wooden ship which are termed the square and cant bodies may be considered as subdivisions of the fore-bodies and after-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 reason 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 athwartship plane and the outline or water-line 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 after-body to point forward.

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.

The keel, in the United Kingdom at least, is generally made 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. 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. The keel is connected forward 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. The floors in the Government service were 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 was filled in solid.

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.

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.

The connexion of the ends of the beams to the sides of the ship has been made in various ways. The points to be considered, with reference to this connexion, 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 waterway 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.

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 connexion 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

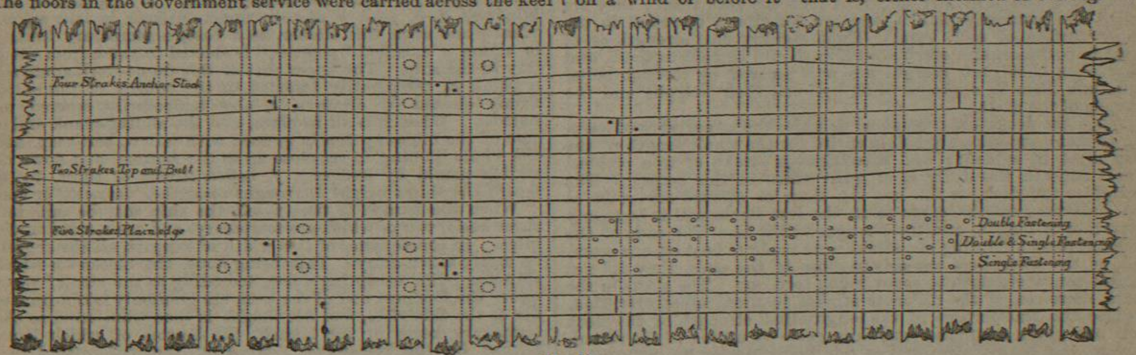

Fig. 13.

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 them, 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's side, as it can be placed.

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, is 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 connexion 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 British navy, were called the channel wale, the middle wale, and the main wale. The strake immediately above the main wale was called the black strake. The strakes below the main wale diminished from the thickness of the main wale to the thickness of the plank of the bottom, and were therefore called the diminishing strakes. The lowest strake of the plank of the bottom, the edge of which 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 alternate seams are 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 fig. 13. 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 British navy the butts were not allowed to occur in the same vertical line, or on the same timber, without the intervention of three whole strakes between them.

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.

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 were any ports, were 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 were called the spirketting of those decks—as gun-deck spirketting, upper-deck spirketting, &c.

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, waterway, 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.

Decks.

The decks of a wooden ship 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 of hard wood, and of greater thickness than the deck itself; they are called the waterway 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 a continuous strake of iron or steel 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 were made to butt on one beam, and, as the fastenings are driven close to the ends, they did not possess much strength to resist being torn out. The shifts of the butts, therefore, of the different strakes required great attention, because the transference of the longitudinal strength of the deck from one plank to another was thus made by means of the fastenings to the beams, the strakes not being united to each other sideways. The introduction of iron decks or partial decks under the wood has modified this.

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.

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 undisturbed, 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 $\frac{10}{16}$ of an inch, that is, about $\frac{1}{16}$ 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.

Ships are generally built on blocks which are laid at a declivity of about $\frac{5}{8}$ 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 $\frac{7}{8}$ inch to the foot for large ships, and a slight increase 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. For this purpose an inclined plane *a*, *a* (fig. 14), 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

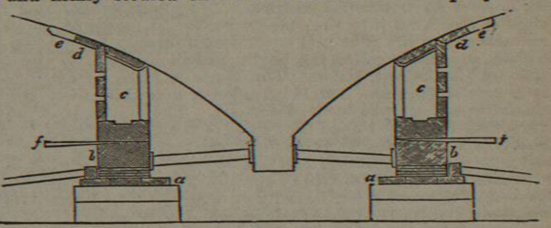

Fig. 14.

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 temporary 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*, called slivers or slices, by which means the ship's weight is brought upon the "launch" or cradle.

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 on each side, with its heel firmly cleated on the immovable platform or sliding-plank, and its head abutting against a cleat 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 fore-foot forces her off.

A different mode of launching is sometimes practised in British merchant-yards, and has been long in use in the French dockyards,

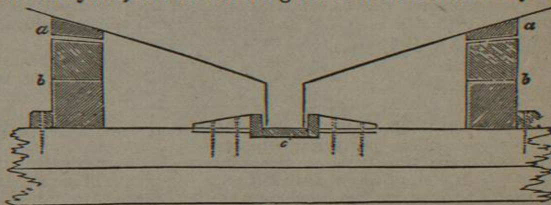

Fig. 15.

allowing the keel to take the entire weight of the vessel. The two pieces *a*, *a*, which are shown in fig. 15 as being secured to the ship's bottom, are the only pieces which need be prepared 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 *c*, fitted under the keel.

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. The two sides of the cradle are prevented from being forced apart when the weight of the ship is brought upon them by chains passing under the keel. Each portion of frame-work composing the launch has two of these chains attached to it, and brought under the keel to a bolt which passes slackly through one of the poppets, and is secured by a long forelock, with an iron handle, 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, 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 bilgeways. 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.

Slop work.

The importance of the work of the designer cannot be too highly estimated. Unfortunately there is, as has been said, "slop work" in designing as well as in putting the structure together. There is often an absence of any attempt at precautions where multiplied accidents have shown them to be necessary, as well as inconceivable carelessness in the details rendering provisions for security, where they exist in principle, useless in practice.

In the *Report* of the Royal Commission on Unseaworthy Ships, dated September 22, 1873, we read as follows:—"Competent witnesses state that many merchant ships are built with bad iron, that they are ill put together, and sent to sea in a defective condition. It is also said that they are frequently lengthened without additional strength, and are consequently weak ships. The number of iron steamers which have been lost in the last few years, many of them having been surveyed and classed under the London or Liverpool registers, raises a question whether the regulations of these registers are sufficiently stringent to insure good shipbuilding. The directors of the Bureau Veritas have deemed it necessary to revise the rules of their register, and to increase the scantling. In the race of competition among shipbuilders it is probable that inferior materials and bad workmanship are admitted into ships."

The Commissioners on Unseaworthy Ships, referring to the proposal that the Board of Trade should superintend the construction, the periodical inspection, the repair, and the loading of all British merchant ships, said: "We consider it to be a question worthy of serious consideration, whether, in the case of passenger ships, the certificate of the Board of Trade, so far as regards specific approval, should not be expressly confined to the number of passengers to be allowed and to the accommodation for their health, comfort, and general security,—all questions of unseaworthiness of hull, machinery, and equipment being left to the owners, subject only to a general power of interference in case of danger sufficiently apparent to justify special intervention."

Where ships have to meet the stress of battle as well as that of the sea faithfulness of work is even more imperative. It is not only necessary to have perfect work, but there must also be multiplied safeguards and provisions against damage by shot, shell, ram, and torpedo as well as against the enemies which are common to all ships. In the article NAVY the peculiarities of the ship of war are described. Regarding them here simply as ships, they may be said to be distinguished neither by size nor speed. They have been far outstripped in size, the longest English ship of war built within the last twenty years being only 325 feet in length, while there are Atlantic passenger ships 200 feet longer. They have also been outstripped in speed. The highest speed ever attained in a vessel of war is that of the "Iris" and "Mercury"; and as they are only 300 feet long it is easier in vessels of greater length to get higher speeds with less engine power, and easy also to maintain it in a seaway both as a question of form and power, and also as a matter of coal endurance. The following table gives the relative dimensions of large 14-knot ships:—

Ship's Name.	Length divided by Breadth (on Water Line).	I.H.P.	Dispt. in Tons.	Dispt.
"Adriatic," (White Star Line)	ft. in. $\frac{435\ 7}{41\ 8} = 10{\cdot}45$	3,600	8,250	408·3
H.M.S. "Dreadnought,"	$\frac{333\ 3}{61\ 6} = 5{\cdot}42$	8,000	10,886	491·2
H.M.S. "Sultan,"	$\frac{330\ 0}{58\ 6} = 5{\cdot}64$	8,600	9,286	441·8
H.M.S. "Inflexible,"	$\frac{324\ 0}{75\ 0} = 4{\cdot}32$	8,000	11,500	509·5
H.M.S. "Neptune," late "Independencia,"	$\frac{304\ 0}{60\ 10} = 5{\cdot}01$	8,500	9,063	434·7

The differences between the amount and complexity of fitting in the ship of war and the merchant ship are represented by the greatly increased cost per ton weight of hull. It must, however, be premised that the war ship has the weight of hull kept down to a very low standard to enable her to carry her offensive and defensive equipment,—far lower than is usual in the merchant ship. The first-class merchant ship costs £28 per ton weight of hull and about £13 per indicated horse-power for the engines. The ship of war built by the same builders under contract with the Government costs from £60 to £65 per ton weight of hull for unarmoured ships, and from £70 to £75 or more for armoured ships. In the case of an unarmoured vessel, having a protecting deck over machinery and magazines, recently ordered, the prices were as follows:—

General average	£60	10	0	per ton weight of hull.
Average of three London firms	66	0	0	,, ,,
Accepted tender	57	6	0	,, ,,

The engines for the same vessel were:—

General average	£15	8	0	per I.H.P.
Average of three London firms	17	5	0	,,
Accepted tender	11	8	0	,,

In the case of a larger armoured ship the rates were:—

Average price per ton weight of hull	£81	2	0
Accepted tender	71	5	0
Average price per I.H.P. of engines[1]	11	1	0
Accepted tender	10	7	0

Distribution of Materials and Cost in Various Types of Ships.

	First-Class Passenger Steamers.	Cargo Steamers.	Armoured Battle Ships (Barbette).	Protected 17-Knot Ships. Unarmoured, Unmasted, and Unsheathed.	Protected 13-Knot Ships. Unarmoured, Masted, and Sheathed.	Protected 10 to 12 Knots. Unarmoured, Masted, and Sheathed.	Torpedo Boats, 19 to 20 Knots.
Length in feet	450	390	325	300	225	170	86
Displacement at load draft (in tons)	9550	6800	10,000	3630	2420	1153	31·3
Weight (in tons) of hull, excluding armour	3800	1960	3,520	2000	1270	616	11·6
,, ,, armour	...	...	3,100[2]	218	152	...	...
,, ,, propelling machinery	1310	240	1,060	485	342	135	11·0
,, ,, guns, mounting, and ammunition	...	...	840	285	154	77	2·75
,, ,, fuel, at usual draft	1500	600	900	500	270	130	3·
Cost of hull per ton of its weight	£32	£20	£81 2	£56	£67·25 [3]	£60	£280
,, propelling machinery, per ton of its weight	£60	£50–55	£105	£111	£85 [3]	£90	£373

The use of heavy ordnance in recent times as the sole weapon for naval warfare brought about a marked distinction between the merchant vessel and the war ship, which had not previously existed. The revival of the ram and the adoption of the torpedo tend to abolish this distinction and to bring about an approximation again.

It is difficult to say what, in the very near future, will be the distinguishing characteristics of the ship of war. They will not be speed or size or coal endurance, or the power of striking with the ram, the torpedo, or the gun. It will be quite easy to arm merchant ships with these weapons, and some of these ships

[1] The indicated horse-power referred to here is that obtained by natural draft.
[2] Of this the vertical armour (costing before it is worked up, £70 to £90 per ton) is nearly 2000 tons.
[3] Average of six vessels built by Elder.

already outstrip the war vessel in the important advantages of size and fleetness and carrying power. It is apparently in protective advantages that the essential difference will lie.

The merchant ship is badly provided against fatal damage by collision, or by a blow delivered in any manner by which water is admitted into the ship. The propelling machinery of these ships and their steering apparatus are also dangerously exposed to artillery fire. Excepting torpedo boats, the ship of war of any size has its propelling machinery either under water or under cover of armour, and in a great number of cases there is either protection for the steering apparatus or there are two propellers. The approximation towards war-ship arrangements which is needed in the merchant ship is the adoption of more than one screw and of greater breadth of ship, so that defences round machinery may be created in time of war. Both these changes in merchant-ship practice are demanded also by mercantile interests. The increase in breadth amidships would greatly reduce the risk of foundering in collisions and give more spacious accommodation amidships. Such increase when accompanied by fine ends is also favourable to speed.

The use of two screws is economical of power, and is a much-needed security against the evil results of an accident to an engine, a shaft, or a propeller. The time will doubtless come when a single propeller in a large passenger ship will be regarded as an unpardonable fault, and when the division into compartments now common will be held to be no better than a delusion and a snare.

The protection given to the regular ships-of-war by side armour, or by a protecting deck, at or near the water-line, will probably become a definite and indispensable feature in them, and may, perhaps, be their only distinguishing characteristic, apart from their outfit and equipment.

If this should prove to be the issue of events, their course will have been very indirect. In the ships-of-war of the last century no attempt was made to employ armour on the sides or to prevent the passage of projectiles and water into the holds by means of a protecting deck. There was a deck just below the water-line, but it had no protective qualities. It served, among other things, to furnish passage ways in action for the carpenter and his crew to get at the inner side of the wooden walls of the ship at and near the water-line, so that when shot entered there the holes might be immediately plugged. When screw propulsion was introduced into these ships, and it was found practicable to keep the engines and boilers under water, it would have been possible to place a deck over the machinery and beneath the water, which would have greatly added to the security of the engines, boilers, and magazines. The space above this deck might also have been so subdivided into compartments as to have protected the buoyancy and stability of the ship against the immediately fatal results of the invasion of water. The protection of the buoyancy and stability by these means would not have been absolute, in the sense of making the ship safe, but it would have been of the utmost value as compared with ships, otherwise similar, but having no such protection.

Committee on designs. Thirty years passed between the date when screw-propeller engines were placed beneath the water-level in ships of war and that at which a committee on designs, under the presidency of Lord Dufferin, proposed to place such a covering deck over them, or to construct a water-line raft-body. The proposal of the main body of the committee was to associate such a raft-deck for the protection of the buoyancy and stability of the ship against artillery with a central armoured citadel. That of the minority was to suppress the armour in the region of the water-line entirely, and to protect buoyancy, stability, machinery, and magazines by a raft-deck alone. In 1873 the plan as indicated by the main body of the committee was put into practice nearly simultaneously in the "Duilio" and "Dandolo" in Italy and in the "Inflexible" in England. In 1878 the system as conceived in principle by the minority of the committee of 1871, although not in the manner they recommended, was adopted in much smaller vessels in the British navy. A raft-deck was introduced into the "Comus" class of corvettes of 2,380 tons displacement, a class which was regarded as unarmoured. Since that date the raft-deck has been adopted in a more or less complete form in nearly all classes of unarmoured ships in the English navy. So it has come about that, out of some 850 unarmoured ships of war built and building in Europe, 47 have such protecting raft-decks. Of these 32 are English. There can be no doubt that all unarmoured ships of war will eventually be protected in this manner. The number of so-called ironclads built and building in Europe is 270. Of these, 34 are based on the recommendation of the committee on designs; 18 of them are English. There are six other English ships with central citadels and under-water protecting decks, built more than twenty years ago, but the raft-body principle is absent in them.

If the passage from the steam line-of-battle ship of 1840–1860 to the "Admiral" class of 1884 had been made under the guidance of the principles of the committee of 1871, European nations would not find themselves possessed of large fighting ships covered from end to end, or over large areas of their sides, with thin armour, penetrable to a very large proportion of the guns brought against them. But the sailors of 1854–1860 did not take the view that buoyancy and stability, and machinery and magazines, were the vital parts, needing defence by armour or by a raft-deck. They dreaded the effects of shell exploding between decks, setting fire to the ships, and converting the decks, crowded with men, into slaughter-houses. Their demand was, "Keep out the shells." So it came about that iron armour-plates, thick enough to keep out the most powerful shell of the time, were worked upon the sides of the ships, and the guns were fought through ports cut in this armour. This feeling was so strong that the English Admiralty built the "Hector" and "Valiant" with armoured batteries overlapping by many feet at each end the armour beneath them, which protected the buoyancy, stability, machinery, and magazines. Guns increased in power, and the armour was gradually thickened to resist them, until from 4½ inches of armour, through which broadside ports were cut, 9 inches and 10 inches were reached. But this thickening of the armour had so reduced the possible number of the guns in a ship of moderate size and the guns required for breaching such armour had so increased in weight, that the broadside ship had to give way to the turret or barbette ship, in which about four such guns were all that could be carried, and these had to be worked on turn-tables in or near the central line of the ship.

The point now reached in all navies is that the broadside ironclad with ports cut through an armoured side, as invented in France by M. Dupuy de Lôme, and copied by every power, is obsolete. Guns must be worked singly or in pairs on revolving turn-tables, each turn-table being surrounded by an armoured tower, forming the loading chamber or protecting the mechanism. The side armour protecting the buoyancy, stability, machinery, and magazines, although not introduced for that purpose originally, is retained in France for very large ships, is given up in Italy in favour of a raft-body, and is retained partially in England and Germany in conjunction with a raft-body.

The use of armour has arrested the development of the shell. But it is not inconceivable that its abandonment in front of the long batteries of guns in the French and Italian ships will invite shell attack, and make existence in such batteries, if they are at all crowded, once more intolerable. It remains to be seen whether in that case exposure will be accepted, or a new demand made for armour, at least against the magazine gun and the quick-firing gun. If exposure is accepted, it will be on the ground that the number of men at the guns is now very few, that the gun positions are numerous and the fire rapid, and that, if the guns had once more to be fought through ports in armour, the number of gun positions would be reduced, and the fragments of their own walls, when struck by heavy projectiles, would be more damaging than the projectiles of the enemy.

Internal armour for the protection of the heavy armour-breaching guns must be retained so long as such guns are used, and if they were abandoned an enemy could cover himself with armour invulnerable to light artillery. This the French attempted to do in inaugurating the system. They have been driven from it by the growth of the gun. Abandon the heavy gun, and complete armour-plating might again be adopted.

We must conclude that the buoyancy, stability, machinery, and magazines must be protected as far as possible against fatal damage from a single blow of these armour-breaching guns. The tendency will be to come to the lightest form of such protection. That lightest form appears to be a protecting deck a little above the water-level throughout the greatest part of its surface, but sloping down at the sides and at the ends, so as to meet the side walls of the ship under the water-line. However the armour is arranged (apart from a complete covering with invulnerable plating),—whether as a belt with its upper edge 3 feet out of the water, as in the French ships; as a central armoured citadel and a raft-body at the ends, like the English and German ships; or as a raft-body throughout, like the Italian ships,—shot holes in action will admit water and gradually reduce the necessary stability of the ship. In the French ships the assistance of the unarmoured upper parts is as necessary to prevent them from upsetting in anything but smooth water as is the assistance of the unarmoured raft ends in the English and German ships. In the intact condition the English ships have far greater stability than those of France. In the English ships a reserve of stability is provided, against the contingency of loss by injuries in action. In the French ships no more is provided than is required for the intact condition. The French have not accepted the position taken up in England that much greater initial stability may be given to heavily-armoured broad ships than is usually given, without causing heavy rolling. Nor have they accepted the further incontrovertible truth that the free passage of water in the raft-body from side to side of the ship in rolling is rapidly effective in quelling the motion and bringing the ship to rest in the upright position.

Propulsion.

The propulsion of ships by sails differs from the drifting of bodies in the air before the wind in a most important respect. Ships may drift or sail in the direct course of the wind, and they will then differ from air-borne bodies only in the comparative slowness imposed by the resistance of the water. Ships having the same length as breadth, or rather opposing the same form and area to side progress as to forward progress could never do other than sail before the wind. No disposition of canvas could make them deviate to the right or left of their course to leeward. But by an alteration of form giving them greater length than breadth, and greater resistance to motion sideways than to motion endwise, they came to possess the power of being able not only to sail to the right or left of the course of the wind, before the wind, but also to sail towards the wind. The wind can be made to impel them towards the point from which it is blowing by means of the lengthened form acted on by the resistance of the water.

Motion directly towards the wind cannot be maintained, but by sailing obliquely towards it first to one side and then to the other progress is made in advance, and the vessel "beats to windward." The action is like that which would be required to blow a railway car to the eastward by the action of an easterly wind. If the line of rails were due east and west, and the wind were always direct from the east, the thing could not be done. But with a wind to the south or north of east, by setting a sail in the car so that its surface lies between the course of the wind and the direction of the rails, it would then receive the impulse of the wind on its back and would drive the car forwards. There would be a large part of the force of the wind ineffective because of the obliquity of the sail; and of the part which is effective a large portion would be tending to force the car against the rails sideways, but there would be progression to windward. In the case of the ship the resistance to side motion is due to the unsuitability of the proportions and form for progress in that direction as compared with progress ahead, but still there is motion transversely to the line of keel. This motion is called leeway. As the ship moves to leeward and ahead simultaneously there is a point of balance of the forces of the fluid against the immersed body—a centre of fluid pressure. The object of the constructor is to place the masts in the ship in such positions that the centre of pressure of wind upon the sails shall fall a little behind or astern of this centre of resistance of the fluid. In that case there is a tendency in the ship to turn round under the action of these two forces, and to turn with her head towards the wind. This tendency is corrected by the action of the rudder. If the tendency to turn were the other way, although that could also be corrected by the rudder, yet there would be danger of the wind overcoming the rudder action in squalls, and the ship would then come broadside to the wind. In that case, while she might have been quite capable of bearing the pressure of the wind blowing obliquely upon her sails, she might have her sails blown away, or her masts broken, or be herself capsized by the direct impulsion of the wind upon the sail and upon the hull of the ship.

Many examples of disposition of sails might be given. Their disposition is always made to satisfy the conditions that as much sail as possible is required, but if the vessel is small it must be capable of being instantly let go in a squall, or when the wind is gusty. Otherwise, where it cannot be readily let go, its area should be capable of reduction in squally weather, still retaining its efficiency, so that no pressure of the wind should be capable of upsetting the ship. If a sudden violent squall should strike the ship she should find relief, not by a large inclination, but by the blowing away of the sails out of the bolt-ropes, or the carrying away of the masts. One or other of these must of course happen if the area of canvas and the strength of the sails and of the spars are so proportioned at the moment the squall strikes the ship as to be less than the resistance offered by the stability of the ship to a large inclination. Ships are sometimes, when struck by a squall, blown over on to their sides, the sails being in the water. If the sails or spars are then cut away or otherwise got rid of the ship may right herself.

In the *Transactions* of the Institution of Naval Architects for 1881, Mr W. H. White says :—

"Any investigation of the behaviour of sailing ships at sea must take account of the conditions belonging to the discussion of their rolling when no sail is set, and must superpose upon those conditions the other and no less difficult conditions relating to the action of the wind upon the sails, the influence of heaving motions upon the stability, and the steadying effect of sail-spread.

"It may fairly be assumed that the labours of the late Mr W. Froude have made it possible to predict, with close approximation to truth, the behaviour of a ship whose qualities are known and which has no sails set, when rolling among waves of any assumed dimensions. By a happy combination of experimental investigation and mathematical procedure, Mr Froude succeeded in tracing the motion from instant to instant, and checked the results thus obtained by comparison with the actual observations made in a sea-way on the behaviour of the 'Devastation.' The details of his method, and examples of its application, will be found in the *Transactions* for 1875, and in the appendix to the report of the 'Inflexible' committee.

"The conclusion I have reached, after a careful study of the subject, is that we need very considerable extensions of our knowledge of the laws of wind-pressure before more exact investigations will be possible so as to enable us to pronounce upon the safety or danger of a sailing ship. Nor must it be overlooked that sailing ships are not to be treated as machines worked under certain fixed conditions. Their safety depends at least as much upon seamanship and skilful management as upon the qualities with which they are endowed by their designers. Moreover, it is idle to pretend that, in determining what sail-spread can be safely given to a ship, the naval architect proceeds in accordance with exact or purely scientific methods. He is largely influenced by the results of experience with other ships, and thus proceeds by comparison rather than by direct investigation from first principles. Certain scientific methods are employed, of course, in making these comparisons. For example, the righting moment at different angles of inclination is usually compared with the corresponding 'sail-moment'; but even here certain assumptions have to be made as to the amount of sail to be reckoned in the calculation, and as to the effective wind-pressure per unit of sail-area. Between ship and ship these assumptions are unobjectionable, but they are not therefore to be regarded as strictly true.

"The calculations of curves of stability and the determination of the ranges of stability for ships form important extensions of earlier practice. But, even when possessed of this additional information, the naval architect must resort to experience in order to appreciate fairly the influence of seamanship and the relative manageability of ships and sails of different sizes. There can be no question but that a good range and large area of a curve of stability denote conditions very favourable to the safety of a ship against capsizing. But, in practice, it frequently happens that such favourable conditions can scarcely be secured in association with other important qualities, and a comparatively moderate range and area of the curve of stability have to be considered when the designer attempts to decide whether sufficient stability has been provided. Under these circumstances experience is of the greatest value; *a priori* reasoning cannot take the place of experience, because (as remarked above) the worst combination of circumstances cannot be fixed, and because some important conditions in the problem are yet unsettled. Certain arbitrary standards may be set up, and ships may be pronounced safe or unsafe; but this is no solution of the problem. There are classes of ships in existence which have been navigated in all weathers, under sail, and in all parts of the world, which might be pronounced unsafe if tested by some of the standards that have been proposed; but the fact that not a single vessel of that class has been capsized or lost at sea during many years will probably be accepted, in most quarters, as sufficient evidence of the seaworthiness of these classes, and as an indication of the doubtful authority of the proposed standards."

For the different kinds of sails, and for sailmaking, see SAIL.

Steam. The "Comet" was the first steam-vessel built in Europe that plied with success in any river or open sea. She was built in Scotland in 1811–12 for Mr Henry Bell, of Helensburgh, having been designed as well as built by Mr John Wood, at Port-Glasgow. The little vessel was 42 feet long and 11 feet wide. Her engine was of about four horse-power, with a single vertical cylinder. She made her first voyage in January 1812, and plied regularly between Glasgow and Greenock at about 5 miles an hour. There had been an earlier commercial success than this, with a steam vessel in the United States, for a steamer called the "Clermont" was built in 1807, and plied successfully on the Hudson River. This boat, built for Fulton, was engined by the English firm of Boulton & Watt. The reason for this choice of engineers by Fulton appears to have been that Fulton had seen a still earlier steamboat for towing in canals, also built in Scotland, in 1801, for Lord Dundas, and having an engine on Watt's double-acting principle, working by means of a connecting rod and crank and single stern wheel. This vessel, the "Charlotte Dundas," was successful so far as propulsion was concerned, but was not regularly employed because of the destructive effects of the propeller upon the banks of the canals. The engine of the canal boat was made by Mr William Symington, and he had previously made a marine engine for Mr Patrick Miller, of Dalswinton, Dumfriesshire. This last-named engine, made in Edinburgh in 1788, marks, it is said, the first really satisfactory attempt at steam navigation in the world. It was employed to drive two central paddle-wheels in a twin pleasure-boat (a sort of "Castalia") on Dalswinton Loch. The cylinders were only 4 inches in diameter, but a speed of 5 miles an hour was attained in a boat 25 feet long and 7 feet broad. The first steam vessel built in a royal dockyard was also called the "Comet." She appears to have been built about the year 1822, and was engined by Boulton & Watt. This ship had two engines of forty horse-power each, to be worked in pairs on the plan understood to have been introduced by the same firm in 1814. In 1838 the "Sirius" and "Great Western" commenced the regular Atlantic passage under steam. The latter vessel, proposed by I. K. Brunel, and engined by Maudslay Sons & Field, made the passage at about 8 or 9 knots per hour. One year earlier (1837) Captain Ericsson, a scientific veteran who is still among us (1886), towed the Admiralty barge with their lordships on board from Somerset House to Blackwall and back at the rate of 10 miles an hour in a small steam vessel driven by a screw.

The screw did not come rapidly into favour with the Admiralty, and it was not until 1842 that they first became possessed of a screw vessel. This vessel, first called the "Mermaid" and afterwards the "Dwarf," was designed and built by the late Mr Ditchburn, and engined by Messrs Rennie. In 1841–3 the "Rattler," the first ship-of-war propelled by a screw, was built for and by the Admiralty under the general superintendence of Brunel, who was also superintending at the same time the construction of the "Great Britain," built of iron. The engines of the "Rattler," of 200 nominal horse-power, were made by Messrs Maudslay. They were constructed, like the paddle-wheel engines of that day, with vertical cylinders and overhead crank-shaft, with wheel gearing to give the required speed to the screw. The next screw engines made for the Royal Navy were those of the "Amphion," 300 nominal horse-power, made in 1844 by Miller and Ravenhill. In these the cylinders took the horizontal position, and they became the type of screw engines in general use. This ship had a screw-well and hoisting gear for the screw. In 1845 the importance of the screw propeller for ships of war became fully recognized, and designs and tenders were invited from all the principal marine engineers in the kingdom. The Government of that day then took the bold step of ordering at once nineteen sets of screw engines. Six of these had wheel gearing; in all the rest the engines were direct-acting. The steam pressure in the boilers was from 5 to 10 ℔ only above the atmosphere, and if the engines indicated twice the nominal power it was considered a good performance. The most successful engines were those of the "Arrogant" and "Encounter" of Messrs Penn. They had a higher speed of piston than the others, and the air-pumps were worked direct from the pistons, and had the same length of stroke. These engines developed more power for a given amount of weight than other engines of their day, and were the forerunners of the many excellent engines on the double-trunk plan made by this firm for the navy. The engines with wheel-gearing for the screws were heavier, occupied more space, and were not so successful as the others, and no more of that description were ordered for the British navy.

Economical engines.

Up to 1860 neither surface-condensers nor superheaters were used in the navy. The consumption of fuel was about $4\frac{1}{4}$ ℔ per one horse-power per hour. In that year (1860) three ships, the "Arethusa," "Octavia," and "Constance," were fitted respectively by Messrs Penn, Messrs Maudslay, and Messrs Elder, with engines of large cylinder capacity to admit of great expansion, with surface-condensers and superheaters to the boilers. Those of the "Arethusa" were double-trunk, with two cylinders; those of the "Octavia" were three-cylinder engines; and those of the "Constance" were compound engines with six cylinders; the first two were worked with steam of 25 ℔ pressure per square inch, and the last with steam of 32 ℔ pressure. All these engines gave good results as to economy of fuel, but those of the "Constance" were the best, giving one indicated horse-power with $2\frac{1}{4}$ ℔ of fuel. But the engines of the "Constance" were excessively complicated and heavy. They weighed, including water in boilers and fittings, about $5\frac{1}{2}$ cwts. per maximum indicated horse-power, whereas ordinary engines varied between $3\frac{1}{4}$ and $4\frac{3}{4}$ cwts.

For the next ten years engines with low-pressure steam, surface-condensers, and large cylinder capacity were employed almost exclusively in the ships of the Royal Navy. A few compound engines, with steam of 30 ℔ pressure, were used in this period with good results as to economy, but they gave trouble in some of the working parts. Compound engines, with high-pressure steam (55 ℔), were first used in the Royal Navy in 1867, on Messrs Maudslay's plan, in the "Sirius." These have been very successful. In the Royal Navy as well as in the mercantile marine, the compound engine is now generally adopted. They have been made rather heavier than the engines which immediately preceded them, but they are about 25 per cent. more economical in fuel, and, taking a total weight of machinery and fuel together, there is from 15 to 20 per cent. gain in the distance run with a given weight.

Reduction in weight of engines.

Wrought-iron is largely used in the framing in the place of cast-iron, and hollow propeller shafts made of Whitworth steel. By these means the weight is being reduced, and it is to be hoped that a still further reduction may yet be made by the use of high-class materials in the engines and steel in the boilers.

Mr Thornycroft, of Chiswick, and others, by means of high rate of revolution, forced combustion, and the judicious use of steel, have obtained as much as 455 indicated horse-power with a total weight of machinery of $11\frac{3}{4}$ tons, including water in boilers. The ordinary weight of a seagoing marine engine of large size, with economical consumption of fuel, excepting a few of very recent construction, would be six or seven times as great. By closing in the stoke-holes and employing fans to create a pressure of air in them capable of sustaining from one to two inches of water in the gauges the consumption of coal per square foot of fire-grate per hour may be raised to 130 ℔ and upwards. The indicated horse-power which can be obtained in ordinary cases with the steam-blast in the chimney to quicken consumption does not exceed ten. But by the forced draft above described it can be raised with ordinary boilers to 17 to 18 indicated horse-power per square foot of fire-grate. In torpedo boats with locomotive boilers over 28 horse-power per foot of fire-grate is attainable.

The following observations on efficiency are taken from the work of Mr Sennett on *The Marine Steam Engine*:—

"In every machine there are always certain causes acting that produce waste of work, so that the whole work done by the machine is not usefully employed, some of it being exerted in overcoming the friction of the mechanism, and some wasted in various other ways. The fraction representing the ratio that the useful work done bears to the total power expended by the machine is called the efficiency of the machine; or—

$$\text{Efficiency} = \frac{\text{Useful work done.}}{\text{Total power expended.}}$$

In the marine steam engine, in which the useful work is measured by its propelling effect on the ship, there are four successive stages, in each of which a portion of the initial energy is wasted, and these four causes all tend to decrease the efficiency of the engine as a whole.

"In the first place, only a portion of the heat yielded by the combustion of the coal in the furnaces is communicated to the water in the boiler, the remainder being wasted in various ways. The fraction of the total heat evolved by the combustion of the coal, that is, transmitted to the water in the boiler, is in ordinary cases not more than from $\frac{5}{10}$ to $\frac{7}{10}$. This fraction is called the efficiency of the boiler.

"Secondly, the steam, after leaving the boiler, has to perform mechanical work on the piston of the engine; but this work, in consequence of the narrow limits of temperature between which the engine is worked, is only a small fraction of the total heat contained in the steam—say from $\frac{1}{8}$ to $\frac{1}{10}$, according to the kind of engine and rate of expansion employed. This fraction, representing the ratio of the mechanical work done by the steam to the total amount of heat contained in it, is called the efficiency of the steam.

"Thirdly, in the engine itself a part of the work actually performed by the steam on the pistons is wasted in overcoming the friction of the working parts of the machinery and in working the pumps, &c. The remainder is turned into useful work in driving the propeller. The fraction representing the ratio that this useful work bears to the total power exerted by the pistons is called the efficiency of the mechanism.

"Fourthly, the propeller, in addition to driving the ship ahead, expends some of the power transmitted to it in agitating and churning the water in which it acts, and the work thus performed is wasted,—the only useful work being that employed in overcoming the resistance of the ship and driving her ahead. The ratio of this useful work to the total power expended by the propeller is called the efficiency of the propeller.

"The resultant efficiency of the marine steam engine is made up of the four efficiencies just stated, and is given by the product of the four factors representing respectively the efficiencies of the boiler, the steam, the mechanism, and the propeller. Any improvement in the efficiency of the marine steam engine, and, consequently, in the economy of its performance, is therefore due to an increase in one or more of these elements."

Under STEAM ENGINE will be found a discussion of the first three of the efficiencies enumerated above. Propulsion and propellers have to be considered here.

"The principle upon which nearly all marine propellers work," says Mr Sydney Barnaby, "is the projection of a mass of water in a direction opposite to that of the required motion of the vessel. When a vessel is in motion at a regular speed the reaction of the mass of water projected backwards by the propeller is exactly equal to the resistance experienced by the vessel. When it is clearly understood that propulsion is obtained by the reaction of a mass of water projected sternwards with a velocity relative to smooth water, the absurdity is at once seen of attempting to get a propeller to work without slip. If there is no slip there is no resultant propelling reaction except in the limiting case where the mass of water acted upon is infinite. The whole problem therefore resolves itself into this—What is the best proportion between the mass of water thrown astern and the velocity with which it is projected, that is, if the screw propeller is under consideration, the ratio between its diameter and its pitch?"

"There are four different kinds of propellers apart from sails—the oar, the paddle-wheel, the screw, and the water jet.

"The first and oldest of them—the oar—may be used in two ways. The action may be intermittent, as in rowing, when water is driven astern during half the stroke and the instrument brought back above the water; or its action may be continuous, as in sculling. When used as in rowing it is exactly analogous to a paddle-wheel, while the action of the scull closely resembles that of the screw. It is supposed that in the ancient galleys, which were propelled by a large number of oars in several tiers or banks, the oars hung vertically and worked inwards and outwards with a sculling action. They were not removed from the water, but served as props when the vessel was aground. The oars were always propelling the vessel, in both parts of the stroke. The rowers generally sat with their faces outwards and forwards. There was great overhang of the sides to allow of several tiers of rowers one above another. The oar as used for rowing is a very efficient instrument. To obtain the maximum efficiency out of it a constant pressure should be maintained upon the oar, so that the water is started gradually from rest, and the acceleration uniformly increased throughout the whole of the stroke. A glance at a university crew will show that the stroke is kept up with a uniform pressure and without any jerk."

Speaking of the screw propeller, Mr S. Barnaby says:—"The speed with which water can follow up the blades of a screw depends upon the head of water over it, but when the immersion is sufficient to exclude air a head of water equivalent to 30 feet is supplied by the atmosphere, as has been pointed out by Prof. Osborne Reynolds. Experiments on the model of the Thornycroft screw have shown that the efficiency, which is as much as 70 per cent. when properly immersed, falls to about 50 per cent. when breaking the surface of the water. As a result of a change from a diameter of 5 feet 10 inches to 4 feet 6 inches the speed of the first-class torpedo boat was raised from 18 to 20 knots, other conditions remaining the same.

"There is no doubt that the stern is the best position for the screw. As a vessel passes through the water the friction imparts motion to the layer of water rubbing against the side. This layer increases in thickness towards the stern, so that, after the vessel has passed through, a considerable quantity of water is left with a motion in the same direction as the vessel. If the screw works in this water it is able to recover some of the energy which has been expended by the ship in giving it motion. The speed of this water, which Rankine estimates may be as much as one-tenth of the speed of the vessel, does not depend upon the form but upon the nature and extent of the surface. As it is a necessity that there should be such a wake, it is a distinct advantage to place the propeller in it and allow it to utilize as much as possible of the energy it finds there. It is important not to confound this water, which has had motion given to it by the side and bottom of the ship, with the wave of replacement, that is, the water filling in behind the ship. It should be the aim to interfere as little as possible with this motion, as such interference augments the resistance of the ship very considerably, even in well-formed ships. The propeller should therefore be kept as far away from the stern as possible.

"In the small high-speed stern launches the propeller has been kept outside the rudder, with advantage to the speed. What is required is that before reaching the screw the water shall have given out upon the stern of the ship the energy put into it by the bow. If a screw propeller is placed behind a bluff stern so that its supply of water is imperfect it will draw in water at the centre of the driving face, and throw it off round the tips of the blades, like a centrifugal pump, thus producing a loss of pressure upon the stern of the vessel. For very high speed vessels several propellers would enable the weight of the machinery to be kept down. The weight of an engine of a given type per indicated horse-power varies inversely as the number of revolutions per minute; that is, the greater the number of revolutions the less the weight per indicated horse-power.

"There is a certain quantity of work which must be lost with any propeller, and it is equal to the actual energy of the discharged water moving astern of the propeller with a velocity relative to still water. As this energy varies as the weight multiplied by the square of the velocity, if we double the quantity of water acted upon we double the loss from this cause, but if we double the velocity with which the water is discharged we increase the loss fourfold. This shows the advantage of acting upon a large column of water, and leaving it with as small a speed as possible relative to still water. For this reason the screw is a more efficient instrument than a paddle-wheel, and the jet propeller, with its small area of jet, is so much inferior to the screw. From the above considerations it would appear that the larger the diameter of a screw and the smaller the slip the greater the efficiency would be. There is, however, another element of loss which has to be considered, which imposes a limit to the size of a screw in order to obtain the best efficiency. This element is the friction of the screw blades. How large the effect of this element may be is shown by the case of H.M.S. 'Iris.' This ship was originally fitted with two four-bladed propellers, 18 feet in diameter, and with 18 feet pitch or velocity of advance per revolution. She obtained a speed with these propellers of $15\frac{1}{2}$ knots with an expenditure of 6369 horse-power. Two blades were then taken from each propeller, reducing the total number from eight to four. The indicated horse-power then required for the same speed was 4369, or two thousand less horse-power. This amount had been lost in driving the four additional blades."

"The causes of loss of work incidental to propellers of different kinds may be summed up as follows:—(1) Suddenness of change from velocity of feed to velocity of discharge. Propellers which suffer from this cause are the radial paddle-wheel and the common uniform pitch screw; while those which in varying degree avoid it are the gaining pitch screw, the feathering paddle-wheel, Ruthven's form of centrifugal pump, and the oar. (2) Transverse motion impressed on the water. Propellers which lose in efficiency from this cause are ordinary screw-propellers, which impart rotary motion, radial wheels, which give both downward and upward motion on entering and leaving the water, and oars, which impart outward and inward motion at the commencement and end of the stroke respectively. This loss is greatly reduced in the guide-propeller, as the guides take the rotary motion out of the water and utilize it in so doing. (3) Waste of energy of the feed water. This is experienced in the jet propeller as generally applied."

The present condition of the case of screw steamship propulsion appears, according to Mr Froude's estimate, to be that, calling the effective horse-power (that is, the power due to the net resistance) 100, then at the highest speeds the horse-power required to overcome the induced negative pressure under the stern consequent on the thrust of the screw is 40 more; the friction of the screw in the water is 10 more; the friction in the machinery 67 more; and air-pump resistance perhaps 18 more; add to this 23 for slip of screw, and we find that, in addition to the power required to overcome the net resistance = 100, we need 40 + 10 + 67 + 18 + 23, making in all 258; *i.e.*, at maximum speeds the indicated power of the engines needs to be more than two-and-a-half times that which is directly effective in propulsion. (N. B.)

Boatbuilding.

The foregoing article may be supplemented by a brief account of boatbuilding. The distinction between this and shipbuilding is not of a marked character and cannot be sharply defined. But for all practical purposes the builder of a vessel without a deck, or but partially decked, and propelled partly by sails and partly by oars, or wholly by oars, may be defined as a boatbuilder.

The boats in general use at present may be classified as racing boats, pleasure boats, or boats used for commercial purposes. Racing boats (compare ROWING) are generally built of mahogany, and are the most perfect specimens of the boatbuilder's art. The outrigger sculling boat measures from 30 to 35 feet long, 12 to 14 inches in breadth, and 9 inches in depth, weighing only from 35 to 45 ℔, and the eight-oared outrigger, being from 55 to 65 feet long by 2 feet 2 inches to 2 feet 5 inches in breadth, weighs about 300 ℔. Pleasure boats vary in form and dimensions, from the 15-feet rowing boat used on the sea-coast to the gondola type found principally on the canals of Venice and used occasionally on the Thames, &c., for ceremonial pageants. Boats used for commercial purposes embrace fishing, canal, and ships' boats. Fishing boats (compare FISHERIES) are gradually passing from the sphere of the boatbuilder to that of the shipbuilder,—the open boats of former years being in many cases replaced by large, strong, decked craft more able to withstand the gales of the British coasts. Canal boats are generally long, narrow, and shallow, from 50 to 70 feet long by 8 to 10 feet in breadth, and from 4 to 5 feet in depth. All sea-going vessels are required by statute to be provided with boats fully equipped for use, not fewer in number nor less in their cubical contents than what is specified for the class to which the ship belongs. The boats vary considerably in form and dimensions as well as in material and construction, according to the service intended. The number of boats a passenger steamer of 1000 tons and upwards is required to carry is six or seven, according to the dimensions of the boats. In either case two of the largest boats must be fitted as lifeboats. If the smaller number is carried, the set will consist of two lifeboats, one launch, two cutters or pinnaces, and one gig.

Lifeboats are built both ends alike, having a sheer or rise from midships towards stem and stern of $\frac{1}{2}$ inch to $\frac{3}{4}$ inch per foot of length. They have air-cases of copper or yellow metal fitted in the ends and along the sides of the boat, of sufficient capacity to give each person carried in the boat one and a half cubic feet of strong enclosed air-space (compare vol. xiv. p. 570). Cutters are similar in form but of smaller dimensions than lifeboats; pinnaces are about the same dimensions as cutters, but have square sterns. Gigs are of lighter construction and finer form than pinnaces. A service boat called a dingy is also carried, for the conveyance of light stores between the shore and the vessel. Boats, when carried so close to the funnel of a steamer as to be injuriously affected by the heat therefrom, have of late years been built of zinc, iron, or steel. Those built of steel have plates $\frac{1}{16}$ inch thick and galvanized, the keel, stem, stern, and deadwood knees being of wood, to which the plating is attached.

The following is an outline of the method of construction. The designer lays down on paper the lines and body-plan of the craft, which are afterwards traced full size on the floor of the drawing-loft. From these full-sized sections moulds are made. The stem and stern posts, having been cut out to the shape designed, are tenoned into mortices in the keel. Two knees overlap, and bind the stem and stern posts to the keel, and are bolted with through bolts and clenched outside over a ring or washer. A stout batten of wood is then nailed between the stem and sternpost heads to connect them together, and a line is then stretched from stem to sternpost to represent the water-line. The keel, stem, and stern posts being in position on the stocks, the stem and stern posts are then plumbed and secured by stays of wood. The rabbets in the keel, stem, and stern posts are then cut out with a chisel, after which the moulds are put into their proper places, plumbed with the water-line, and kept in position by stays. The planking is then proceeded with, strake after strake, and when the boat is planked up to the top strake the floors and timbers are put in. The floor extends across the keel and up to the turn of the bilge. They are fastened through the keel with copper or yellow metal bolts and to the planking with copper nails.