A TREATISE

ON

NAVAL ARCHITECTURE

AND

SHIP-BUILDING

OR

AN EXPOSITION OF THE ELEMENTARY PRINCIPLES
INVOLVED IN THE SCIENCE AND PRACTICE
OF NAVAL CONSTRUCTION.

COMPILED FROM VARIOUS STANDARD AUTHORITIES.

BY

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TO

Vice-Admiral David D. Porter, U. S. N.,

UNDER WHOSE AUSPICES AS

SUPERINTENDENT OF THE NAVAL ACADEMY,

THE IMPORTANT STUDY OF NAVAL CONSTRUCTION

WAS EMBODIED AS PART OF THE REGULAR COURSE AT THAT INSTITUTION,

This Compilation is Respectfully Dedicated.

PREFACE TO THE SECOND EDITION.

THE matter contained in this volume has been mainly gathered from such standard works as those of Scott Russell, Rankine, Murray and Knowles, with some assistance from Fairbairn, Fishbourne, Marrett and Peake—the object in view being to furnish a text-book for the use of the students at the United States Naval Academy.

A naval officer of fair mathematical ability can readily make himself familiar with all the essential principles governing the design of a ship, as well as the method of making the necessary calculations; but to become a naval constructor is quite another thing, and needs the long and patient apprenticeship of the "mould-loft" and ship-yard. Yet there is no more mystery about naval construction than about steam-enginery; and any intelligent officer may soon be theoretically, at least, conversant with both, while the importance of acquiring such knowledge, in these days of progress, is self-evident.

In accordance with these views, this compilation has been made, and is now submitted for the consideration of my brethren of the naval service.

COLD SPRING, N. Y., June, 1869.

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NAVAL ARCHITECTURE.

NAVAL ARCHITECTURE.

CHAPTER I.

THE SCIENCE OF NAVAL ARCHITECTURE.

THE Science of Naval Architecture treats several chief problems:

1st. How to make a ship swim.

2d. How to make her carry heavy weights.

3d. How to make her stand upright when the waves or the winds try to upset her.

4th. How to make her obey the will of her commander.

5th. How, in addition to all these, to make her go easily through the water at high speed.

Subordinate to the above are the following:

6th. How to give a ship a given draft of water and no more; *first,* when she is light, and *second,* when she is laden.

7th. How, with the given draft of water, to prevent her oversetting when she is light, and rises high out of the water; and how to prevent her being overturned by the great burden laid upon her when she is heavily laden.

8th. How, when a heavy sea strikes on one side of the ship, to prevent it from rolling into her, without, at the same time, heeling her so far over as to expose her to danger on the other side.

9th. How to make her bow rise to the sea, so that the waves may not roll over her deck, without, at the same time, making her rise so far as to plunge her deeply into the succeeding hollow, and make her uneasy and slow.

10th. How to make her stern of such a form that, when *scudding,* the sea shall not break over her poop.

11th. How to make her so stiff on the water that the pressure of the wind on her sails shall not upset her, without, at the same time, giving her so much stiffness as to endanger her masts by the jerk of the sea.

12th. How to make her turn quickly, and in short space, in obedience to her rudder, no matter how fast she may be going; and how to make her weatherly.

13th. How, in combination with the foregoing, to make her fast before the wind, against the wind, across the wind, when she is laden, when light, when the sea is smooth, and when the sea is rough.

These are some of the undertakings with which the science of the naval architect must cope. They are all matters the principles of which belong to science. They are all matters of forethought and calculation, for which exact results are to be sought and ascertained, long before the ship-builder can even set about his work. They form the *science* of Naval Architecture, as distinguished from the *art* of Ship-building.

CHAPTER II.

THE ART OF SHIP-BUILDING.

THE Art of Ship-building consists in giving to the materials of which the ship is to consist all the forms, dimensions, shapes, strengths, powers and movements necessary to make them fulfill and comply with the conditions resulting from the calculations of the naval architect.

1. To make the ship swim, she must be tight and staunch everywhere, so as to take in no water through her seams or fastenings.

2. To make her swim so deep, and no deeper, the weights of *all* her parts, taken together, must be equal to the measure the naval architect has given, and which he has called her "*light displacement.*" This done, it is the business of the naval architect, and not of the builder, to see that a given load placed in the vessel will not sink her beyond her given load draft.

3. To make the ship strong enough to carry her load without straining herself is part of the art of ship-building: the quantity of material put into the ship being limited by the naval architect, it belongs to the craft of the ship-builder to select the fittest quality of material, to put it in the most effectual place, and to unite the pieces in so substantial a manner that no piece, when strained, shall part from its neighbor, but that every part shall not only do its own work, but be able to help, in need, every other part, so that all, joined together, shall form one staunch whole.

4. In making the ship strong enough for the work she has to do, the builder must preserve throughout the whole such a just distribution of the weight of the parts as that she shall not be too heavy at the bottom, nor at the top, nor at the bow, nor at the stern, but that the weights of the parts, in their places, shall so accurately corre-

spond to the nature of the design that there shall be *a perfect balance of weight around the exact centre* intended by the architect. This is necessary in order that the trim of the vessel at the bow and the stern, and her *stiffness*, or power to stand upright, shall turn out to be what is meant in the plan. The best designs have failed through unnecessary weights being, in the execution of the work, placed where they did harm, instead of where they could have done good. *Disposition of weight*, therefore, in the hull is an important point in practical ship-building.

5. The geometry of ship-building is one of the most important branches of the ship-builder's art, and the exact fitting and execution of parts truly shaped is one of the best points in which he can show his skill. The design to be executed having been put into his hand, the ship-builder has first to lay it down on the *mould-loft floor* to its full size; next he has to divide and show on this drawing, in its full size, every part of which the ship is to consist; of each of these parts a separate and independent drawing has now to be made, and a shape or *mould* made from this in paper, in wood or in iron. To this mould the material of the ship, whether pieces of iron or wood, has to be *exactly* shaped; and these independent drawings or moulds must show every face and every dimension of each part. When it is remembered that in every ship, consisting probably of several thousand parts, generally speaking no two are alike, and only two, at most, resemble each other—namely, the counterpart pieces on the two opposite sides—and that every one of those pieces has probably four sides, each with a different curve from the other, and containing possibly one hundred perforations,* which must have precise positions with reference to these curves, it will be seen that making the measurements and drawings is a labor which must be performed with the utmost precision and intelligence, in order to have good, honest and reliable work, and requires no small amount of geometrical skill from the builder.

6. The art of the ship-builder frequently extends not only to the mere construction of the ship's hull, but also to the construction, or fitting in, of all those separate things which are not parts of the ship proper, and yet without which she cannot be sent to sea. There are parts which, if not made by the ship-builder himself, must be so

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* See Iron Ship-building.

provided and fitted as if he had himself made them. A ship is not complete unless she has a *rudder* and *steering mechanism, compasses* and their *binnacles, anchors* and their *cables, capstans* and *windlasses* to raise and lower the anchor, *boats* and *davits,* and the *tackle* to raise and lower them, *masts* and *yards,* and *standing rigging* and *running rigging,* and *sails* and *blocks,* and all the means of placing, fastening, supporting and working them. There must be, also, *pumps* to work in case of accident, besides a large inventory of smaller things, all to be found before a ship is complete or fit to go to sea. All these, for the most part, the ship-builder has to find; and, while it is a matter of doubt, opinion, custom, or special contract, how many, and which of them, are parts of the hull, or parts merely of the equipment of the hull, or of stores for her voyage, yet it is always in the ship-builder's province to consider fully all these things, and so to arrange for them that no unnecessary difficulties may be interposed in the way of those who have to supply and to fit them. Generally speaking, the rudder and steering-gear, the mechanism for fixing and working the anchors and cables, the masts and spars, and the means of attaching the rigging and working the sails, and boats and the ship's pumps, are reckoned part of the ship proper, to be done in the ship-builder's yard, while the rigging itself, the sails, the anchors, the cables, the compasses, and all the minor inventory are reckoned as "*Equipment*" only. It is part, therefore, of the craft of the ship-builder to understand thoroughly, as well as to execute, that part of the equipment and the fitting which is reckoned as part of the hull.

7. But it is the finishing-stroke of the ship-builder to place his vessel safely in the water. To this part of his skill belong all the traditions of launching. In this the traditional ship-builder excels; for science has taught him nothing. The knowledge of launching has grown, and, with the odd variations in form, there is a wonderful unity in substance, even in different countries. The construction of the *cradle* in which the ship is committed to the deep, of the *ways* which carry her from the shore into the water, of the slope on which she glides so smoothly down, even to the mixture of soap and grease which lubricates her passage,—all is known by fixed tradition; and so skilled has the long progress of practice rendered this finishing-stroke of art, that constructors, when ordered to lengthen a ship already built, have been known to cut her in two, and to give to the

after part so gentle a launch, that it stopped exactly when it had reached the point of distance from the fore part to which the lengthening was meant to extend. So, also, when an attempt was made, as in the launch of the "Great Eastern," to bring in other than ship-building skill, the result was an extravagant failure.* This, therefore, is one of the points in which the ship-builder cannot do better than adhere to his traditions. But along with these general principles of matured experience, there is enough variety of practice to leave the ship-builder a wide choice. Some nations launch with the bow, some with the stern foremost, some broadside on. Some launch with the *keel* resting on the *ways*, the *bilges* clear; others launch with the bilges on the ways, and the keel clear; but in all these different modes a tolerable attention to the precepts of tradition will enable the ship-builder to execute this "tour de force" with a fair certainty of success. In England, some have even ventured to carry this so far as to launch steamers with masts up, rigging fitted and sails bent, their equipment on board, their engine and boilers fitted in them, their fires lighted and steam up; and they have left the ship-yard from the launch-ways in perfect safety, propelled by their own steam.

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* This vessel was launched, broadside on, from the Isle of Dogs in the Thames river.

CHAPTER III.

THE METHODS OF PROPELLING SHIPS.

THE naval architect, the ship-builder and the marine engineer represent three classes of professional skill, all of which go to the achievement of a perfect steamship. The duties of all must be successfully performed, in order that the duty of the steamship may also be performed successfully. It is not necessary that the three duties should be performed by three separate men, but all are essential. They may even be all performed by one man, and he may first form the design of the whole, then build the ship, and, lastly, construct the engines;* but, in theory, it is better to keep these parts separate, although, in practice, they cannot be too closely united.

Steam navigation, or the propelling of a ship by steam, is effected by means of three instruments. The source of the entire steam-power of a ship resides in the *boiler*, and it is the power of this boiler to produce steam which ultimately determines the question of the power and speed of the ship. Boilers, therefore, are the first consideration in marine engineering. The second part is that which applies the steam made in the boiler to the purpose of producing mechanical motion, and forms what is called the machinery, or *steam engine*. It is by the engine that the steam is turned to use and worked; but engines accomplish their purpose differently; they all waste some steam in moving themselves and not in moving the ship; and some waste much steam and do little work. It is difficult to know how much is wasted, even by the best marine engines, for some of great reputation waste more than others of less. The marine engineer must see that he effects the least possible waste, and gets

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* This is the case in the French navy, where the chief constructor is also the constructing engineer.

out of his engines the maximum possible effect; but this result he can only know by taking careful measures, not merely of the work done by the steam in the engine, but also of the work given out by the engine after working itself. It is his duty, therefore, thoroughly to master all these points.

The third instrument of steam navigation is that by which the ship is made to move. The boiler makes the steam, and the steam moves the engine merely, but not the ship. The engine has to move something, which, by moving the water, shall compel the ship to move. Though all three instruments move the ship, or tend to move it, it is only this last which directly touches the water, and which moves it and the ship; it is called the *motor* or *propeller*. The steam propeller is, therefore, the third instrument employed in steam navigation. The kinds of propellers are many and various; some being a single instrument, as a *screw propeller*, and the *paddle-wheel propeller*, when used singly in the stern of a steamer, or in the centre of a double or twin vessel. There are also *double propellers*, as where *twin screws* are used in one vessel, or where two paddle-wheels are used on a vessel. There is also the *jet propeller* (both steam and water), the *chain propeller*, the *stern propeller*,* and a host of others not now in practical use. There are propellers out of the water and under water, at the sides and the bottoms of ships, at the bow as well as at the stern; and almost every place that can be named has been selected by *somebody* for a propeller. It is the business of the practical marine engineer to devote his attention *to those modes of propelling which are in general use*. He must examine the laws which govern all steam propulsion, and thus learn to measure the degree in which it can be made perfect, and the degree in which, in the nature of things, it must remain imperfect, aiming continually to get as near to perfection as possible. He must never forget, however, that it is absolutely impossible to attain this perfection, since water slips away from the propeller, and that, in thus escaping, it carries off power in the very act of motion. This power so lost is called loss by *slip*. A scientific knowledge of the laws of propulsion enables him to judge when this slip runs to waste merely, and when, on the other hand, it is no more in quantity than is necessary to produce the propulsion of the vessel. In order to propel the vessel, the propeller must take

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* This has been called the *steam oar*.

hold of and push the water; the water *will* slip away from its hold, but in the very act of slipping the propeller must dextrously lay hold of it in just so many instants of time as to take out of it the greatest push with the least slip; *no* slip is nonsense—*much* slip is folly; as little slip as is practicable may be fairly demanded of the competent marine engineer.*

Besides propulsion by steam, there is another method of propulsion, the subject of an entirely distinct profession from that of the engineer and architect; that is, driving ships by sails, instead of steam. This is properly the vocation of the seaman; and it is his business to know and say how he would best like all arrangements of the masts, sails and yards, so that he and his crew can best handle and manage them. But there is one part which the naval architect should do: he should thoroughly study the *balance of sail,* as every ship, according to the qualities of her design, will carry her sails badly if they have not been perfectly balanced in conformity with the peculiar properties, proportions and dimensions of each ship. It is the naval architect's business to provide the seaman with a perfect balance of sail; and it is the latter's province to know how to use it, and handle his ship properly when he has got it. Balance of sail, therefore, must be studied along with *balance of body, draft of water, trim* and the other original mathematical elements of the design of a ship.

There is, finally, another point in which the professions of the seaman and naval architect touch each other very closely. This is, the *trim* and *stowage* of the ship; and the reason why the business of the sailor here touches so closely upon that of the architect is, that a little ignorance or folly on the part of the seaman can neutralize and undo all that the naval architect and ship-builder have done for the good qualities of the ship.

If he has not knowledge enough of the place where the *centre of balance of weight* of the ship is put, and does not contrive to keep it where it ought to be, but fills the ship with improper weights at improper places, he will ruin the performance and mar the reputation of the finest ship in the world.

But few seamen know these things thoroughly, and thereby acquire reputation both for themselves and their ships. With an ignorant

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* The term Engineer is here used to denote the designer or builder of an engine.

officer it is impossible to know whether the ship be a good or a bad one.

Now, although it may not be possible for a sailor to be also a naval architect, inasmuch as each profession demands the study of a lifetime to learn it, yet a sailor *can learn and should know* enough of the architectural points of a ship to turn them to the very best account; and it will be necessary, therefore, farther on, to investigate some of those points common to the seaman and naval architect.

CHAPTER IV.

DIFFERENT CLASSES OF SHIPS FOR PEACE OR WAR.

ALTHOUGH the principles which guide the naval architect in the construction of ships, and govern their behavior in the sea, are fixed and invariable, it will be the use the ship is to be put to which must govern the naval architect in the application of those principles to practical use. Ships employed for purposes of commerce, for mere pleasure or for purposes of war must be as different in their construction as in their objects, and, accordingly, the different classes of ships, designed for such different uses, give rise to distinct departments of naval architecture.

For the purposes of war, the conditions which the naval architect has to fulfill are widely different from those he has to meet in the design of a merchant vessel. The principles which guide him are the same, yet the points of practice are in some respects easier, in others more difficult. The merchant ship, in its voyages around the world in search of freight, has to undergo all sorts of conditions of emptiness and fullness, of lightness and deepness of draft, and has to stow all sorts of cargoes, with every variety of bulk and of specific gravity. Sometimes she has to carry a heavy deck-load with little in her hold, and at other times, so much weight, so deep in her bottom, that it would seem to be almost impossible to reunite two such opposite uses in the same ship.

The man-of-war has but *one* duty—to convey a known weight of guns and of men to a known place; and this kind of work, being so exactly known, ought to be infallibly and exactly done. That a ship-of-war, under such known conditions, should ever have a mistake made, or an inaccuracy found, in her draft of water, her stability or her speed, might seem therefore disgraceful if it were not, unhappily, too common. The explanation which is sometimes given is, that those whose business it is to order these ships are unable to settle, beforehand, what they are intended to do, and that they are generally afterward ordered to do exactly that for which they were not originally designed.*

There is one peculiarity which belongs equally to both kinds of vessels—that, whatever her load may be, she must, above all things, be *fast*. In commerce, time is money; in war, time is victory; and victory, the sole object of war, is entirely in the hands of the man who has the choice when and where to meet his enemy. This is an axiom, and needs no argument.

To have *easy movements* in bad weather is also the indispensable requisite of a good ship of both sorts; but the quality which constitutes a good sea-going vessel may have to be given to them in different ways.

In a merchant ship, the lading of the ship being variable, and its arrangement entirely under the disposition of the shipmaster and owner, the internal adjustment of weights may be so made as to give her every variety of quality. In the ship-of-war, on the contrary, the disposition of weights being both invariable and inevitable, and fixed by the indispensable purpose of the vessel, the sea-going qualities must be given by the naval architect alone, in his original design; and the subsequent adjustment of the qualities of the ship, by disposition of weight, can be carried out only within narrow limits. It may happen, and it does happen, that the necessary disposition of the greatest weights of the ship-of-war are hostile to the sea-going qualities of the vessel and to the desire of the naval architect. The battery of the ship may be a great weight, acting high out of the water; and that will be a great difficulty, acting with great power against him.

It may be that he has to carry heavy loads of iron armor at great distances from those centres of his ship around which he is anxious to have the most complete repose, even at the time when the efforts of the sea are greatest to put those weights into violent motion; yet these very causes of bad qualities for the sea-going vessel may form a specific virtue for the fighting vessel. The successful reconciliation

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* This was the case with the "double-enders" during the late war—they were designed for river service, but were employed at sea, on blockade.

of such antagonism is the highest triumph of the skill of the naval architect in the design of a ship-of-war.

A third condition of both kinds of vessel, differently carried out, according to the diversity of use, is what it will be necessary to call "*capacity of endurance.*" In a merchant ship, sailing or steamship, this means ability to carry a large freight, to carry it at small cost, within an assigned time. To do this, a merchant ship should maintain her given speed with regularity, independently of weather, should do so at moderate wear and tear in all the elements of her first cost, and should effect, at the same time, great economy in all the usable and consumable stores which form a great part of her floating equipment and provisions, and on which, in great measure, the profit or loss of a voyage depends.

For a ship-of-war the capacity of endurance must be of a nature somewhat different. She must certainly have the power of arriving with certainty at the place where she is wanted, independently of weather; but her sustaining power may often consist in her ability to keep herself in good fighting order for a long time, at a great distance from home, and, without exercising her greatest power, to be in a condition to do so at a moment's warning, without such exhaustion of her resources as may leave her helpless at a critical moment. This is a kind of economy of a very different nature from that of a merchant ship, but must be originally conferred on the vessel by the forethought of the naval architect, and must be studied and carried into effect by the wisdom and knowledge of the officer in command.

There is another branch of professional knowledge and skill, without some acquaintance with which the naval architect cannot design a ship-of-war. A ship that cannot work and fire her guns when wanted may have every other good point, and be worthless for want of that. The architect must know, then, what is necessary, in order that the crew may work the guns to the greatest advantage, and thus aid in achieving victory.

Should two ships engage in a rough sea, the mere fact that the guns in one could be better handled than those in the other in that state of the weather, might be the turning-point of victory.*

Ignorance of this point, therefore, on the part of the designer of

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* So far back as the time of the celebrated Chapman, constructors were keenly alive to the importance of this point.

the ship, would be failure, and he must have the knowledge of all the points relating to the placing and working of the guns before he begins his design—*not*, as we frequently see, *after* the ship is built, and when it is too late.

But magnificent-sailing men-of-war must be considered now as finally dismissed from service. The line-of-battle-ship, fighting under canvas, is no match for the little iron-clad gunboat. It is probable that no such vessel will ever again enter into action. The production of the fleets of the future is at present a race of competition, of science and of skill between the great maritime powers of the world. Who will win this race must depend much upon the wisdom, forethought and capacity of the men who preside over the navy of each country.

Taking this view of the subject, it becomes a matter of paramount necessity that the young officers who will eventually command our ships and lead our fleets should thoroughly understand the conditions which regulate and control the designs of the steam fleets of modern warfare, and the methods used in their practical construction; and it is hoped that this knowledge may promote the advancement of the national interest, both political and mercantile.

CHAPTER V.

GENERAL CONDITIONS OF THE PROBLEM OF NAVAL ARCHITECTURE.

THE professional duty of the naval architect being to frame and complete the *design* of a ship—the word "design" implying plan, use, or purpose—therefore the first duty of the architect is to ascertain accurately, note exactly and conceive clearly the intention and purpose which the vessel is designed to fulfill.

If the case under consideration is that of a merchant vessel, to the owner, then, the naval architect must apply for a clear understanding of all that the ship is meant to be and to do; and therefore the following questions may be of service in eliciting the information necessary before commencing the design of the vessel:

The owner must be asked—first, what he wants his ship to do? He may answer: To trade between New York and New Orleans.

2. What kind of trade he proposes to carry on?—*Answer*. A miscellaneous trade, partly merchandise, partly passengers.

3. What quantity, bulk and nature of cargo?—*Ans*. 500 tons of dead weight; 25,000 cubic feet of bulk, for cargo in the hold.

4. What kind and number of passengers?—*Ans*. 25 first-class, 20 second-class passengers.

5. What sort of voyage?—*Ans*. Once a month, stopping nowhere on the way.

6. At what speed?—*Ans*. An average of 8 knots.

7. Carrying much canvas or little?—*Ans*. To depend mainly on steam, the sails being auxiliary.

8. At what estimated cost per voyage?—*Ans*. $1.75 per mile.

9. How much is the owner prepared to pay for his vessel?—*Ans*. $125,000.

10. How much is the owner prepared to pay for a more or less durable ship? how much for more or less durable engines and boilers? and how much for a more or less complete equipment?—*Ans.* Ship to be classed twelve years, A No. 1; engines and boilers to be those least likely to fail when wanted, most economical in repairs and consumption of fuel; and 15 per cent. preference to be allowed on the price of good engines and boilers over indifferent.

11. What draft of water?—*Ans.* Load draft not to exceed 15 feet; no other limit as to dimensions.

12. What class of shipmasters and engineers to be employed? *Ans.* The best master and engineer, without reference to salary. (The owner will do well to select his master and engineer, and put them in communication with the naval architect before the ship is built.)

13. Is the ship to be confined exclusively to this trade, or may she have in future to be employed on other voyages?

Now from the master and engineer the architect may receive information on the following questions:

14. What is the true length of the voyage according to the course usually followed?

15. What has been the average performance of any known vessels on the line?

16. What would require to be the maximum speed of a vessel in good sailing trim in order to realize an average working speed of eight knots an hour on the voyage?

17. What sort of ships and engines have hitherto been employed to do this sort of work?

18. With how many officers and hands as crew, and how many in the engine-room, is this ship proposed to be worked?

19. Besides the room required for cargo, for passengers and for attendants, how much is to be reserved for machinery, for coals, for ship's company, for ship's stores, for provisions and equipment?

20. What is the exact nature of the equipment required for this peculiar voyage?

21. What are the weights to be carried under these respective heads?

These are the conditions of the problem, without which, as preliminaries, the design of the ship cannot even be begun, and all of them must be sought and given to the naval architect at the outset, in order to prevent much of his work being mere waste.

The result of all these inquiries will lead him to this most important and primary issue, which may be said to determine the chief characteristic of his ship—namely, the *burden* she must carry and the *bulk* she must stow. In addition to her own powers to swim, she must have power to carry; and the total weight she must carry when full is 1000 tons. But the vessel herself will weigh a known quantity—a quantity either suggested to him by some vessel he already knows, or which he must find out by calculation; but suppose it be assumed that his ship will weigh 500 tons in addition to the 1000 tons before stated.

The ship, therefore, with her equipment, her freight and her stores, gives a dead weight to be dealt with in the design of 1500 tons. This is technically called "the total deep-load displacement of the ship," and forms the first condition of the problem. It is the dead weight to be carried; and the question is, How best to carry it? This is treated of under the head of "Displacement."

The foregoing, drawn from the necessities of the merchant service, will serve also to suggest a similar series of requisitions to be made before commencing the design of a vessel of war. The nature of the service on which a man-of-war is to be employed, the harbors she is to enter, the length of a voyage on which she may be sent, the number of her crew, the weight of her guns, ammunition, equipment and stores, and, for a steam vessel, the power required to drive her at a given speed, and the coal required to take her a given distance, with a multitude of particulars quite as minute as those given in the case of the merchant vessel, must be obtained by the naval architect before he can commence his design.

It is sometimes the practice to ask a designer to build a ship-of-war, and to tell him that it will be time enough to consider all the details of her armament, equipment, special construction and destination after the design has been completed and while the ship is in progress. This is a fallacy: it will not be time enough; it will be too late.

Most of the failures in this country have been produced by building the ships first and settling what they were to do afterward. The naval architect who respects his profession should never design his ship until all the requisite data have been given him. Without this there can be no science of naval architecture, and no plan of a ship worthy of being called a design.

But when these have been obtained, he should arrange them, reconcile them, and finally determine them by setting them out in a formal manner, in what may be called the

SCHEME OF CONDITIONS OF CONSTRUCTION,

which forms afterward a programme of work to be done in forming the design of a ship.

Scheme for the Construction of a Merchant Steamer.

	Bulks. Cubic feet.	Weights. Tons.
A miscellaneous cargo	25,000	500
Passengers, 25 first-class	6,250	.....
" 20 second-class	3,000	.....
Engines and boilers (with water)	7,500	150
Fuel and engineer's stores	10,000	200
Equipment and sea stores	7,500	150
Ship's hull and internal fittings	17,500	350
Provisions and water	2,500	50
Officers, engineers, servants and crew	7,500	10
Spare capacity and weight	3,250	90
Gross capacity and weight	90,000	1,500

Voyage of 1500 sea miles (knots).
A mean speed of 8 knots.

Load draft	15 feet.
Speed in smooth water	10 knots.
Fuel per mile	1½ cwt. (168 lbs.)

Ship's company	Officers	5	30 hands.
	Engineer and assistants	3	
	Crew and coal-heavers	22	

Time of single voyage, eight days.

Scheme for a Man-of-war Screw Steamer—(1st-Rate).

	Bulks. Cubic feet.	Weights. Tons.
Engines and boilers (with water) Engineer's stores	50,000	1,000
Fuel	50,000	1,000
Guns, 50	100,000	300
Powder and tanks, including space for light rooms	6,000	50
Shot and shell	2,000	100
Ordnance stores	3,600	50
Water for four weeks, for 500 men	3,500	75
Bread for six months, for 500 men	4,500	50
Other provisions for six months	7,000	100
Masts, yards, rigging and sails	....	155
Spare sails and sailmaker's stores	3,000	30
Navigator's stores Boatswain's stores	2,000	25
Carpenter's stores	1,300	20
Boats	....	12
Chain cables	1,500	65
Anchors	....	22
Officers' stores	2,500	10
Paymaster's and marines' stores	2,000	16
Galley and condensers	600	12
Officers, crew and effects (500)	....	60
Shaft alley.	5,000	...
Wing passages	5,000	...
Ventilating passages	2,000	...
Mast-rooms and hatchways	2,800	...
Spare bulk and weight	24,000	118
Weight of ship's hull	....	3,000
Total capacity and weight	280,000	6,300

For the calculation of the displacement of a man-of-war, the following may be useful:

	Weight.
One XI-inch Pivot gun, with ammunition and equipment complete (see Table I.)	52,935 lbs.
One IX-inch gun, etc., complete (Broadside carriage)	22,656 "
One VIII-inch " " "	16,342 "
One 32-pounder " " "	11,054 "
One 100-pounder Rifle gun, complete (Pivot carriage)	34,153 "
One 60-pounder " " "	19,435 "
One 60-pounder " " (Broadside carriage)	15,630 "
One man, with clothes and other articles	0.11 tons.
Provisions, with *tare* and fuel for cooking, etc., for one month	0.07 "
Water, with *tare* for one man for one month	0.14 "
Steam engines with boilers, and water in boilers, coal bunkers and stores per *nominal* horse-power	0.71 "
Coal for one *nominal* horse-power in 24 hours	0.15 "

In the old sailing frigates, *ballast* was carried to ensure stability. This was sometimes twice the weight of the guns. Ships with full steam-power do not need ballast for stability, yet a little is usually carried for trimming ship.

TABLE I.

Weights of Guns, Carriages, Ammunition and Equipment Complete—U. S. Naval Ordnance.

	XI-inch (Pivot).			IX-inch (Marsilly Carriage).			VIII-inch (Marsilly Carriage).			32-pounder (Broadside).			100-pounder (Pivot).			60-pounder (Pivot).			60-pounder (Broadside).		
	No. of.	Weight of each.	Aggregate Weight.	No. of.	Weight of each.	Aggregate Weight.	No. of.	Weight of each.	Aggregate Weight.	No. of.	Weight of each.	Aggregate Weight.	No. of.	Weight of each.	Aggregate Weight.	No. of.	Weight of each.	Aggregate Weight.	No. of.	Weight of each.	Aggregate Weight.
		lbs.	lbs.		lbs.	lbs.		lbs.	lbs.		lbs.	lbs.		lbs.	lbs.		lbs.	lbs.		lbs.	lbs.
Gun	......	......	16,000	......	......	9,000	......	......	6,500	......	......	4,500	......	......	9,700	......	......	5,400	......	......	5,400
Carriage	......	......	9,310	......	......	1,250	......	......	*1,000	......	......	*850	......	......	8,416	......	......	3,315	......	......	900
Service charges of powder	175	20.1 15.9	2,710	110	13.1 10.9	1,133	110	7.	770	110	6.	660	175	8.	1,400	175	6	1,050	175	6	*1,050
Saluting " "	50	6.	300	50	5.	250	50	4.	200	50	4.	200									
Shell, loaded " unloaded	90	135.5	12,195	65	73.5	4,778	65	52.75	3,426	65	26.5	1,722	95	80.	7,600	95	50	4,750	65	50	4,750
Shrapnel	35	141.	4,935	15	75.	1,125	15	52.	780	15	32.	480	25	*80.	2,000	*25	*50	1,250	15	*50	750
Shot	10	166.	1,660	10	90.	900	10	65.	650	10	32.5	325	15	70.	1,050	15	60	900	10	60	600
Grape	5	125.	625	5	74.1	370	5	53.25	266	5	33.5	167	Round shot. 15	32.5	487	15	18	270	10	18	180
Canister	10	120.	1,200	5	70.	350	5	50.	250	5	30.	150									
Total	......	......	48,935	......	......	19,156	......	......	13,842	......	......	9,054	......	......	30,653	......	......	16,935	......	......	13,630
Shell-boxes Junk-wads Powder-tanks Breechings Rammers and Sponges Tackles, &c. *	......	......	4,000	......	......	3,500	......	......	2,500	......	......	2,000	......	......	3,500	......	......	2,500	......	......	2,000
Grand Total	......	......	52,935	......	......	22,656	......	......	16,342	......	......	11,054	......	......	34,153	......	......	19,435	......	......	15,630

* Estimated.

The number of men may be taken as follows:

TABLE II.

Pivot Guns.						Broadside Guns.						
XI-inch X-inch 16,000 lbs.	X-inch, 12,000 lbs. 64-pounder, 106 cwt.	IX-inch, 9000 lbs. 100-pounder Rifle.	60-pounder Rifle.	30-pounder Rifle.	20-pounder Rifle.	IX-inch, 9000 lbs. 100-pounder Rifle.	VIII-inch, 63 cwt.	VIII-inch, 6500 lbs. VIII-inch, 56 cwt.	32-pounder, 57 cwt.	32-pounder, 4500 lbs. 32-pounder, 42 cwt. 60-pounder Rifle.	32-pounder, 33 cwt. 30-pounder Rifle.	32-pounder, 27 cwt. 20-pounder Rifle.
24	20	16	10	8	6	16	14	12	12	10	8	6

The additional men for powder division, master's division, engineer's and other divisions must be calculated from the tables in the Book of Allowances. A ship to carry a specific battery must have the total number of persons in accordance with that battery, together with the extra number for her power as a steam vessel, fully ascertained before a design can be commenced. The Book of Allowances, United States Navy, gives all the requisite data for finding *full* complement. For steam merchant vessels the following is an *approximation*. Sailing vessels carry somewhat smaller crews.

Cargo in tons.	Number of men as *crew*.	Cargo in tons.	Number of men as *crew*.
100	8	600	22
150	9	800	28
200	11	1000	32
300	13	1500	45
400	16	2000	60
500	20		

CHAPTER VI.

DISPLACEMENT—HOW TO MAKE A SHIP SWIM AND CARRY.

It was Archimedes, the philosopher, who discovered the law of displacement; or that *floating bodies* displace a weight of water exactly equal to their own weight, and it is owing to this discovery that the principles of flotation are understood.

The law of displacement consists of two parts: *first,* that a body placed under water displaces as much water as its own bulk; *secondly,* that it floats when it weighs less than the water it displaces.

This principle, although the foundation of ship-building, has also a great many other useful applications. If you have anything of awkward shape, and you want to measure its bulk—say a piece of wood or a model of a boat—take a vessel of water large enough to hold it; place it where it may run over, and where the overflow of the water can be retained; put the substance under water and measure the overflow. That in gallons, or in cubic inches, is the exact bulk of the body. For rough and ill-shaped substances there is no better way than this. Bodies, therefore, which are designed to float in the water must be so designed that when they are put into the water sufficiently far to swim just so much out of the water as is intended, the part in the water shall be of the exact size necessary to displace the quantity of water intended, while the body which floats shall be of the exact weight of the water it is designed to displace. In short, displaced bulk for immersed bulk, and weight for weight, the floating body and the water, whose place it occupies, must be identical.

Let us see what will happen if this be not accurately done. Suppose the bulk of the body has been made too small for the weight which it is intended to carry,* then the vessel will sink deeper into

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* The "*light-draft*" monitors built during the late war are instances of an error of this kind.

the water than had been intended; and by sinking so much will displace the additional quantity of water necessary to make up the extra weight, and so, though it swims, will swim too deep. More displacement must therefore be found to meet the deficient weight; the vessel which was intended to swim light will swim deep in the water, unless her weight be diminished by lightening until she return to her former intended depth: what is to be taken care of in the calculation, therefore, is that at whatever depth it has been decided that the ship shall float in the water—or, which is the same thing, at whatever height the upper part is to float above the water—in that position the bulk of the part in the water and the weight of the whole ship and its contents must be so designed as to be exactly equal to the bulk of the water to be displaced by the ship and the weight of the water to be so displaced.

In a ship, however, it is necessary to do more than calculate *one* displacement. There are *two* critically important displacements to be calculated for every vessel.

Displacement when she is lying in the water ready to take in her guns or stores or cargo, or in the lightest state in which she will ever swim—that is, with a clean-swept hold; this is called, technically, "*light displacement.*" The other is "*load displacement,*" which is calculated for the heaviest weight she will ever carry, and the deepest draft of water to which she will ever sink under a load. These are the two important *drafts* or depths of the ship in the water.

To calculate these the constructor must first ascertain the exact weight of the hull of the ship. He must include in the weight of the hull all the essential parts attached to and connected with that hull. He must add to that the full equipment necessary to fit her for sea-going use; but he must not include those stores (water, provisions, coals, etc.) which are to be consumed in actual service. This weight of hull and equipment for service constitute the data on which to construct the light displacement of the ship.

The load displacement is next to be calculated. The data for this consists—first, of the light displacement; and secondly, in addition to this, of all the stores, provisions, water, coals and consumable commodities to be used on the particular voyage or service intended, together with the cargo, freight, etc., of every kind which has to come on board.

To the "light displacement" corresponds what is called "*the light draft*" or light line of the ship. To the load displacement, "*the load draft*" or load water-line. There is also the "*light trim*" and "*the load trim*"—trim meaning difference of draft, or rather the difference between the depth of the after part of the ship under water and that of the fore part.* It is usual to give a ship such trim that the draft of water abaft is somewhat greater than the draft forward, and in this case she is said to be *trimmed by the stern.* If it were the contrary, she would be said to be *trimmed by the head.* This is what is meant when we say a ship is trimmed 2 feet by the head, or 2 feet by the stern; this difference of 2 feet being technically called the trim. When a vessel trims neither by the head nor stern, but draws the same water forward and aft, she is said to be "*on an even keel;*" and it is usual to take a middle draft, halfway between the two, and to call it "*the mean draft,*" so that a ship which is trimmed to 21 feet by the stern and 19 feet at the bow, is said to have "a mean draft" of 20 feet. In this case it is common also to call this 20 feet "the draft of the ship," and to call the greatest draft of water (21 feet) "*the extreme draft;*" but in the calculation of displacement it is general to use the "mean draft."

The elements to be considered in calculating displacement are as follows:

1. Dead weight when light.
2. Dead weight when laden.
3. Light draft of water.
4. Light trim.
5. Load draft of water.
6. Load trim.

These elements being settled, the naval architect may calculate exactly the displacement of a ship of any given form of which he may possess a design—*first,* for her light draft of water; *second,* for her load draft.

First. For her light draft he marks off on the drawing of the ship the exact part of the body of the vessel which will be under water when she floats light. He calls this "*the immersed body*" of the vessel (light). He then measures exactly and calculates geometrically the bulk of this immersed body; this bulk will be expressed in

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* Commonly called "*drag.*"

so many cubic feet—say 18,000. He next takes the weight given for the ship and her equipment when light—say 500 tons.

Now he knows that a ship will float at a given draft of water when the quantity of water she displaces is of exactly the same weight as herself, and in this case the weight is given as 500 tons. The question, therefore, is, Whether the volume of water—namely, 18,000 feet —which is the bulk of the immersed body (and which is therefore the quantity of water displaced), will weigh more or less than 500 tons?

Now, it will be found that the bulk of 500 tons of water is just 18,000 cubic feet, and the displacement of the ship, as measured, is also 18,000 cubic feet; this, therefore, is the true light displacement.

Secondly. For her load draft he marks off on the drawing of the ship the exact part of the body of the vessel that will be under water when she is deeply laden. He then measures exactly and calculates geometrically the bulk of that part of the vessel which was formerly out of the water, but which has now been sunk under it by the lading. Suppose this bulk to be 36,000 cubic feet. Thirty-six thousand cubic feet weigh 1000 tons; therefore, 1000 tons is the dead weight of cargo which the ship will carry on the given load water-line.

But the total load displacement of the ship consists, first, of the light displacement of 18,000 cubic feet; second, of the lading displacement of 36,000 cubic feet more; so that the total displacement of the ship when laden is the sum of the two, or 54,000 cubic feet. The immersed body of the ship at the load draft has, therefore, a total displacement of 54,000 cubic feet; and the ship with her cargo floats a total weight of 1500 tons.

Calculating the weight a ship will carry at a given draft of water, is then a mere question of the measurement of the bulk of that part of the ship which will then be under water, and which is called the "immersed body." For every cubic foot of that immersion the weight of a cubic foot of water is allowed, and thence is obtained the number of tons weight the water will support; this is called the "floating power" of the ship, and really represents the buoyant power of the water acting on the outside of the ship. The ship itself has no power to carry anything, or even to float; all it does is to exclude the water and enclose the cargo. The ship is merely passive, the water carrying both ship and cargo.* *Buoyancy* is, therefore, the power of

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* An iron ship will best illustrate this.

water to carry a given ship. It is proportioned *exactly* to the bulk of the body of the ship under water, and its force is measured by the weight of the water displaced, and which is called the ship's displacement.

The floating power of a ship has nothing to do with the *shape* of the ship, but is entirely due to its *size* or *bulk*. Practical shipbuilders, ignorant of the *laws* of naval architecture, have imagined that they could confer surprising powers of flotation and ability to carry heavy weights, merely by giving certain "*proper*" shapes, imagined by themselves, to the immersed bodies of their ships. This delusion was common at one time, but has now passed away; yet it will take a great deal of thought to understand thoroughly why no possible invention of shape can give to a ship the power of greater or less buoyancy than is measured by the exact weight of water of her displacement. It is herein that the merit of the discovery by Archimedes consists, since the existence at one time of an opposite opinion tends to show that the principle of flotation is by no means self-evident.

TABLE III.

Standards of Displacement.

WEIGHTS.	BULKS.	SIZES.
*1 ton........	*36 cubic feet fresh water.....	2 × 3 × 6 feet.
†1 "	†35 " sea water.......	2 × 2.5 × 7 "
*62.5 lbs.......	*1 cubic foot fresh water.....	1 × 1 × 1 foot.
†64 "	*1 " sea water.......	1 × 1 × 1 "
‡10 "	1 gallon of fresh water......	6 × 6 × 7.69 inches.
1 lb..........	‡27.648 cub. inch. fresh water	3 × 1 × 9.216 "
1 ounce	1.728 " "	1 × 1 × 1.728 "
0.58 ounce..	1 cubic inch "	1 × 1 × 1 "
2 tons........	72 cubic feet "	6 × 6 × 2 feet.
5 "	180 " "	6 × 6 × 5 "
10 "	360 " "	6 × 6 × 10 "
100 "	3,600 " "	6 × 12 × 50 "
200 "	7,200 " "	6 × 12 × 100 "
1,000 "	36,000 " "	12 × 24 × 125 "
10,000 "	360,000 " "	24 × 50 × 300 "
20,000 "	720,000 " "	24 × 75 × 400 "

* 62.5 pounds = $\frac{1}{35.84}$ tons = $\frac{1}{36}$ tons nearly, and 1 ton = 35.84 ft. *distilled* water.

† 64 lbs. = $\frac{1}{35}$ tons exactly, and 1 ton = 35 cubic ft. salt water.

‡ The *imperial* gallon contains 10 lbs. of distilled water at a temperature of 62.5 Fahrenheit, and also measures 277.274 cubic inches. If ordinary fresh water is taken at a lower temperature (say 40° Fahr.) as the standard, a cubic foot of fresh water will weigh exactly 1000 ounces, or 62.5 lbs. All the figures given above are correct within a very small fraction. In round numbers, 36 cubic feet of fresh water and 35 feet of sea water measure 1 ton. The *standard* gallon of the United States weighs 8.338 pounds, and measures 231 cubic inches.

CHAPTER VII.

BUOYANCY—POWER OF WATER TO FLOAT BODIES HEAVIER THAN ITSELF.

Iron and steel are heavier than water, nevertheless out of them can be formed ships which will not only float well above the surface, but will carry within them weights much heavier than themselves. Iron is nearly eight times heavier than water, and sinks instantly; lead is fourteen times heavier, and gold nineteen. Nevertheless gold and lead may be floated in ships of iron and steel; and structures every portion of which would, if separate, sink to the bottom of the water, can be so combined as to float lightly on the top. The means by which this is accomplished is a dextrous application of the forces of pressure of the water in such a manner that the downward pressure of the weights on a ship shall be counteracted by an equal upward pressure from the water under the ship, and so the vessel be prevented from descending into it more than intended.

But this is not the only use to be made of the pressure of water, since a ship, although supported from below, may roll over by its own weight, or may be overset by the force of the wind or the force of the waves; and so it becomes necessary to call in the aid of the force of the water, not merely to keep the ship from sinking, but to prevent it from being overset. In the first case, the water gives buoyancy only; in the second case, it is said to give *stability* also. In the former case, it gives *vertical* support; in the latter case, it gives *lateral* support. The two great services required of water are, therefore—*first*, buoyancy to support bodies much heavier than itself; *second*, stability to be given to bodies which are unable to keep themselves in an upright position without its aid.

Thus, from an element which is light, movable and unstable is to be drawn support and stability by the art of naval construction. It is plain, therefore, that art and skill can have no sure foundation except in a complete comprehension of the nature of water and of the laws which govern the application of its force.

The *first* property of water, commonly called its *liquidity*, is its absolute indifference to shape; that is, it presses on all shapes equally. The *second* quality of water is *the absolute proportion of its pressure to depth.* The *third* property of water is *the proportion of its pressure to the extent of the surface on which its presses, altogether regardless of the direction of that surface.* The three elements, therefore, for the calculation of the mechanical force of water are *weight, depth* and *extent of surface.*

It is the liquidity of water which takes from it any tendency to assume fixed form in its own masses (as frozen water or ice does), or from exerting any force (as solid bodies do) to keep a shape in which it has been put. As a liquid it will take the exact shape of any vessel into which it is poured, as well as the exact shape of any solid placed in or on it. Therefore, to know how much any vessel of curious shape will hold, fill it with water and then empty its contents into some vessel of known size; the result is the exact capacity of the vessel.

Again, if you wish to know the bulk of anything of complicated form, plunge it into water, forcing the overflow of water into something that you can measure it with. The bulk of the displaced water is exactly what is occupied by the body now in water. This free flowing, easy running and perfect fitting of water seems to imply that it has no force, no resistance to moving, no power of effort. Could it be fancied that water had no weight, it might be fancied also without strength or resistance.

Therefore, as liquidity allows water to be parted hither and thither, and turned into any and every shape indifferently, one must look for the source of its power to sustain, to resist and to act in its next quality—weight, which quality of matter is also indifferent to shape. The weight of a piece of iron, for example, cannot be altered by changing its shape. The weight of a quantity of water is the same whatever the shape of the vessel it may be put into, or whatever shape of outline may be given to it.

The measure of weight in a given quantity of water is as follows:

Quantity of Water.	Weight.	
1 cubic inch	250 grains =	.036 lb.
12 " inches	3000 " =	.43 "
28 " "	7000 " =	1. "
1 " foot	1000 ounces =	62.5 "
36 " feet	1 ton.	

These numbers are convenient for the purpose of the naval architect, yet it must be remembered that all water is not precisely alike in weight. The purer waters are represented by the above figures sufficiently well for all practical purposes; but salt water weighs more than river water, and varies in different seas. Some sea water is so heavy that 35 cubic feet will make a ton, instead of 36, and such salt water carries ships better than fresh, in the proportion of 36 to 35.

In calculations of ships for the sea, 35 feet may be conveniently taken as a ton, and 64 lbs. as the weight of a cubic foot.

The nature of the pressure of water is, that it will flow freely into any vessel into which it is allowed to run, and will fit it exactly. But if, in the bottom of the vessel, it find a hole or a weak place, it will rush out there if not stopped by force. If force be applied to the hole or the weak place to prevent the escape of the water, this force is measured exactly by the height of the water above it and by the size of the hole.

The next point in the nature of the pressure of water is, that under the pressure due to its depth the water is indifferent to direction; for if, at the depth of one foot, the pressure downward is .43 lb. on an inch of surface, there is that pressure of .43 lb. on that inch, whether it lie with its face downward or upward, backward or forward, to the right or to the left, or in any degree of obliquity of direction. Pressure proportioned to depth, to extent of surface, but alike for all shapes and for all directions, is characteristic of water pressure. The quantities given as the weights of water enable one to measure exactly its pressure. If the water be a foot deep, and the hole a square inch, the pressure of the water outward is measured (for fresh water) by the weight .43 lb.; at double the depth, .86 lb.; and for every foot of water an equal added weight. To stop it requires just this weight applied the contrary way. The pressure of water trying to get out of a full vessel which confines it is not different in kind or quantity from the pressure of water that surrounds a vessel, trying to get into it. If an opening be made under water in an empty vessel, like a diving-bell or a ship, the water around it will press into it with just the same force as it would press out of a full vessel, because the water is indifferent to the direction of the pressure.

The pressure of water into a vessel submerged in it being about .43 lb. for each inch, it follows that at the depth of 36 feet the pressure on one inch of the vessel is 15.5 lbs.

Therefore, in a deep ship the pressure is greatest at the bottom, since the water presses against her on every inch of "skin" with a force of .43 lb. for each foot of draft. At 1 foot draft, the water presses inward .43 lb.; at 7 feet, 3 lbs. on the inch; at 28 feet, 12 lbs. on the inch; and at 36 feet, 15.5 lbs. to the inch. This is the measure of the force required to prevent water leaking into a ship through the seams of the sides and bottom, as well as the force that crushes her inward, and requires strength in the hull to resist it.

The power of water to float bodies is given by nothing more than the pressure of water under the vessel which is pushing it upward. To measure the buoyancy is nothing more than to measure the pressure of the water on the whole bottom of the ship upward. Let it be conceived that she has a flat, level bottom and upright sides, and floats 10 feet deep in the water, then the buoyancy and floating power of the ship will be measured by the upward pressure of the water. At 10 feet below the water, this pressure is 625 lbs. upon each foot of skin. Therefore reckoning the number of feet on the bottom to be say 1000, the upward pressure of the water, or buoyancy, will enable her to carry 625,000 lbs.

In this calculation of buoyancy, the upward pressure of the water has been measured by the same rule as if it had been downward pressure, because it has already been shown that it is the characteristic property of water pressure that it is proportionate to depth, and is not affected by direction. It is this universality of the pressure of water, with its indifference to direction, which makes the calculation of buoyancy so simple and easy. This principle of buoyancy and its measurement make it clear how bodies like iron, steel and brass, so much heavier than water, can be made to swim, even although, according to the law of displacement, they weigh much more than the same quantity of water.

The art of making heavy bodies swim consists, then, in this: to spread them out in a thin layer over so large a quantity of water and at such a depth that the pressure of the water upward shall be greater than the pressure of weight downward.

A cubic foot of iron weighs 448 lbs., and would sink in water instantly. But take that mass and roll it out into a thin plate 8 feet long and 8 feet wide, and turn up its edges all around a foot deep; then the upward pressure of the water on the 36 feet of bottom, at the depth of one foot, will give 62.5 lbs. on each foot, or one ton of 2240 lbs. on the whole piece. The buoyancy, therefore, of the water on this extent of iron is enough not only to float the original 448 lbs. forming the cubic foot, but also to carry a load of 1792 lbs. besides.

This example shows, in a striking manner, how a ship may not only be built of iron, which sinks by itself in water, but may be so built as not merely to carry its own weight of iron, but a burthen in addition four times greater than its own weight.

Such is the buoyancy of water: and therefore to carry any known weight, it is only necessary that the surface of the bottom of the ship be large enough and placed at a sufficient depth below the water to produce an aggregate upward pressure equal to the aggregate weights carried.

TABLE IV.

Pressure on the bottom of a Ship in Sea water.

Depth under water.	Pressure on a square foot.	Pressure on a square inch.	Depth under water.	Pressure on a square foot.	Pressure on a square inch.
feet.	lbs.	lbs.	feet.	lbs.	lbs.
1	64	.44	13	832	5.78
2	128	.89	14	896 = .4 ton	6.22
3	192	1.33	15	960	6.67
4	256	1.78	16	1024	7.11
5	320	2.22	17	1088	7.56
6	384	2.67	18	1152	8.
7	448 = .2 ton	3.11	19	1216	8.44
8	512	3.56	20	1280	8.89
9	576	4.	21	1344 = .6 ton	9.33
10	640	4.44	28	1792 = .8 ton	12.44
11	704	4.89	35	2240 = 1. ton	15.56
12	768	5.33			

CHAPTER VIII.

STABILITY—POWER OF WATER TO MAKE A SHIP STAND UPRIGHT.

THAT the most unstable of elements, water, should be required to confer stability or give uprightness to heavy bodies raised to a great height above its surface, would appear to be an unreasonable expectation, were it not accomplished every day.

If it is merely imagined that the bottom of a ship is made the heaviest part and the top the lightest, it would seem naturally to follow, as a first impression, that the bottom, being the heaviest, would stay at the bottom, and the top, being the lightest, would stay at the top. This disposition of weight is not what always or often, in fact, takes place. A Mississippi or North river steamboat is 30 feet high out of the water, and but 3 to 6 feet, or so, deep in it. The heavy weights of its machinery are generally high out of the water; its boilers are entirely above the water, reaching in some cases above the hurricane deck. Its cargo is also carried above the water, and its bottom, if not quite empty, is merely occupied by sleeping apartments. Such vessels, if supported on pivots fixed at the water-line, would certainly tumble over, bottom up, since they are certainly top-heavy, and pivoted *on land* would upset. By some power, nevertheless, *in the water* they are kept upright, and made to form huge floating castles, their chief weights high in the air.

It is, therefore, necessary to examine, understand and measure by what power water gives stability and uprightness to a large, top-heavy, out-of-water structure.

It might be imagined, at first sight, that the upward pressure of the water on the bottom should help to give uprightness to the structure it upholds from below. But this idea will not stand examination; since to push the bottom of a vessel upward may only be another method of trying to upset it. What is wanted is to keep the top up and the bottom down.

How, out of these contradictory elements, to elicit stability is neither an obvious nor an easy investigation, for it is certain that the upward pressure of the water on the bottom of a ship, instead of being a cause of stability, is a powerful agent of instability, and that the greater it is in quantity and the more effectual in power the more it tends to upset the floating body.

Nevertheless, a perfect understanding of the way in which the power of water contributes to stability in a top-heavy, out-of-water structure will give one a profound appreciation of this remarkable quality of water. The way in which this unstable element gives stability to a top-heavy structure, as it heels over, is by continually transferring its action to the side to which the vessel is about to fall, where, by continually giving a stronger push upward on the falling side, it counterbalances the falling weight, and thus keeps the vessel upright.

A top-heavy ship is technically called "*crank*"—"a drunken ship"—and it really seems so; but by art, the force of water is made to pass from side to side, faster and farther than the ship heels, and therefore, though she may heel over, she cannot capsize, for the water puts its strong pressure under the falling "*shoulder*" of the ship, and gives it a powerful lift. The way in which this "shoulder" is formed, the leverage with which the water acts, and the powerful lift which it gives at the right time and in the right way, is something which it requires much thought to conceive, skill to direct and craft to apply with success. This portion of the ship is therefore called the "*shoulder*," to distinguish it from the bottom or "*bilge*" of the ship.

It is the tendency of the bottom or bilge of the ship to be pushed upward by the water, and the pressure is so great upward as to tend not only to keep it up, but to push it too much up, and thus upset the vessel. One way of counteracting this would be to put heavy weights of lead or iron on the bottom of the ship, so as to keep it always, in all circumstances, bottom down. But to put on the bottom of a ship useless weight is not merely a confession of great want of skill, but is a serious sacrifice of the usefulness of the ship.

It was the practice of a former day to make up for want of stability by great quantities of ballast; but the naval architect of the present day knows how to give sufficient "shoulder" to the ship so as to make use of the fluidity of the water as a substitute for the "*dead weight*" of ballast; and its just application is a test of his skill.

By the "shoulder," therefore, is meant that part of the side which is just about the water-line, which is sometimes a little out of and sometimes a little under the water as the ship reels about. It is frequently called, for that reason, the part of the ship "*between wind and water;*" but it will be quite accurately defined if it is said that the "shoulder" of a ship is that part which, being under the water when the ship heels over one way, is then left bare, out of the water, when she heels as far over the other way.

Take, for example, a ship that has been standing upright, and has first leaned over on one side until 2 feet of her *skin* are put into the water, and then leans over just as much on the other side till 2 feet more of her skin are out of water,—those 4 feet of skin on each side which lie between these extreme positions are "the shoulders," on which she depends for power to sustain top weight.

If from the body of the ship the two "shoulders" are taken, the remainder of the bottom, which never leaves the water, may be defined as the "*under-water body*" of the ship, and this under-water body is the part tending to upset her. The life of the ship is, therefore, a balanced effort, the under-water body continually tending to upset her, and the two "shoulders," turn and turn about, trying to keep her upright. The one is the "*upsetting*" part, the other the "*righting*" part of the ship. The effect of each of these contrary elements has to be measured—*first*, by the quantity of each element; *second*, by the more or less effectual manner in which it is applied. To make the upsetting body the largest in quantity for the purpose of carrying useful loads, yet so to contrive it as to give it the least power for harm—to make the "shoulders" the smallest, yet so contrived as to have the most power for good,—that is the consummation of the art of the architect.

In every ship it will be a question depending on her peculiar structure how much of this righting power has been given to her; in other words, how much top weight she can carry, and how high out of the water she can carry it, without upsetting. The simplest way of putting it is, perhaps, to ask at what height the whole weight of the ship herself and all she carries might be kept without overpowering the stability, overworking the "shoulders," and thus upsetting the ship.

This height is, therefore, a chief point to be calculated and known, and may be called the "upsetting point." It is, however, called the "meta-centre;" and if this be taken to mean the point beyond which you cannot go in raising the weights, it is a proper word enough. The limiting height of top weight is, therefore, the proper meaning of what is called the meta-centre, and the measure of this is manifestly one of the most important things to be known about a ship, for on it most of her good qualities depend.*

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* The point M in figs. 2 and 3 is the meta-centre for the given "angle of inclination." It is evident that unless this point be above the *centre of gravity of the ship*, the vessel will upset.

CHAPTER IX.

STABILITY—POWERS OF "SHOULDER" AND UNDER-WATER BODY.

To understand the functions of the "shoulder" of the ship and those of the bottom, and the tendency of both to affect the stability, it will not be necessary to consider any but the simplest form which can float. For that purpose, suppose a square box of say 36 feet wide, 27 feet high, and of indefinite length, to be sunk by a weight 18 feet deep in the water—each foot of length of a box of these dimensions will carry a ton weight for every foot of its depth in fresh water; therefore, 18 feet of depth carries a weight of 18 tons. And supposing the box itself to weigh 6 tons per foot, the vessel would carry, beside its own weight, a weight of 12 tons. Draw such a box, and across it the line of the surface of the water, which call the "*water-line.*" Let the weight be represented in square form on top of it. (Fig. 1.)

This box truly represents a ship, the weight truly representing a heavy deck-load proposed to be carried by the ship. It may represent the weight of a man-of-war's battery, or the weight of an iron-cased battery, an iron-clad's turret, or any other top load.

The question is—the ability or inability of that ship to carry that weight at that height out of the water. For this purpose, suppose it to lean over on either side, and then examine whether it tends to return to the upright position and stand up, or to overset and drop the weight into the sea. Draw the ship, therefore, in these two positions. (Figs. 2, 3.) When this is done, it will be seen that there is a part of the ship which is never out of water, but keeps always under the water-line. This is the under-water body, or the upsetting part of the ship.

This under-water body is bounded by, first of all, the bottom of the ship; secondly, by the bilges, or corners of the bottom; and thirdly, by a water-line of the ship in each of its two opposite positions. It is, therefore, pointed at the top where it forms an equal-sided triangle, the apex of which is in the water-line. Two flat surfaces, therefore, form the top of this under-water body, while the rest of it forms the bilges and bottom, or under-water skin of the ship. The part shaded (fig. 4) is that part which tends to upset the ship, and the nature of this upsetting force, produced by the under-water body, must be examined.

To this end observe that it is a symmetrical body, the right and left sides being of the same size, of the same shape, and in the original upright position of the body exactly balancing on both sides. Its whole effect, then, may be assumed as concentrated in a point in its middle line. This point call B, or the centre of effort of the under-water body.*

The buoyancy or upward pressure of this under-water body will take place directly upward in the line B*b*, and it will be seen that this is quite on one side of the centre of the vessel. It is next to be noticed, in figs. 2 and 3, that the centre of the weight W is on the opposite side of the upright line. When the ship careens over to the right, the weight also inclines to the right and downward. When the ship careens over to the left, the weight also inclines to the left and downward. The direction of its effect is marked by the downward line W*w*.

Therefore, when the ship is lowered on the right side, the effect of the weight from above is to press it downward on that side, while at the same moment the effect of the under-water body is equally bad in raising the opposite side out of the water. The ship is beset by two opposite forces, which, nevertheless, conspire in their bad effect. One sinks the right in the water, while the other lifts the left out of the water, so that with opposite means both tend to overset the ship. It is thus seen why the under-water body is the upsetting part of the ship. The larger it is, and the greater its power to carry weight, the more it will tend to overturn the weight it carries.

Some counteracting power must, therefore, be looked to, not merely to neutralize the overturning effect of the top weight and the upsetting force of the under-water body, but to do more than

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* Of course this point represents the resultant of an infinite number of pressures.

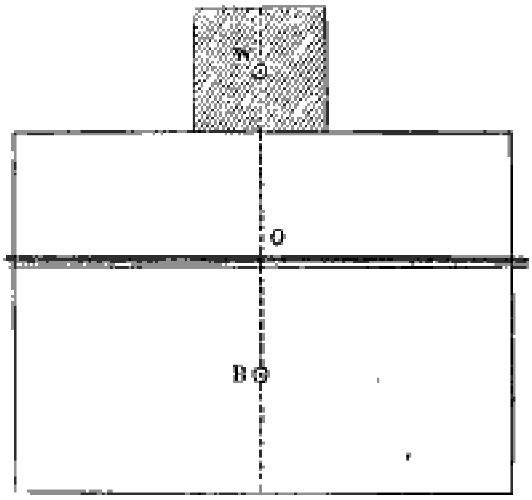

FIG. 1.

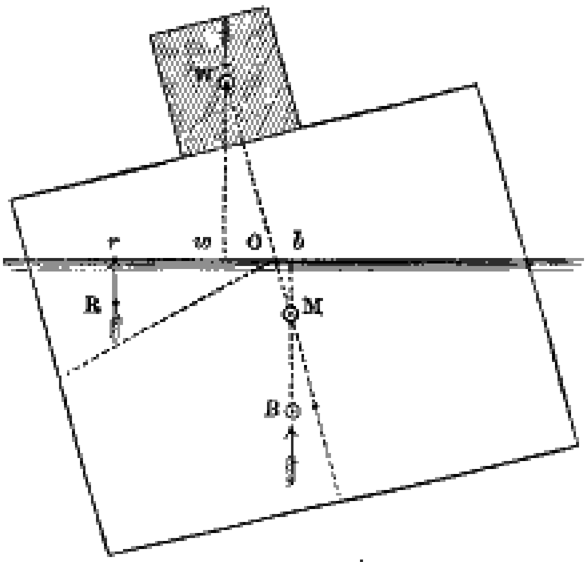

FIG. 2.

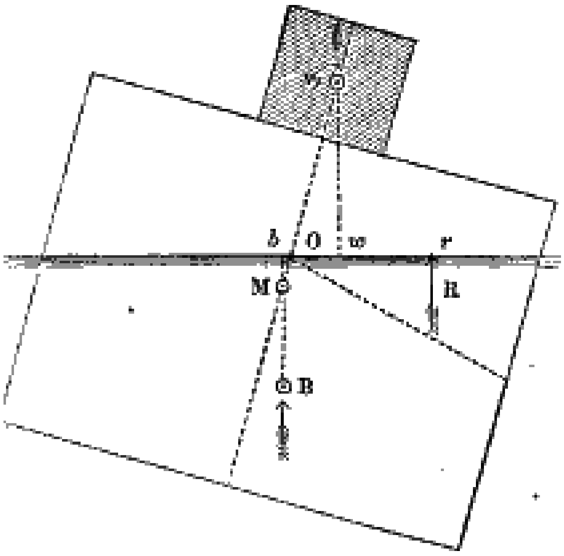

FIG. 3.

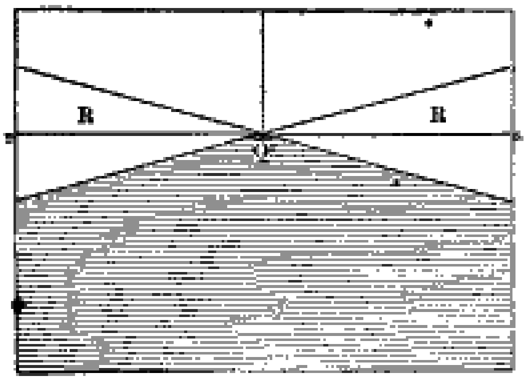

FIG. 4.

neutralize them—to give a balance of righting force which shall constitute the stability of the vessel; in other words, the power to right herself after she has been forced over.

This righting force is found in the "shoulders," which lie between wind and water, and are continually going in and out of the water on one side or on the other. When she leans over to the right, the whole of the right "shoulder" is immersed; and the same may be said of the left "shoulder," each consisting of a wedge-formed body, with its point at the middle, and the base or heel of the wedge on the outside of the ship, the whole of the base or heel rising out of the water, and falling into it again as the ship careens. One-half the angle of this wedge is called "*the angle of heel*" or "*the angle of inclination*," and is taken as the measure of the roll or careen of the ship. A ship, for example, is said to roll or careen 15° when the angle of this wedge is an angle of 30°. It is convenient generally to speak of some fixed angle for this purpose, and 28° may therefore be assumed. For ships of war it has been common to use 15°, as it is desirable for the sake of the guns that the ship should *not* roll or careen *more* than this;* but for merchant ships, under a press of sail, there is no harm in their careening 14° in and 14° out of water, a total of 28°. These wedges or "shoulders" are sometimes called "*the wings*," sometimes "*the solids of immersion and emersion*."

To examine the effect of each "shoulder," when it has been forced under water, to rise again and raise the top weight with it, one must consider the *amount* of its effort, the *place* where it may be reckoned as concentrated, and the *direction* of its effort. The quantity of its effort is measured by its buoyant power, or the number of cubic feet of water it displaces. Its bulk in water, therefore, gives a measure of its buoyant or upward force. The place in which this buoyant effort takes effect is about two-thirds ($\frac{2}{3}$) outward from the point O of the wedge (fig. 4). The effect it produces may be assumed then as concentrated in R, and the buoyant effect, being directly upward, tends to upright the vessel on the side which has been depressed under water.

But it should be observed that that side of the ship on which the "shoulder" lies under water is also that side on which the top

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* With the exception of our monitors, few of our screw men-of-war can claim ever this.

weight tends to descend and overset; and it is therefore obvious that the tendency of the "shoulder" is to help the descending weight to rise again, and therefore to right the ship.

But the vital question is, Whether the "shoulder" has *power* enough to do so? In order to be effectual, it will not be sufficient that it should be capable of supporting the top weight merely. It has also to counteract the upsetting tendency on the opposite side produced by the under-water body.

It must not escape notice that the under-water body is always on the contrary side from the "shoulder," always tending to upset the ship on that side from below, so that unless the "shoulder" be more powerful and act more energetically than the under-water body, the ship will infallibly upset. The "shoulder," therefore, has these two tasks at once: It must be strong enough to neutralize the upsetting force of the under body at the same time that it sustains and counteracts the oversetting force of the top weight, and the surplus power beyond these two will right the ship.

It is this surplus power, beyond the two effects counteracted, which gives stability, its measure being called "*the measure of the stability of the ship,*" and the art of the constructor is to make it always just as much as is wanted for this purpose, and *no more*, for more is of itself an evil, and defeats other good points.*

To measure the upsetting force of the under-water body, its volume is measured, after which its power is found by taking the weight of an equal quantity of water. Then assume that power as applied at its centre of action, commonly called "centre of gravity"(B). Draw a line directly upward through this point, and call that "the line of action of the upsetting force." Mark the place (*b*) where this line cuts the water. It is on the water-line that the comparison between the forces causing stability can be most directly seen; hence it may be called "the line of comparison."

To measure the righting force of the "shoulder," in like manner measure its volume, then find its power by taking the weight of an equal quantity of water. Reckon this power as applied at its centre of action or centre of gravity (R), and draw a line directly upward through this point, calling it the "line of action of the righting

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* Too much stability is almost as great an evil as too little. (See Art. 11th, p. 18.)

force." Mark the place (*r*) where this line cuts the water, and here its action may be compared with that of the other two forces.

The third force has been already measured; it is the top weight placed on the vessel, and it is 12 tons for each foot of length. To compare this with the others, let fall through its centre of gravity (W) its line of action, which cuts the water at some place intermediate between the other two. Mark this place (*w*). The water-line now shows the three points of comparison desired.

Of the three—first, compare the upsetting and righting force of the body and "shoulders," which are on opposite sides of the middle of the ship and counteract each other. In the case under consideration, one, the upsetting force, is much larger in quantity than the other, the righting force—larger in the proportion of 3 to 1; but the smaller force acts more advantageously than the greater, so much so as to overpower it, because its centre of action (*r*) is four times farther from the centre of the ship on one side than the point of action (*b*) of the other. The combined result, therefore, is in favor of the righting force, and the ship has stability and will right itself. If the other force had preponderated, it would have had instability and have overset, even without a deck load. The question now remains: How much stability has it? In other words, how much top weight will the ship carry, and how high?

To find this, multiply the volume of the under body by the distance (O*b*) of its line of action from the centre, subtract it from the righting force multiplied by the distance of its line of action (O*r*) from the centre; the balance, in figures, shows the balancing quantity of force the "shoulder" is able to carry. This may amount to a weight of 12 tons, multiplied by the distance of the line of action (O*w*) of the top weight from the centre of the line of comparison. If this be so, the vessel has stability enough not to be overset; if, on the contrary, the surplus is less than this, the vessel will be overset. This surplus sustaining power, however, is the measure of stability. But in this calculation all consideration of the effect of the weight of the ship itself, either in oversetting or in righting, has been omitted. It may happen, and does happen in practice, that the weight of the ship alone, without a deck load, is enough to upset her.* In such

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* It has occurred in practice that vessels upon being launched have immediately turned bottom up.

case the weight of the deck load must be treated as the whole weight of the ship, the point of action of this weight being taken in the centre of action of the sum of all the weights of all the parts of the ship and her equipment. In this view of the case, after substituting in the calculation the total weight of the ship, as well as the weights on it, instead of the deck load, we must examine the height at which the whole of these could be carried without upsetting.

This height is taken as a convenient way of estimating the surplus righting power of the "shoulders" of the ship; because in comparing different ships one may, without reference to their weights or displacements, compare their righting powers or stability by the height above the water at which they have power to carry their own weights. For example, a ship which has power to carry her own weight 6 feet above the water, and another which has power to carry hers 3 feet out of the water, may be said to have relative stabilities of 2 to 1; but if the magnitude of the ships also be considered, and one is double the bulk of the other, and has power to carry its weight twice as high, the absolute stability of the one may be four times that of the other, although their relative stabilities, reckoned by height alone, are as 2 to 1. The upsetting power of the bottom of a ship and the righting power of the "shoulders" are, therefore, the two rival forces which continually oppose one another.

These two forces depend entirely for their quantity, their proportion and the manner of their action upon the forethought, knowledge and skill of the *designer* of the ship.

The proper balance of these forces in the design makes the ship a good or bad carrier of top weight, and the height at which it can carry all its weights is a point of the greatest value in every ship, and in men-of-war especially. If a considerable mistake be originally made, it is scarcely possible to correct it by anything short of rebuilding the ship.

CHAPTER X.

ON THE PROPORTIONS WHICH MAKE A STABLE OR UNSTABLE SHIP.

IN framing the design of a ship few things are of greater importance to be clearly seen, and unceasingly kept in mind, than the effect of the bottom to diminish, and the "shoulder" to increase, power to carry top weight. In order to give a ship this good and indispensable power, it is important that the naval architect should not for a moment lose sight of the contrary nature and tendency of these two forces, since it is from the omission of, or inadequate consideration given to, these two effects that crank, unstable and unseaworthy ships have so often been built.

Crankness was a general fault of ships built in the early part of this century, and means two things: inability to stand upright, and facility of being upset by top weight. The cause of crankness is often supposed to be shallow draft of water, which would be cured by deeper immersion. This is a radical error; there is no more common source of crank ships than this general impression. The contrary is the truth.

Take a square ship, like a box, filled with a light material, so as to sink no deeper than *one-fourth* part of its breadth, it will stand upright well; fill the same with heavier materials, so as to sink it to *double* that depth in the water, it will immediately turn bottom up. This is a very common proportion of draft to breadth, especially in old ships, and is quite sufficient to make a bad ship. As a general rule, then, ships with a deep and large bottom and narrow "shoulders," or with a straight, upright side and flat bottom and sharp bilges, will be crank.

In most cases ships that are crank may be cured by altering them so as to increase the breadth of their "shoulder" without altering their bottom.* They may also be cured by lengthening them, so as to make them, with a given load, draw less water. Both plans have been tried with success.

Table V. at the end of this chapter is given to show the limits of the power of a square-built, wall-sided ship to stand upright under heavy and high loads. To each breadth there is a given height, up to which she can carry top weight, and the table shows with what proportion of depth in the water to breadth she can or cannot carry her weights above water; thus the table shows that such a vessel, 36 feet broad and 18 feet deep in the water, cannot carry her weights if their common centre lie above the water, and that she would require to be 48 feet broad to carry them just 20 inches above the water.

In this table the figure 0 shows that if the whole weight carried were no higher than the surface of the water, the ship would, nevertheless, be incapable of standing upright, and would either list over or upset. The figures show how high the centre of gravity of all the weights carried, including both the material of the vessel itself and the burden with which she is laden, might be raised above the water-line without instability or danger of upset.

The value of this table is manifold; it shows how the extremely shallow, flat vessels of the Mississippi and other rivers are able to stand up under their very heavy top loads and carry enormous floating hotels three and four stories high above the surface of the water. It is their small proportion of depth in the water, combined with their great breadth, which does it.† It is this proportion which enables them to carry not only their light cabins, but also their heavy engines, boilers, fuel and deck loads above the water.

It shows the proportions for floating-docks, which have to take ships of great weight, raise them high and dry above the water, and carry them steadily there. It also shows how high the centre of gravity of a ship may be which a floating-dock of given proportions can carry, taking into account, also, the weight of the floating-dock itself. It shows how the shallow floating platforms of such con-

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* This is sometimes done by means of "sponsons." For the same reason a side-wheel steamer is more stable than a screw ship. This was effectually proved in the cases of the "Saranac" and "San Jacinto," both of the same model, the guards of the former increasing her stability.

† Refer to table of American river steamers, and this will be seen at a glance.

trivances as Clark's hydraulic docks are able to sustain ships under repair by using the right proportion of depth to breadth for a ship which has her centre of gravity at a certain height above the water.

This table enables one to see, also, how the square-built, wall-sided, deep-bottomed ships, so often built by uninformed or careless shipwrights, turn out unstable and unseaworthy.

In using this table to judge of a ship or design, it must not be forgotten that the case assumed is that of a *box-formed* or *wall-sided* vessel, nearly *rectangular* in shape; but it is nearly true, also, of a vessel slightly rounded off at the corners, and will be pretty exact for many large, capacious ships. It must be carefully borne in mind that the table shows the extreme or upsetting heights to which the centre of weight must *not* be raised. The weights of a well-trimmed ship, intended to carry sail well, should be kept so that the *centre of gravity* may be several feet under the limiting height.

It should be further noticed that the *length* of the vessel is not given in the table. The *breadth* and *depth* being given, the length has *no* effect on the height at which the whole load can be carried. But length has everything to do with the *quantity of weight* which that ship will carry at the *height* in the table. Thus, a ship of 36 feet beam carries one ton for every foot deep; and for every foot in length, as many tons as there are feet of her depth in the water; therefore it is to be remembered that the weights carried at these heights are limited by the total displacement tonnage of the floating body. With these explanations this table is a safe guide for the judgment in regard to rectangular, box-shaped or wall-sided, square-bilged vessels.

TABLE V.

POWER TO CARRY TOP WEIGHT.

Heights out of water up to which loads can be carried by vessels of square form and of different proportions of breadth of shoulder to depth of draft.

DRAFT.		**BREADTHS. (Feet.)**													
Feet.		12	18	24	30	36	42	48	54	60	66	72	78	84	90
...	Limiting heights of load in feet and inches.	0	......	......	......	......	......	......	......	......	......	......	......	....	....
6		0	1.6	5.0	9.6	15.0	21.6	29.0	37.6	47.0	57.6	69.0	81.6	95.0	100.6
12		0	0	0	0.3	3.0	6.3	10.0	14.3	19.0	24.3	30.0	36.3	43.0	50.3
18		0	0	0	0	0	0	1.8	4.6	7.8	11.2	15.0	19.2	23.8	28.6
24		0	0	0	0	0	0	0	0	0.6	3.1.5	6.0	9.1.5	12.6	16.1.5
30		0	0	0	0	0	0	0	0	0	0	0	1.8.4	4.7.2	7.6
36		0	0	0	0	0	0	0	0	0	0	0	0	0	0.9

Proportion of Breadth and Draft at which such vessels will upset if they carry Top Weight.

BREADTH.	**DRAFT.**	**BREADTH.**	**DRAFT.**	**BREADTH.**	**DRAFT.**
Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
12	4.8990	54	22.0455	14.697	6
18	7.3485	60	24.4950	29.394	12
24	9.7980	66	26.9445	44.091	18
30	12.2475	72	29.3940	58.788	24
36	14.6970	78	31.8435	73.485	30
42	17.1465	84	34.2930	88.182	36
48	19.5960	90	36.7425	102.879	42

CHAPTER XI.

THE METHOD OF MEASURING STABILITY.

1. The first method is to determine how much top weight will careen the ship to a given large angle—say 14° out of the perpendicular, or in war vessels 7°—in order to compare the stability of different ships with one another at this angle.

2. The second method is to find the extremely small degree of careening which will be produced by an extremely small top weight.

By this investigation is discovered a curious quality belonging to crank ships—namely, that although a very small top weight may make them lean over a little, they may, nevertheless, offer great resistance to a great weight tending to incline them much. It is common to speak of such ships as being "*tender,*" rather than crank.

The following are the successive steps (figs. 2 and 3):

1st. Measure the bulk of the under-water body, the ship being inclined on alternate sides to the given angle.

2d. Measure the buoyant force of that bulk, taking 36 cubic feet of bulk for each ton of buoyancy.

3d. Find the place of the centre of effort (B) at which this force acts, which is the point commonly called the *centre of gravity of the under-water body.** Next, through the point thus found draw an upright line (Bb) cutting the water-line at some distance from its middle. Then measure this distance (Ob) from the middle line of the ship.

4th. The line (Ob) just measured is called "*the effectual distance of the upsetting force,*" and being multiplied by the number of tons already found as the measure of that force, the product is called "*the momentum of the upsetting body.*" This momentum is taken as the measure of the upsetting force.

* Or centre of buoyancy.

5th. Measure the bulk of the righting body, or "*shoulder*" under water, when the ship is inclined at the given angle.

6th. Measure the buoyant force of the bulk of the "shoulder," taking 36 cubic feet for each ton of buoyancy.

7th. Find the place of the centre of effort in the "shoulder" (R) at which this force acts, which is the point commonly called *the centre of gravity*, and is nearly two-thirds the breadth of the "shoulder" from the centre of the ship, or one-third from the outside.

Next, through the point (R) thus found draw an upright line (R*r*), cutting the water-line at a point (*r*); of which measure the distance from the middle line of the ship (O*r*).

8th. The line (O*r*) just measured call the "*effectual distance of the uprighting force*," and multiply it by the number of tons already found as the measure of that force; this product call "*the momentum of the uprighting force*," and take it as a measure of the uprighting force.

9th. Next subtract the smaller of these two *momenta* from the greater. If the upsetting force be the greater, the ship will overset in that position, unless some heavy weight be placed on the bottom, or some equivalent force be applied to prevent its oversetting, and such a force will, in order to be effectual, require to have a *momentum* at least equal to the difference.

10th. But if, on the contrary, the uprighting force be the greater, the ship in that position tends to upright itself, and can carry increased top weight, until this increased momentum becomes equal to the *surplus* righting momentum.

It is this surplus momentum, either way, that is taken to measure the stability or instability of the ship.

11th. If the surplus righting momentum be *divided* by the entire weight of the ship, the distance will be found to which this whole weight might be removed to one side without upsetting. This distance is reckoned as another measure of stability. If, now, this last measure be divided by the sine of the angle of inclination, the height will be obtained to which the whole weight of the ship might be raised without upsetting it; and this is a third measure of the stability of the ship, and is called the measure in height of stability of form.

It may be found geometrically by taking the point B, and through it erecting a perpendicular to the water-line, which will cut the upright middle of the ship at this height.

Thus measures of stability are obtained in three forms:

1st. Power to carry a given weight at a given distance out of the middle line.

2d. Power to resist a given heeling force.

3d. Power to carry the whole weight at a certain height above the water.

The second method of calculating the stability of a vessel is to calculate all the quantities given above, for some extremely minute angle of deviation (say 41″) from the vertical position. This may be said to measure the resistance of the vessel to deviation from the vertical, whereas the former method measures her tendency to return to the vertical after having been compelled to make a great deviation from it.

ELEMENTS OF STABILITY.*

Breadth.—The stability of a vessel increases or diminishes enormously with its variation, whether the displacement remain constant, or, the draft remaining constant, the displacement vary with the breadth. In the latter case the height of the meta-centre varies as the *square* of the breadth.

Displacement.—If the breadth remain constant, the stability increases as the displacement decreases. And since in that case the centre of displacement rises, the height above the water-line to which the vessel's load may be carried receives a further increment.

Draft.—Assuming both the breadth and displacement to remain constant, the increase or diminution of draft lowers or raises the centre of displacement, and with it the meta-centre. It does not otherwise effect the instantaneous stability.

Stowage of Lading or Ballast.—The meta-centre indicates the height to which the centre of weight of the vessel may be brought

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* There are two kinds of stability, viz.: *Statical* and *Dynamical.* STATICAL STABILITY *is the moment of* FORCE *(or effort) by which a floating body endeavors to regain its upright or vertical position after having been deflected from that position.* DYNAMICAL STABILITY *is the amount of* WORK (*i. e.*, weight of the body in lbs., avoirdupois, multiplied by the vertical height in feet of the sum or differences of displacements of the centres of gravity of the body and of the water it displaces) *done on any body, in order to deflect it through any angle from its upright position.*

without upsetting; and the amount of stability for very small inclinations is measured by the distance between the meta-centre and the centre of weight. The stowage, therefore, effects the instantaneous stability in so far as it raises or lowers the centre of weight, and not further or otherwise. As the meta-centre fixes an absolute maximum, which being reached the vessel has no stability whatever, the weights must, in practice, be kept considerably below it, as the vessel must have reasonable stability.

Curve bounding Plane of Flotation or Form of Water-line.—This element of variation may be considered apart from all others, and even independently of the proportion between length and breadth. *Cæteris paribus,* fine lines may reduce the stability, measured by the height of the meta-centre above the centre of displacement, to one-half what it is in the *rectangular box.* (Fig. 5.)

Length and Lateral Stability.—This element may be always disregarded, except in the mere calculation of actual weights, provided the same breadths and depths at proportionate lengths are maintained.

Weight.—This element is merely a factor, and is of no other account in the investigation of stability.

A vessel with nothing movable in her has her stability completely determined by the moments on the water-line of the three following forces, only two of which are independent:

1st. Her weight.

2d. The upward pressure due to her displacement.

3d. The force required to keep these in equilibrium.

Distinction between Heeling and being Listed.—A vessel is said to *heel* when she is pushed over by an extraneous force, on the removal of which she would alter her inclination.

She is said to be *listed* when she has found equilibrium in any position other than upright, whether owing to an unsymmetric distribution of her weight or to any peculiarity of form. A *list,* therefore, implies equilibrium (though unsymmetric); *heeling* excludes equilibrium.

As applied to a vessel *heeling,* the meta-centre has no meaning, except to indicate how an alteration of the weights might be made to give equilibrium. As applied to a *listed* vessel, it has the same import as to a vessel floating upright. In both these cases it affords practical means of comparing many different forms, especially where the variation to be considered is in the water-line.

As a rule, when two floating bodies are homogeneous and homologous, and their breadths B and *b*, their stabilities are to each other as B^4 to b^4. If two homogeneous bodies have homologous transverse sections, but not homologous longitudinal sections, and their lengths are L and *l*, and breadths B and *b*, their stabilities are to each other as $L \times B^3$ to $l \times b^3$. A *rough* comparison between two ships may therefore be made by comparing the products of their lengths and cubes of their breadths.

Fig. 5 is 36 feet in breadth and 27 feet in depth—scale, ⅛th inch to 1 foot. After inclining this form to the taken degree, and after having calculated the piece OO′ as mentioned in the table, another line is drawn below the upright water-line on the side of the immersed part, going through O′, making an angle, φ, with the upright water-line. Through this line the whole immersed body is divided into two parts—the "upsetting" part and the "righting" part.

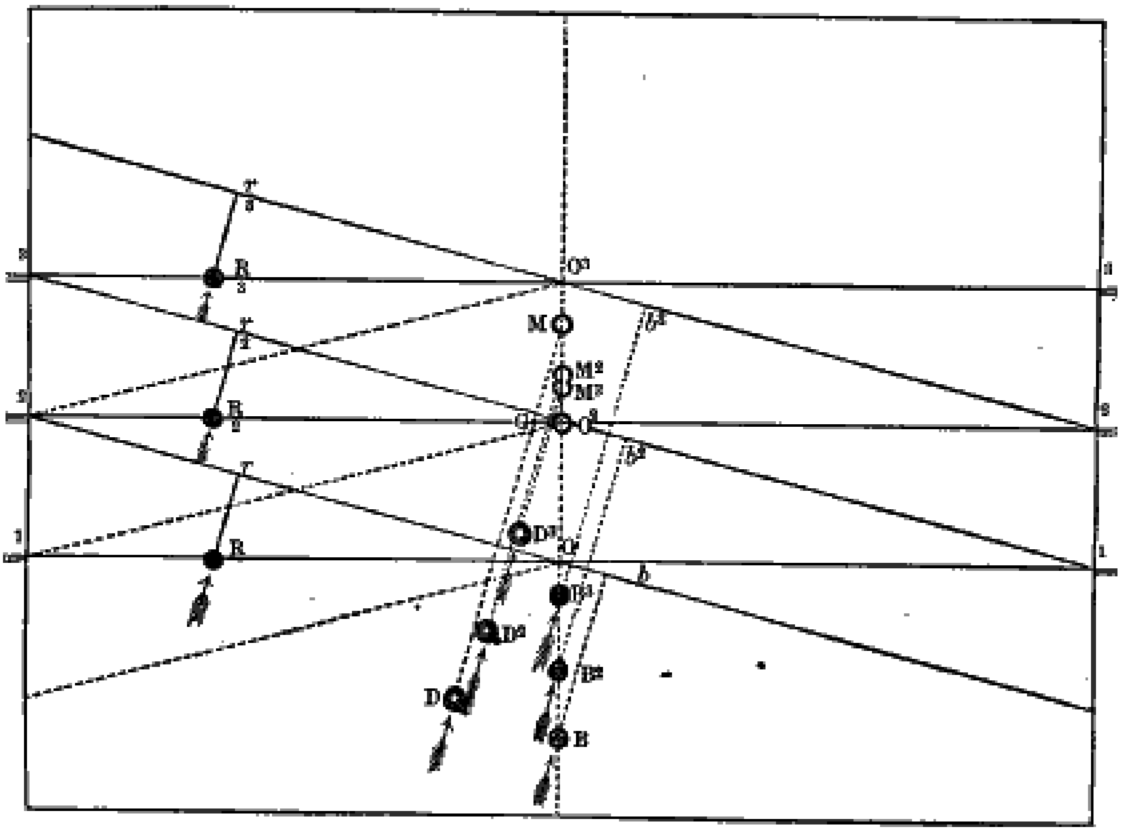

FIG. 5.

TABLE VI.—(*Calculations applied to Fig. 5.*)*

Reference No.	Angle of inclination, ϕ =	14° 9′.			41″, or Index.		
	Draft of water, d =	Feet. 9	Feet. 13.5	Feet. 18	Feet. 9	Feet. 13.5	Feet. 18
1	Volume of displacement in the upright position, D =	324.	486.	648.	324.	486.	648.
2	Volume of displacement in fractions of parallelogram, $b \times d$	1.	1.	1.	1.	1.	1.
3	Centre of buoyancy below water-line, Do =	4.5	6.75	9.	4.5	6.75	9.
4	Centre of gravity of vessel below water-line	4.5	0	— 4.5	4.5	0	— 4.5
5	Volume of immersed part	40.5	40.5	40.5			
6	Volume of emersed part	40.5	40.5	40.5			
7	Difference	0	0	0			
8	Height to which the vessel has been raised to make inclined displacement equal to upright displacement = OO′ = $\frac{\text{Diff.}}{ob \cos \phi}$	0	0	0			
9	Volume of upsetting part	243.	405.	567.	323.93	405.	647.93
10	Volume of righting part	81.	81.	81.	0.0648	0.0648	0.0648
11	Centre of gravity of upsetting part below O′, Bo′ =	5.5	7.8	10.07	4.5	6.75	9.
12	Centre of gravity of righting part from O′, Ro′ =	12.	12.	12.	12.	12.	12.
13	Centre of gravity of overturning part above O′, Go′ =	4.5	0	— 4.5	4.5	0	— 4.5
14	Leverage of upsetting part, or $bo' =$ Bo′ × sine ϕ =	1.33	1.89	2.44	0.0009	0.0013	0.0018
15	Leverage of righting part, or $ro' =$ Ro′ × cos θ =	11.64	11.64	11.64	12.	12.	12.
16	Leverage of overturning part, or $go' =$ Go′ × sine ϕ =	1.09	0	— 1.09	0.0009	0	0.0009
17	Effects of upsetting force or upsetting moment, B × bo'	323.19	765.45	1383.48	0.2915	0.5265	1.1662
18	Effects of righting force or righting moment, R × ro'	942.84	942.84	942.84	0.7776	0.7776	0.7776
19	Balance in favor of righting moment, or moment of stability of form	619.65	177.39	— 440.64	0.4861	0.2511	— 0.3886
20	Moment of stability divided by D, or measure of stability of form	1.91	0.36	— 0.68	0.0015	0.0005	— 0.0006
21	Limiting height of the centre of gravity of vessel above water, or height of meta-centre above water-line, or MO′	7.88	1.51	— 2.8	7.5	2.5	— 3.
22	Measure of stability, with weight	0.82	0.36	0.41	0.0006	0.0006	0.0006
23	Moment of stability, with weight	266.49	177.39	265.68	0.1944	0.2511	0.1944
24	Limit to which centre of gravity of vessel may rise from its original position, or height of meta-centre above centre of gravity of vessel	3.38	1.51	1.7	3.	2.5	1.5
25	Distance of meta-centre above centre of displacement (or buoyancy)	12.39	8.25	6.2	12.	9.25	6.
26	Interval between the meta-centre and centre of displacement, or $\frac{b^3}{12 \times D}$	....	....	....	12.	8.	6.

* This table is merely inserted to show the method adopted by Scott Russell in calculating "Stability." For a full discussion of the subject refer to his work.

CHAPTER XII.

STABILITY—POWERS AND PROPERTIES OF THE "SHOULDERS."

THE sum and substance of what is known of the nature of stability is that the "shoulders" *alone* give to the ship righting or uprighting power, and that no other part of the ship can be so formed as to increase the righting power given by them. This righting power is equally effective in squaring the ship to the water, whether it be still water or rough wave water.

The under-water body can in no way help the ship to keep upright, since there is no kind of bottom on which she can be said to rest in the water. The most that any under body can do, either by shape or size, is to take *less* away from the stability given by the "shoulders" than some other shape or size of under body takes away. Size of bottom, therefore, or quantity of under-water body, *lessens* the stability of a ship, and has to be counteracted by the power of the "shoulders." In short, bottom tends to upset the ship; so much so, indeed, that if it be large and powerful, it may take more than the whole power of the "shoulders" to keep it down and prevent the ship from capsizing. In any case it weakens the effect of the "shoulder" by the whole of its upsetting power.

It is only, therefore, the surplus power of the "shoulder" remaining over and beyond what is employed to keep down the under body which is available for use in carrying a press of sail, or in supporting top weight out of the water. If there be any such surplus, it is necessary to find out how much there is, to see if it be enough to carry a press of sail, and enough also to carry top weight, as then the ship may be able to do without *ballast*.

By ballast, in the general sense of the term, is meant weights carried under the water, in contradistinction to weights carried above the water, or top weights. There are two ways of ballasting a ship;

one is by the real lading of heavy weights under the water; the other is by putting weights, which are not parts of the lading, nor essential parts of the ship, low down in the ship for the mere purpose of helping the "shoulders" to carry top weight; this latter being the old principle of ballasting.*

Weight placed under the water in either way may be said to have the following effects: first, by being under the water as far as the top weights are above it, it neutralizes the bad effect of these top weights and balances them. In this way under-water weight assists the "shoulders" in carrying top weight.

There is another way of looking at the effect of under-water weight in giving stability; it aids the "shoulders" in keeping down the under body. In this way, as well as in counterbalancing top weight, under-water weight helps the "shoulders."

Thus it is that there are three agents in stability—two arising from the shape alone, and one from disposition of weights. The shape and size of "shoulder" give stability of *form;* the shape and size of under-water body give instability of form. What of the power of the "shoulder" remains beyond counteracting this under body is the true surplus stability, or measure of righting power, for that form. This surplus is all that can be used for navigating a ship and carrying her top weights. If more stability be wanted, it can be obtained by *weight* alone. All the weights of a ship which have their common centre of gravity in the middle of the ship, just between the two "shoulders," neither help the stability nor hinder it. Only weight placed *below the middle of the "shoulders"* gives help and increases stability; and if the centre of all the weights of the ship, cargo and ballast, taken together, fall *above* the water-line, the surplus power of the "shoulders" may enable her to carry sail; if not, there is no resource left but to lower the weights in her, or to place ballast in her bottom; in other words, to supply the defect of *stability of form* by adding *stability of weight.*

As, therefore, stability of form is that power which the naval architect alone can confer on his ship—while stability of weight may afterward be regulated by those who lade, and control, and navigate the vessel—the form and action of the "shoulders" are the province in which the skill, contrivance and forethought of the designer of the ship can be most powerfully and usefully employed.

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* Fincham states that in 1783 "three-decked ships" carried 480 tons of this dead weight.

CHAPTER XIII.

HOW TO GIVE A SHIP STABILITY WITHOUT GREAT BREADTH OF "SHOULDER."

Breadth of "shoulder," properly placed, gives power to stand upright and to carry heavy weights above the water; but cases often occur in which stability is sought and breadth of "shoulder" denied. This may arise from local causes, such as the narrowness of a dock entrance, or from a wish to obtain certain other qualities which may be inconsistent with great breadth.

In this case the dimension of length is the only one not limited, and the question arises, How can length take the place of breadth? To find out how stability may be given by length where the breadth is limited, it must be remembered that if the two *ends* are made very fine, in proportion to the *middle body*, they may be considered as having little effect in giving *increased* stability to the middle. Now, in *all* vessels with fine ends, very large portions of the two ends have merely stability enough to upright themselves, and have no power whatever to help the middle body to carry top weight. These two portions, therefore, may be taken as *neutral* parts of the vessel—neither helping the middle body nor requiring help from it, and therefore it simplifies the subject very much to leave them altogether out of the question.

Suppose fig. 10 to represent the *bow* of a ship, and fig. 14 to represent the *stern* of a ship at the mean depth of water. The form fig. 10 barely stands upright with its own weight. In like manner the form fig. 14 barely stands upright with its own weight, and a very slight elevation and depression of weights would make them absolutely neutral.

It is plain, therefore, that these forms, if taken as types of a certain kind of bow and stern, do not affect the stability of the middle body either way. These two ends may be assumed as types of the

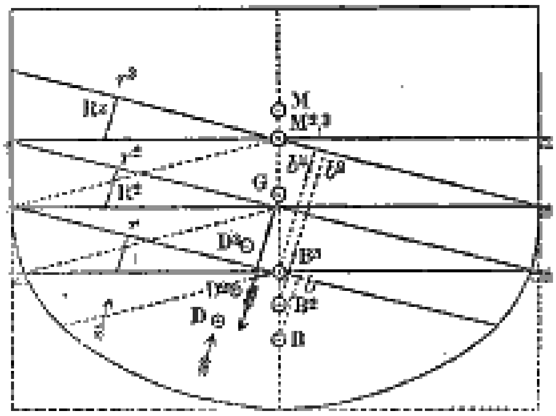

FIG. 6.

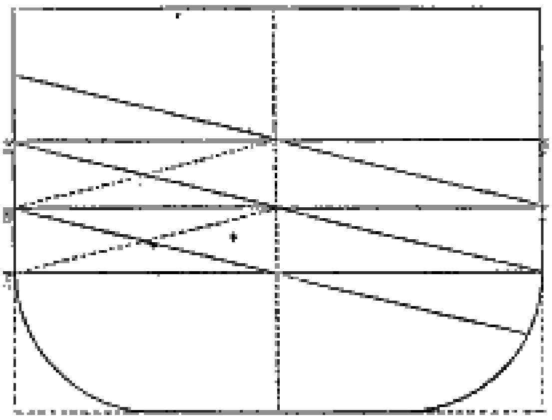

FIG. 7.

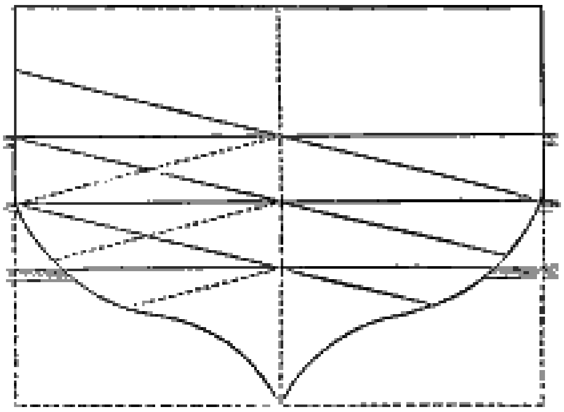

FIG. 8.

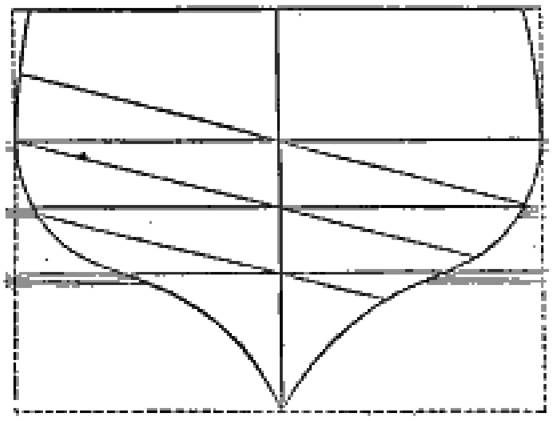

FIG. 9.

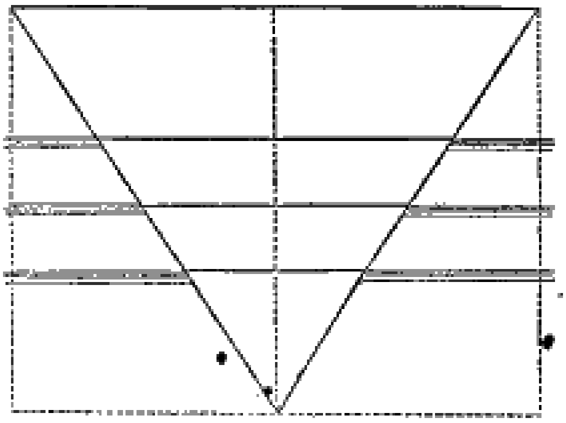

FIG. 10.

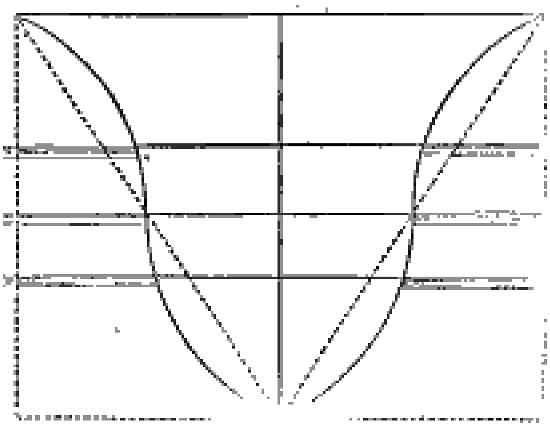

FIG. 11.

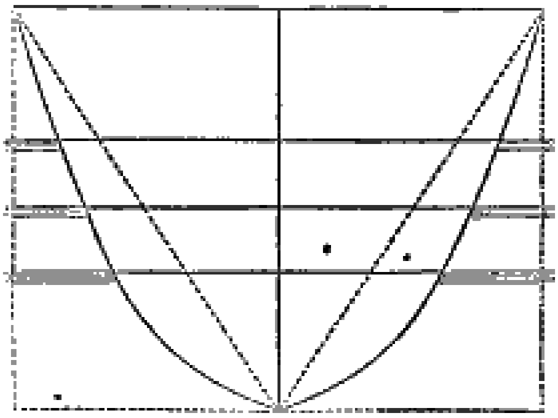

FIG. 12.

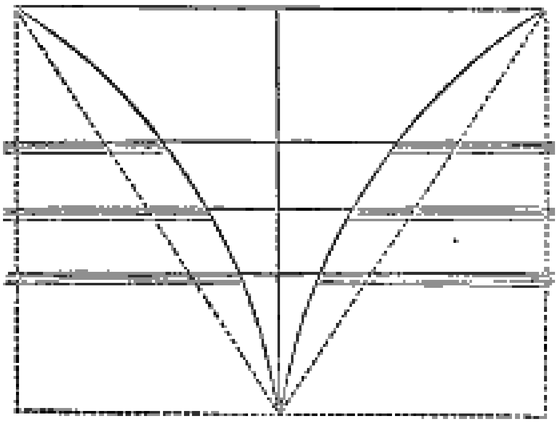

FIG. 13.

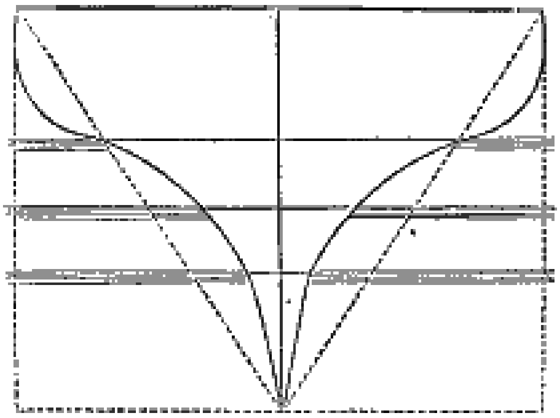

FIG. 14.

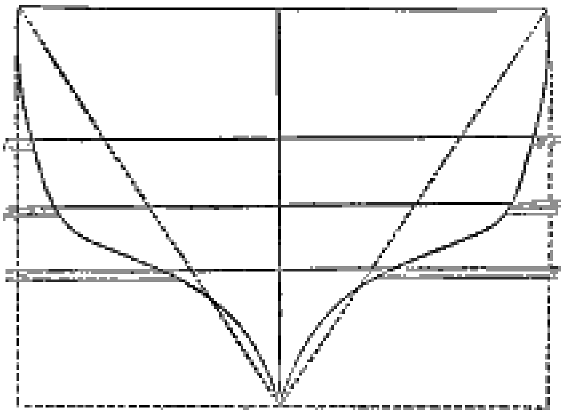

FIG. 15.

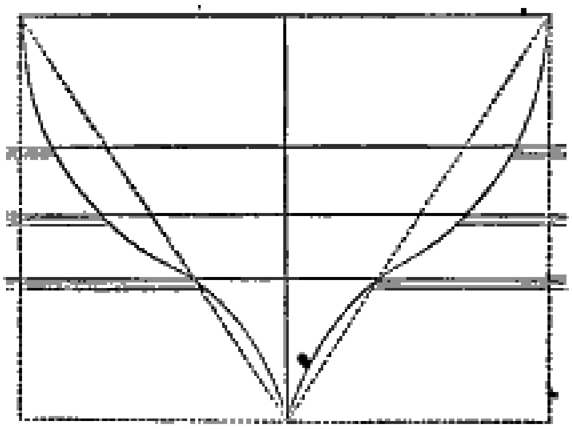

FIG. 16.

"*clipper*" bow and stern. Suppose fig. 11 to represent a "*bell*" bow, and it is seen that instead of being any use, this "*bell*" bow is unable to carry itself, and would require help to a very great extent. Fig. 12, on the other hand, taken as a type of the "*wave*" bow, has a powerful surplus stability at its deepest immersion, while only at its lightest immersion does it need help. Fig. 13, which is the extreme of the "*flare-out*" bow, is unstable at all immersions, and worse than helpless. It is plain, therefore, that the naval architect need not trouble himself to seek much help from any of these bows: it is to the *stern* that he should look for any help he may want in supplying the needful stability.

It is found, by long practical experience, that there exists a wide scope for obtaining power, stability and *weatherliness* to a ship of limited beam by a wise design of the *after* body.

A crank, narrow ship, may be rendered stable and weatherly by a very moderate alteration to the bulk and form of the after body. The secret of success consists in uniting with a very fine line under water a very full line at the surface of the water. Fig. 15 has great stability at its two deepest immersions, and is not deficient in stability even at its lightest. So great is its stability that very few *midship sections* even compete with it, and to most of them it would, at its deepest drafts, impart an enormous increase of that quality.

There is another point where the constructor can use the form of the stern with great effect, for the power of a middle body to carry top weight lessens as the draft of water increases. This is the same as saying that in proportion as heavy top weight presses the vessel more down in the water, so does this very depth in the water diminish the power of the midship body to carry its top weight. The reason for this is already known to be that bottom buoyancy increases both the quantity of the upsetting force and the advantage with which it acts. Now let it be observed how the after body can be used, so as exactly to counterbalance this defect of the middle body, and make good the stability of the ship in exact proportion to the increasing top weight which presses it down in the water.

The skillful architect will carefully cut away bottom buoyancy from the stern of the ship, which will enable him to make the "*run*" as clean and fine as he wants it to be. Nearer the middle the stern may be like fig. 15, and further aft like fig. 16; and finally like fig.

14. Each of these forms has a growing surplus of stability over that necessary to support itself, in something like the following proportion to the increasing draft of the water: Fig. 15—3 when lightest, and 7 when deepest; fig. 16—3 at middle draft, and 6 when deepest; and fig. 14 only 4 when deepest, but negative at the two other drafts. The more, therefore, of a form approaching to fig. 15 the constructor can put into the stern, the more powerful will be the resources he will have developed in the stern to aid the good qualities of the middle body, and to supply stability to do the work required exactly at the time and in the manner where it is most wanted.*

Constructors of the old school declaimed against a full after body and insisted on a fine run; but in truth there was no reason why either should have been sacrificed, in so far as concerned its practical use. On the bottom of the stern give the finest possible run: it is there where it is wanted, there alone where it is useful; so there give it to the utmost. Near the surface of the water, on the contrary, fineness of run is not only of no value to speed, but has many disadvantages of every kind. A wise constructor will seek there the stability he wants; since the buoyancy may be taken in large quantity near the surface of the water without impediment or increase of resistance; in short, as much as is wanted to make the vessel a good and stable ship. A mine of good qualities is here to be found, formerly comparatively unworked, mainly on account of a vague but widespread prejudice, having no better basis than the old saying: "Cod's head and mackerel tail." "Cod's head" meant simply the putting the fullness required for stability to carry sail in the bow; and "mackerel tail" meant taking it away from the stern. In former days it was not known that putting fullness in the bow, to create stability to carry sail, was putting it in a place to render that sail useless, for there it prevented it from carrying the vessel rapidly and easily through the water. The "wave" principle enables the modern naval architect to take away all that bluff buoyancy from the bow, where it does so much harm, by simply transferring as much or more buoyancy and stability into that part of the stern where, instead of doing any harm, it does good in every

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* The form of the cross sections should be such that the volume of the wedges of immersion and emersion should be equal; otherwise the centre of gravity will rise during the motion of rolling, and produce an uneasy and very straining motion.

way, because it leaves the bow fine, of the form of least resistance, least disturbance and of greatest speed, while it transfers to the stern heavy weights which would harm the bow, and brings bulk where it gives room, buoyancy and stability.

Moreover, this room is given in that part of the ship where it is generally of the greatest value, both in a mercantile point of view and—in ships propelled by the screw—in a mechanical point of view; for it is exactly a form of stern, extremely fine and clean below, which is best suited for the screw's effective action, while the buoyancy and room above are all required in order to carry and counteract the great weights and mechanical forces due to the action of a propelling power in the after end of a ship.

CHAPTER XIV.

HOW TO MAKE A SHIP DRY AND EASY.

THERE is probably no point in naval construction subject to such variety of opinion as how to obtain ease and dryness in a ship head to wind, since there are several causes of seaworthiness and consequently counterpart causes which make a ship wet, uneasy and laborsome.

It is necessary to examine this subject to arrive at just conclusions, because these same causes also make it either easy or difficult for a ship to ride at her anchors in heavy weather or in a storm in the open sea when lying-to. The qualities proposed for consideration are among those which it is most important to decide accurately, because they are those which enable a ship to survive in safety the perils of the sea.

The first elements of riding easy are form and size of bow above the water. Some thirty years ago it was believed that a seaworthy, comfortable, safe vessel must have a high, wide, roomy, round, bluff bow, and that such a bow would enable a ship to throw aside every head wave and rise high and dry above the sea, the idea being that great over-water bulk and buoyancy was the grand consideration for securing the ease, safety and comfort of the ship.

It must be admitted that the example of the Dutch and of many others countenanced these opinions of the old school, and certainly any one who has seen how the Dutch fishing-boats and the pilot-boats, on the coast of Holland, ride out a storm on that dangerous and shallow coast, and ride safely over the breakers, would be apt to form a prejudice in favor of a buoyant, bluff bow.

There are many points in the structure of these craft which peculiarly fit them for their special purpose; their bows are more bluff even than a circle, they recede inward under the bowsprit, so that they are the extreme and perfection of bluffness. But there could be no greater error than to take them as the type of seagoing ships, although it is a common blunder to fancy that the form which answers well for one purpose on a small craft answers equally for all purposes on the scale of a large ship. This natural belief has, however, been the parent of the greatest errors in naval architecture: it is an idol of tradition.

The best constructors of the present day hold a belief contrary to all this, and it is believed to be the experience of all intelligent seamen who have sailed in good vessels of the modern form, that the long, fine, hollow wave, or even straight-line bow, carried well above the water, rides easy and gently head to wind, when a full bluff bow could not live.*

Russell mentions an instance in which he illustrated this some twenty years ago.† He says: "I built four cutters of four large ships, all of the same dimensions, with four different shapes of bow—a "*wave*" bow, a "*straight*" bow, a "*parabolic*" bow, and a round, "*bluff*" bow. I allowed the four captains to choose each his own boat in the order of seniority. The oldest captain took the bluffest bow, of course, as the best sea-boat, and the "wave" bow was left for the last. In order to test their dryness and safety, head to sea, I had all four taken out together and forced through the water at the same speed by a steam-tug. The speed was steadily increased, until at last the water was coming over the bows of the bluff cutter in such quantities that the trial had to cease in consequence of the head sea pouring into her and filling her; the boat at the same time yawing about wildly beyond the control of her rudder, and threatening to go down. All this time the crew of the fine "wave" bow, at the same speed, were dry, easy and comfortable; and so there was an end, in

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* A marked illustration of this fact occurred during a cyclone in the road of Funchal, Madeira, in March, 1858. An English sailing barque (built of iron), with the long fine bow, as above, rode out the gale and heavy sea with the utmost ease and dryness, without striking any yards or spars; while the full, bluff bows went on shore and were wrecked, with the exception of the U. S. frigate "Cumberland," which was only saved by the superior nature of her ground tackle and equipment, and a fortunate change in the wind at a critical moment.

† See the "Modern System of Naval Architecture," by Mr. J. Scott Russell, from which a great portion of this work is taken.

this case at least, of the prejudice that the full bow was the safe and dry boat."

On a large scale, however, the circumstances may be different, though observation of the effects of propelling vessels with full bows, head on to the sea, leads to but one conclusion, whether the full-bowed ship be propelled by steam against a head sea, or riding at anchor, or laid-to head to wind in a storm.

For the fullness of the bow does cause the ship to rise over the waves and to ascend on the coming sea; but, unluckily, it rises too high and too far, whence it follows that when it reaches the top of the sea a great quantity of the bow is left high and unsupported in the air and out of the water. In the next second the unsupported body falls with a rapidly-accelerating velocity, and by its *momentum* in falling plunges deep into the hollow of the wave. It is there met by the rising face of the next wave, which lifts it high in the air, when it again plunges heavily into the hollow of the next sea. It is *this* plunge into the succeeding sea which produces that violent shock that *no ship* can withstand for a long time. The English steamer "Great Britain" was an example of a vessel very fine below, with a great projection given to her above, under the idea of obtaining seagoing qualities; in her first trial, however, she received serious damage from a sea striking her in the manner above described. The same thing happens to a ship with a full out-of-water bow when she rides a gale; the bow receives from the ascending wave a rapidly-ascending motion till she comes to the top of the wave, and then, going over the crest, the whole weight of her unsupported, overhanging bow pitches down into the succeeding hollow; half buried, she is brought up with a violent shock in the following sea, and so she goes on *'scending* and *pitching* violently over every crested wave.

It will be seen that such a vessel *cannot* make much headway through the water, since the force propelling her no longer goes to speed. It goes toward driving her up on the ascending wave and down on the descending wave, and each heavy stroke of the water on the immersed bow is just so much force expended in stopping the ship, straining the timbers and *wasting* the propelling power. Effective speed loses, therefore, as much by such a form as ease and security.

But it may be asked, "How should a vessel move, if not up and down over the sea?" To which it may be replied, "Up and down certainly; but not violently—as gently as possible." The movement up should be gentle, the vessel ascending just so much that the rising wave may not enter the ship, and descending on the other side just far enough to recover easily and without a shock at the bottom of the wave. In short, the motion of the vessel up and down should be a little less than that of the wave, and a little slower; and this desirable equilibrium is accomplished by a certain well-proportioning of the bulk of the over-water part of the bow to the under-water part. When the under-water part is very fine, the out-of-water part must be made fine likewise. When the under-water part is full, the out-of-the-water part will have to be proportionably full, and this proportion may be best given by so arranging it that the bow of the ship on the ascending part of the wave and on the descending part of the wave shall have nearly equal bulks, alternately exposed below the water-line and immersed above it.*

It is to be observed, however, that at the bottom of the wave the way of the ship exercises more force upon the approaching wave, to bury itself, than at the corresponding point of the top of the wave to rise out of the water. It is right, therefore, that the out-of-the-water part of the bow should be fuller than the under-water part—just enough to prevent her taking in a sea.

It is evident, therefore, that this approximate equality of fullness of bow above and below water has a tendency to make the sides of the bow between wind and water nearly straight, and also nearly vertical.

To this kind of bow there exists two in marked contrast, termed the "*flare-out bow*" and the "*tumble-home bow.*". The "*flare-out bow*" is often called the "*clipper bow;*" and there is another kind of it, formerly called the "*bell bow;*" and midway between all these is another sort of bow, neither tumbling home nor tumbling out: this may be styled the "*upright bow.*"

The "*bell bow*" was a favorite form with the builders of the packets trading between New York and Liverpool thirty years since, before the mail steam lines ruined that trade. It was a fancy of the builders of those fine ships to give the bows a form somewhat resembling a church-bell inverted, the swell outward, or "*flare out*"

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* The bow of the "Great Eastern" has been said to accomplish this in *all* weathers.

as it is called, beginning about the "light line," and flaring out all around to the top of the bulwark, so that the forecastle occupied, as it were, the mouth of the bell.

There was, no doubt, something graceful and majestic about the aspect of these great bows, and they, no doubt, buffeted the waves triumphantly, but meanwhile the vessel was engaged in other work than its duty. Its business was to have gone not *up and down*, but *forward*, and this the bell bow hindered, and expended useful force in unnecessary but magnificent struggles. A bow was wanted that should elude the waves and pass them—escaping its enemy, not fighting it.

The clipper bow was next introduced to accomplish the design of the bell bow without involving its defects. Believing still in the advantage of a large flaring-out bow, the inventors of the clipper bow endeavored to obtain the supposed advantages of great buoyancy without the impediment produced by so much immersion in the water as the bell bow involved. "For this purpose," said they, "let us bell the bow laterally and draw it out longitudinally into a fine point; thus we shall preserve its bulk, but improve its shape."

Hence the fashion came in of prolonging the bulwarks of the ship at the level of the upper deck a great way forward, even 10, 20 or 30 feet in front of the actual ship, and there they were drawn out into a fine point above, and joined to the real ship about the water-line, everywhere with a kind of hollow flaring outside. This system certainly mitigated some of the evils of the bluff bell bow, and a large volume of buoyancy in the upper part of the bow, enormously in excess of the part in the water, was obtained.*

Yet it must always be regarded as a bad quality to have on the sides of a ship large overhanging projections, whether they "bell out" or "flare out." It is enough to say that they injure speed, and that they give uneasy motion to a ship, and that overhanging surfaces generally strike the water violently and uneasily. There can hardly result any good in a large flaring-out bow, whatever its shape may be; and it must be paid for in weight of material, in want of strength, in resistance to speed and in uneasy motion.

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* The clipper vessels of Messrs. McKay of Boston and Hall of Aberdeen are very successful instances of the application of this system.

The most plausible recommendation of a "flare-out" bow is, that it throws the water off and makes a ship dry; but this is true only in a certain degree and in certain circumstances—not general—and rarely belonging to the cases now under consideration. If a vessel of fine and upright form in every respect have a slight "flare out" given to it at the top, it will turn over the tops of the waves and prevent some spray from coming on board; but if it really strike solid water instead of spray, it will do so with such force as to send that water into the air in large quantities; and if the vessel really take in green water over the "flare-out" bow, the danger to the ship produced by the mass of water in that place is so serious that no imaginary beauty can even justify such a defect.

It is believed that a much better form of bow is the nearly upright, or say the "tumble-home" bow, provided the construction of the other part of the ship will admit of it.

A dry vessel is made not by a bluff, overhanging bow to bruise, beat and buffet the waves, but by a long, thin, sharp bow to elude the waves, to pass through them so as never to break the water at all; in short, a bow so formed as to offer the minimum resistance to the passage of the vessel through the water, not in one direction merely, but in every direction all round the bow, above and below.

According to this fashion, the full projection of the bow should be on the water-line, which alone should first penetrate the waves, while the top sides of the vessel should "tumble home," and the whole be rounded off so beautifully and smoothly that nothing should either catch the water, stop the sea or break it. Observation and experience show that such vessels are the dryest and fastest in bad weather, as well as the easiest sea vessels, and, above all, the safest. If green seas ever come over the bows of such vessels, they have a much smaller quantity to take in, they hold much less, and what little does come in is much farther back, and consequently much less injurious.

The "tumble-home" bow has never yet become "a fashion," but vessels have been built with it which have proved themselves so much the better for it that it is thought that ultimately it will be generally adopted. For speed, easy riding at anchor, ease in a gale of wind, or safety from the danger of shipping a sea, no other form is equal to it.*

There are two exceptions, however, to this reasoning: A very small vessel must have a large body above the water, if it be an open boat, to prevent its being swamped or filled with water; and where buoyancy cannot be given by other means, it may be given by flaring out.

Another case is that where the bow of a vessel is filled—as, however, it ought *not* to be—with extremely heavy weights, corresponding buoyancy must be placed on top of the bow to make it rise to the waves. This, however, is curing one evil by means of another.

No vessel designed for great speed ought to have much capacity under water in the extreme bow, and in no case should that part of the vessel be occupied with heavy weights.†

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* A considerable number of the English blockade-runners captured during the late war were built with this bow. Though of small tonnage and limited beam, as a general rule they proved admirable sea vessels in *bad* weather.

† Therefore heavy pivot guns, in "the eyes" of sharp-bowed men-of-war, are great *mistakes*.

CHAPTER XV.

ON LONGITUDINAL STABILITY.

If, in conformity with the maxims in the preceding chapter, the flaring bow (which causes a ship to pitch high, 'scend deep and make bad weather) is removed, a long step will have been taken toward making her easy and dry, and many common causes of unseaworthiness are thus obliterated. But there still remain some arbitrary matters, a choice of which goes far to enhance or improve the good qualities of a ship.

The over-water bulk above the water-line is removed; but in the choice of the *proportion* and *form* of the *water-line* itself much has to be settled on which may improve or injure the ship. It by no means follows that a vessel without overhanging or flare-out bows is either easy, dry, safe or steady, whether riding at anchor or going through a heavy head sea, since the form of the water-line is also a powerful agent in ease and seaworthiness.

The power of the sea to lift a ship's bow, and the force with which, when lifted and left by the wave, it falls into the hollow of the succeeding wave, depend on the form of the water-line, and on the place in which the water-line allows the weights of the ship to be carried. As regards pitching and 'scending, it may be inquired how the water-line can be formed so as to make the ship ride and drive easiest through the sea?—understanding by "easy" that she shall rise and fall gently, slowly and not far. Fortunately there is a measure which tells this exactly. The power of the slope of a rising sea to raise a ship is measured by the same elements and methods as those by which we measure the power of the water to support the ship sideways against the depressing power of her canvas on the lee side, or enable her to carry a heavy load upon one side.

The power of a head sea to lift the bow of a ship is, therefore, measured in the same way as lateral stability, only the elements are reckoned *lengthwise*, instead of being taken across the ship.* To proceed, then, to the consideration of measuring the tendency of the sea to raise a bow which has been depressed under its natural water-line, let it be imagined that the bow (fig. 17) is pressed under water by a displaced weight moved from O, the middle of the ship, and placed in the bows at W. This weight presses a wedge-like part of the bow into the water, and raises the stern out of the water. The wedge of immersion of the bow acts by its buoyancy at its centre of effort with a righting force proportioned to the bulk of the wedge, and to the distance of the centre of effort from the point O. It acts in *length* just as the wedge of lateral immersion does in width. Its *raising power* is to be found, therefore, by multiplying its *volume* into the *distance of its centre of effort* (R) from O. The power of the sea to lift the bow of a ship depends on the *bulk* of the bow immersed, the *length* of the bow, the *fullness* of the water-line and the *place* of that fullness. If a water-line be *full* forward, it will have great lifting power; if *fine* forward, small lifting power.

Having measured the power of a sea to lift a given bow, it is necessary to measure the force with which, when left unsupported, it falls upon that sea. That depends upon the weight left unsupported and on the point at which it acts. If the weights lie far forward on the bow, it will fall with great force into the water, descending with a speed proportioned to its *distance from the centre*, and plunging to a depth proportioned to the *square* of its falling velocity.

From these two considerations it is plain that a ship in 'scending will be raised out of its horizontal seat on the water-line in a very high proportion inverse to its fineness of bow, and that, in pitching, the ship will plunge less in proportion as the weights left unsupported are removed from the extremities toward the middle body of the ship. The importance in trimming a ship of so distributing her weights as to diminish their effect in causing her to pitch heavily, is therefore evident. A bow fine at the extremity, but taking fullness farther aft, makes a ship much easier than one which is leaner aft and fuller forward.†

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* There is therefore a *longitudinal* meta-centre.

† Since longitudinal stability is the antidote to pitching and 'scending, lateral stability may be said to ease, increase or diminish the motion of rolling. A "juste milieu" must be sought in either case.

The form and proportion of the stern has not here been noticed, since the stern of a ship has not to be driven against a sea, and in all ordinary practice is so sheltered from it that overhanging form and unsupported weight, which would be a source of insecurity in the bow, may be tolerated with safety and convenience. What is said of the bow may therefore apply only to the stern in a very modified form.

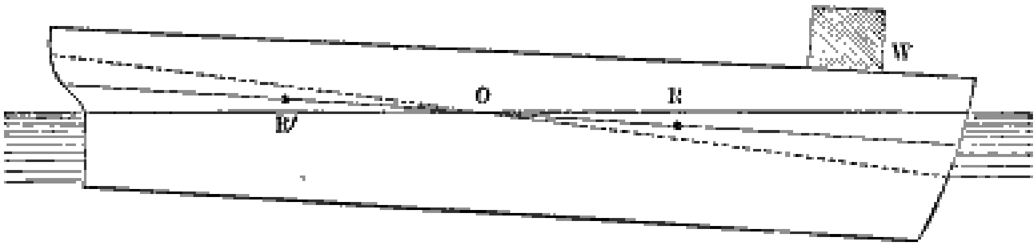

FIG. 17.

CHAPTER XVI.

ON THE QUALITY OF WEATHERLINESS, AND HOW TO GIVE IT.

THE nature, cause and cure of crankness or instability having been considered, it is now known how to make a ship stable under every ordinary condition of load, by giving her power of "shoulder" to stand up stoutly and carry a heavy press of canvas in a stiff breeze—a quality which is therefore called *stiffness*.

This quality of stiffness under sail, or uprightness, requires, as an addition to it, *weatherliness*—a virtue as opposed to *leewardliness*. A leewardly ship is liable to be driven with the wind, though her head be laid in an opposite direction. By leewardliness ships drive broadside on toward a lee-shore instead of lengthwise through the sea, and so, lacking weatherliness, are lost.

Next, therefore, after stiffness comes weatherliness to go in the direction intended—to make headway across the wind and against the wind, instead of driving broadside to leeward.

This quality is to be obtained by considering an entirely different aspect of the vessel from that hitherto examined. The ship has been viewed through her breadth merely; she must now be looked at through her *length* and *depth*.

The full-length side view of a ship, as she sits upright in the water, presents a much larger extent of surface than the cross view of her breadth.

A ship of 36 feet beam and 18 feet depth in the water, may have 648 square feet of *immersed cross section*; and, in order to force the vessel through the water, those 648 square feet of *midship section** must be pushed in the direction of the length of the vessel. This the propelling power must do; and supposing it requires a pressure of 30

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* Generally known as the 𝔛 (or *dead-flat*) section.

lbs. to push each foot through the water at the rate of 10 miles an hour, if the sails of the ship have enough pressure of wind upon them to give this force of 30 lbs. for each square foot of section, the vessel will go ten miles an hour before the wind.

This, however, is *not* the thing wanted; for the sails may be so trimmed, and the vessel's head so laid, that by means of the obliquity of the sails to the course, and of the course to the wind, the ship shall sail technically "on the wind." Now it is the business of the seaman to lay her head in the proper direction, and to see that her sails are trimmed to the proper angle; but it is the naval architect's work to see that the *form* of the vessel prevents her driving to leeward.

It must be understood, therefore, that when the ship does not run straight before the wind, but lies obliquely to it, the force of the winds acts in two directions. Partly it forces the ship its own way or to leeward, and partly it forces her in the direction in which her head is laid, or to windward; the practical question being how to make the first as *little* as possible, and the second as *much* as possible —in short, how to make the ship *weatherly*. This the naval architect has to do.

The means by which weatherliness is given consists in interposing the greatest possible obstacle between the leewardly part of the wind and its effect. The ship must be so constructed that it will be hard for her to drive to leeward and easy for her to go to windward; and the antidote to leewardliness is *large longitudinal section*. As 648 feet of cross section are to be driven in the course of the ship, there must be much more than this, and as much more as possible, in the other direction at right angles.

If the constructor can put six times 648 feet between the ship and her going to leeward, she is made six times as hard to drive to leeward as to windward. By this means it is contrived that her progress to leeward shall be very small in comparison to her progress to windward, even when the sails are so trimmed that there is as much force pushing her the one way as the other.

In considering weatherliness, therefore, he has only to see by what means as great a surface as possible can be interposed in the water, so as to prevent the ship being forced to leeward. If the ship can be made six times as long as she is broad, and preserve her depth below the water all the way to an average of 18 feet—or say 17 feet at the bow and 19 feet at the stern, which is the same thing—then she has a longitudinal section 216 feet long by 18 feet deep, presenting, in the whole, a resisting area of 3888 square feet.

Thus it is that a considerable excess of length beyond breadth is necessary to give weatherliness, and therefore it will be plain that unless adequate length be given, all the stiffness to carry sail, for which so much breadth of "shoulder" has been given, will be thrown away; because if the ship can carry sail merely, and that sail only force her to leeward, it is useless. Stiffness, therefore, or breadth of "shoulder," must have *length* to back it or it is worthless.

The area of longitudinal section to give weatherliness must bear a due proportion to stiffness and to area of cross section. *Stiffness* measures power to drive the ship under canvas; *cross section* measures the force necessary to drive it ahead; and *longitudinal section* measures resistance to being driven to leeward.

Another element which comes in to assist weatherliness is the ease with which the fine shape of a vessel will permit her to be driven endwise through the water, and it is a fact that some vessels are so well contrived for this purpose as, by sharpness alone, to reduce the power necessary to propel them to *one-twelfth* of what it would be if they opposed to the water simply a flat bow.

In the example the area to resist leeward motion has been made greater than that resisting forward motion in the proportion of 6 to 1; and if the form be so fine as to reduce the resistance to forward motion still further in the proportion of 6 to 1, the combined effect will be in the proportion of 36 to 1. This would be a successful achievement, for it would reduce the loss of motion by leewardliness to a very small quantity.

It is generally reckoned that the extent of sail which a ship can carry in a fresh breeze may be six times the area of her longitudinal section in the water. This, in the size of ship taken as an example above would give an area of sail equal to 3888 × 6 or 23,328 square feet. Now this area of sail has got to propel the vessel with an effective force of 30 lbs. to each square foot of midship section, and as there are 36 square feet of canvas for every foot of driven section, the result is 30 lbs. divided over 36 feet, or $\frac{5}{6}$ of a lb. as the required force of the wind on a square foot. Therefore it is plain that a little less than one pound pressure on each square foot of sail, effective in the direction of the vessel's course, would be necessary to propel her ten miles an hour, and this a very moderate force of wind would accomplish.

But an equal force would, with a given trim of sail, be pressing the ship to leeward. The effect of this other force would, however, be expended on six times the area, and that area has six times as much resistance to leeward as ahead. Under these circumstances the motion through the water being as the *square root* of the force, the leeward motion would be to the onward motion as the square root of 36 to 1, which is of course 6 to 1.

The result is that the ship is driven six miles forward while she is driven one mile to leeward, and such a vessel would be an ordinary *full*, but *not fast nor weatherly* ship.

There are three ways in which the naval architect can improve the weatherliness of this ship. He may diminish the area of the cross section, fine the shape of the ship so as to offer less resistance, increase the area of the longitudinal section, and give increased resistance to leeway by increase of length or of depth; or he may do any or all of these things at once.

The process stated above assumes that the naval architect is at liberty to give sufficient longitudinal area by the disposition of the body of the ship; that is, that he can have such a draft of water and such a length of body as he may select. When his ship is not of suitable dimensions, he has to resort to various expedients. If he has not depth of water enough naturally in the body of his ship, he has to add timber or *deadwood* to increase the weatherly section of the ship. When he adds this on the bottom it becomes *keel* or *false keel*, and is often carried to a great extent. If this is not enough, he adds further deadwood in the shape of stern and *cut-water;* and to assist and balance these he adds as much deadwood as he can in the *run* before the rudder. It is thus that vessels with a small body may obtain a great weatherly section; and racing vessels, yachts and clippers are frequently built in this manner to so extreme an extent as to be nearly all deadwood and keel and little or no body. A vessel of this sort becomes a mere racing phenomenon. But, nevertheless, by extending deadwood in every direction—before, abaft and below—extraordinary weatherliness may be obtained at the sacrifice of *capacity*.

When these arrangements fail, or cannot be applied, there remain other expedients for securing weatherliness. The *lee-boards* of the Dutch craft attain this. On the shallow, sandy coast of Holland no deep keel is possible, and therefore the Dutch vessel at sea would drift to leeward for want of depth of body; to provide against which she carries on her lee side a large flat board of enormous area, which is let down into the water in such a manner that the whole of the board must be driven off the flat side, leewardly through the water before the vessel can make leeway. One of these *lee-boards* is carried on each side of the vessel, so that either side when it comes to leeward has its own "*lee-board*" for alternate use. This is the Dutchman's substitute for windwardly section, of which his small draft deprives him.

Another substitute has been used, termed a "*sliding keel*" or "*centre-board*," and is formed by providing a hollow, upright aperture in the middle of the vessel, in which a large flat board is contained, so that it can be lowered through a slit in the bottom into the water.*

These, however, are expedients merely in the last resort, when the naval architect is denied the means of giving his vessel due proportions. If due length can be given, it is much wiser to obtain weatherliness by proper length and fine form than to seek artificial expedients, either in "*lee-boards*" or "*centre-boards*," or in exaggerated deadwood; but of none of these expedients should he be ignorant; and it is better to obtain weatherliness by all, or any of them, than to have a leewardly vessel.

In these days a sailing vessel of ordinary form is generally about six times as long as broad. To drive her at the rate of ten knots an hour through the water requires about 48 lbs. of force for each foot of her midship or greatest cross section. Suppose the vessel has 100 square feet of immersed midship section, requiring a force of 4800 lbs. to give her headway, and that the sails are placed at such an angle that they press equally forward and over, or so that there shall be equal forces causing headway and leeway—there will then be a force of 4800 lbs. causing leeway, and this force is spread over 600 square feet, forming the immersed longitudinal section of the ship. On each square foot of this section there will be, therefore, only one-*six-hun-*

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[*] "*Centre-boards*" are only used in yachts and other small vessels.

dredth part of 4800 lbs., or 8 lbs. per square foot of section. This 8 lbs. will cause a leeway of less than 2 *knots*. This example shows the great advantage obtained in sailing vessels by large hold of the water. It is plain that by giving this vessel greater length and depth, her resistance to leeway might be doubled, so that the force causing leeway would be divided over double the area, and be reduced to 4 lbs. per foot intead of 8, and this 4 lbs. per foot would only give a leeway of 1.25 knots per hour.

Table VII. shows what happens when the sails are set at an angle of 45° to the course of the ship, and the wind is right abeam. In these cases there is equal pressure along the ship's course and to leeward. The lesser leeway arises from two causes: the greater area of longitudinal section than of midship section and the fineness of the shapes. It will be seen that in the full form of vessel the leeway, under the pressure that produces 12 miles an hour, is 2 miles an hour. Under a pressure of 1 lb. on the sails, the headway is 10 miles an hour, and the leeway 1⅔ miles. This would be the case in a fresh breeze carrying all sail. When the vessel is proportioned for greater speed, with a greater proportion of length to the same area of resistance and a finer form, the leeway is reduced and the speed increased.

These calculations are made upon the supposition that a vessel's resistance to leeway is the same as that of a thin plate equal to her longitudinal section. But vessels with round bilges let the water pass underneath them from one side to the other more easily than a vertical plate, and so do all ships when they careen much. A little more leeway must be allowed for in these cases.

TABLE VII.

Leeway and Headway.

The sails set at an angle of 45°, the wind abeam. The force of the wind reduced to allow for obliquity.		*Full form of ship, with the cross section to the longitudinal section as 1 : 6.* *36 square feet of sail area to a square foot of cross section.*				*Finer form of ship, with cross section to longitudinal section as 1 : 8.* *36 square feet of sail area to 1 square foot of cross section.*			
Effective force of the wind per square foot of sail.		Drifting force to leeward per foot of longitudinal section.	Driving force ahead per foot of cross section.	Drift to leeward.	Speed ahead.	Drifting force to leeward per foot of longitudinal section.	Driving force ahead per foot of cross section.	Drift to leeward.	Speed ahead.
Leeward.	Ahead.								
Lbs.	Lbs.	Lbs.	Lbs.	Miles.	Miles.	Lbs.	Lbs.	Miles.	Miles.
0.2	0.2	1.2	7.2	0.8	4.5	0.9	9.6	0.6	6.0
0.4	0.4	2.4	14.4	1.1	6.3	1.8	19.2	0.9	8.5
0.6	0.6	3.6	24.6	1.3	8.3	2.7	28.8	1.1	10.4
0.8	0.8	4.8	28.8	1.5	9.0	3.6	38.4	1.3	12.0
1.0	1.0	6.0	36.0	1.7	10.0	4.5	48.0	1.5	13.6
1.2	1.2	7.2	43.2	1.9	11.0	5.4	57.6	1.6	14.6
1.4	1.4	8.4	50.4	2.0	12.0	6.3	67.2	1.7	15.8

CHAPTER XVII.

HOW TO MAKE A SHIP HANDY AND EASY TO STEER.

THE first part of *handiness* consists of *balance of sail;* the second, of *balance of ship;* the third, of *proportion of rudder.*

Unless the sail be balanced, the ship will *drive* with the wind, instead of moving toward her destination; for if there be a sail on the forward part of the vessel only, the wind will force the forward part to leeward, and she will drive head foremost; and if there be a sail on the after part of the vessel only, her stern will go to leeward, and she will drive stern foremost; wherefore, in order that neither of these things shall happen, the sail on the fore part of the vessel must be so placed and proportioned to the quantity and place of the sail on the after part that they shall *exactly* balance one another in effect, so that neither one nor the other can prevail. This is virtually to take away from the wind all power of determining the direction of the ship; and the seaman, by properly regulating this balance of sail, can keep the ship's head in any direction he pleases.

This is balance of sail, but it depends on another element—namely, the balance of ship. The effect of sail at the bow may be exactly balanced by that at the stern; yet, nevertheless, there will be no enduring balance if the bow be more easily forced to leeward than the stern, for then the head of the ship would go around to leeward. A balance of sail forward and aft, and a balance of ship lengthwise in the water—the one called "*trim of sail,*" the other "*trim of ship*" —the forethought of the naval architect must provide. To maintain this equilibrium depends upon the ability and thoughtfulness of the commander of the ship.

It is thus only that a, handy ship is obtained and kept so. The sails *must* balance, the body *must* balance, and both *must* be kept together in perfect trim, while the seamanship of the commander, the hand of the helmsman and the blade of the rudder do the rest.

Something more, however, can still be done by the naval architect to give the sailor complete command over his ship. The balance he has established is enough to deprive the wind of the control of the vessel and give it to the seaman; but the ship may still require from him the exertion of very great controlling force when he wishes, in the course of his manœuvres, to change its head rapidly from one course to another. Balance of sail and of body will help him to do this, but it will not help him to do it *quickly*.

To make a vessel very handy and turn very quickly her longitudinal section should be *deep*, rather than long; and when its extreme length is decided, its effective length should be diminished as much as possible by removing longitudinal area from the ends and placing it near the middle. Above all, much *cut-water* and *fore-foot* makes a vessel unhandy and slow to come around.

It is better, therefore, to have deadwood *aft* than forward, but removed from both ends as much as possible. Rounding off the *fore-foot* and shortening the *heel* are the most effectual ways to make a ship handy without injuring her other qualities—the effect of *heel* and *fore-foot* being to cause *gripe*, or resistance to turning, which is the contrary of handiness.

With balanced ship and balanced sail, good trim and little gripe, not much can be wanting to handiness. The *rudder* must do the rest. The rudder, however, is nothing but a power to control; it merely acts as a drag on one side; it always *diminishes* speed in turning the ship; and the cleverest helmsman is he who uses it *least*, the best ship is that which wants it *least*, and the best sailor is he who does most without it. A steersman always yawing a ship about steers badly. A ship requiring much helm is badly trimmed, and sails requiring much rudder are badly set or balanced. Nevertheless, it is above all things necessary that the rudder should have ample power—great power, seldom used. A ship that will run along for hours with scarcely a touch of the helm is a ship well trimmed and sailed; but when needed, the rudder must be able to turn a ship short and sharp around, and this may save her in an emergency.

The way to give power to the rudder is to proportion it to the *length* of the ship, for a long ship requires a broad rudder. It is thought that for every 100 feet in the length of a ship she should have 2 feet of breadth with one foot added. Thus a ship 100 feet long needs 3 feet breadth of rudder; 200 feet long, 5 feet breadth; 400 feet long, 9 feet, and so on.*

As to the shape of the rudder, there is not much in it. Some say the top of the rudder is the most valuable part, for the water there has the most effect, and that the rudder should be widest there; others say it should be widest at the bottom, for that there width is most effective. Both are crotchets; but still there may be something peculiar in the case of some ships to render both exceptionally true.

The fault of having the widest part of the rudder near the load water-line is, that there a rough sea may strike the rudder most heavily. There is less harm in making the rudder widest near the keel, for, being well buried under water, the wave surface of the sea has less action upon it, and in bad weather the helmsman is not liable, as in the first case, to have the helm taken out of his hand. But on the other hand the heel of a wooden screw-ship may be, and probably is, her weakest part, and to put more strain than necessary on a weak place is unwise, to say the least. The best way is to have the widest part of the rudder near its centre, rounding it off toward the top and heel, the one to keep it from the force of the waves, the other to protect it from the ground in a narrow and shallow channel.

It will always be a question about the quantity of rudder to be given to a vessel destined for any special purpose. If the ship is always to be committed to wise hands, who will never use more than is necessary, it is safe to give plenty of rudder, leaving it to their discretion to use it as they may desire, because, with powerful rudders, manœuvres can be performed which are impossible with small ones. To be able to turn very fast will often give a ship the advantage of another; and in a contest for victory, or of sport for a challenge cup, ability to execute difficult manœuvres rapidly is often in itself a source of success. A ship well in hand is often better than one which is faster but runs wild. Therefore, put into wise hands a powerful rudder.

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* Of all descriptions of rudder for *long* vessels, the "equipoise" or balance rudder is the most in use, as its advantages are great breadth without any more increase of strain on either *pintles*, *gudgeons* or *wheel ropes* than is produced by an ordinary rudder of one-third the size.

CHAPTER XVIII.

OF BALANCE OF BODY AND BALANCE OF SAIL.

HANDINESS, therefore, or the ready obedience of a ship to the will of her commander, arises out of the due combination of balance of sail, balance of body and power of rudder, for without these a vessel steers wildly, and can hardly be controlled in her movements.

When, either through want of balance of sail or balance of body in the water, the ship shows a tendency to *fall off* or *fly-to*, she is said to have two opposite defects—the first called *leewardliness*, the other called *ardency*. These defects must be corrected either by *trim of sail* or *trim of ship*. If not corrected, they must be counteracted by the action of the rudder; but as the rudder is a sort of *stop-water* applied on one side, and in no case a help, speed is lost in the degree in which the rudder is used. The tendency to fly into the wind, and the tendency to fall off from the wind, or ardency and its opposite, require remedies of opposite kind. Ardency implies that the ship must always carry *weather helm;* want of ardency, that she must always carry *lee* or *slack helm*. Of the two evils, ardency is considered the less, and it is usual, therefore, to trim a ship so that she shall always carry *a very little* weather helm.

The point in the length of a ship on both sides of which the sails balance is called "*the centre of effort of the sails;*" the point in the water on both sides of which, fore and aft, the body balances, "*the centre of lateral resistance of the ship.*"

In a state of perfect trim of sail and trim of ship—that is, when a ship is so perfectly balanced as to be neither ardent nor leewardly, requiring neither lee nor weather helm—the centre of effort and the centre of resistance meet exactly in the same point of the length of the ship,* and so the effort of sail and resistance of water, fore and aft, exactly counterpoise one another.

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* That is, they are exactly *over* each other.

Unfortunately, there are but few ships so constructed as that this coincidence shall take place and be maintained at all speeds, and in all states of wind and sea and weather.

In a perfectly-formed "wave-line" vessel the coincidence of the two has been found to be exact and perfect; but by a very slight deviation from this form the perfection of this balance is at once deranged. In order to correct this want of adjustment, the centre of effort of the sails has to be moved forward, and in certain cases very considerably so.*

In every vessel built on the old system, this derangement of balance had to be taken into account and allowed for as an element in the original construction of the ship. Unluckily, it was sometimes allowed for by guess merely, and therefore nothing was so common as to hear that a new vessel had to undergo an entire change of arrangements† from the impossibility of managing her, owing to the centres of effort and lateral resistance not coinciding. In such a case the usual remedy (if the error was slight) was to *rake the masts* either a little forward or a little aft, in order to correct the balance of sail, or else to put on a little deadwood forward or abaft, or to add a tapering false keel—all for the purpose of restoring the lost balance; and when these expedients failed, the masts, or some of them, had to be shifted—an arrangement not only expensive, but deranging to a great extent the interior economy of a ship of war.

One of the great advantages of the "wave" system is, that the centres of effort of sail and of resistance of body coincide. It is impossible to adjust these two centres to a more perfect balance for practical use, so as to have a ship easy to steer, requiring little helm, quite under command and handy, than by merely taking care that they coincide in the same point of length.

But this perfection of balance and handiness is not to be obtained without an equal perfection of wave form, since every deviation from *exact* truth in the form of a ship will exhibit derangement of balance. In exact proportion as any part of the bow is filled up beyond the pure "wave" line, the balance of sail and of resistance will be dis-

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* The English line-of-battle-ship, "Duke of Wellington," for example, in which the whole of the masts and sails had to be placed forward from the true centre of resistance the space of 14 feet.

† That is, as regards her masting and sail draft.

turbed, and it will be necessary either to correct the shape of the body, or to remove the centre of effort of sail forward, or to shift the centre of lateral resistance aft. The reason of this is that the "wave" form is the form of least resistance, the truth of which is practically shown when the vessel (in deep water) shows no bow wave or breaks no water at the bow. Any untruth in the "wave" form at once shows itself in broken water or the well-known wave at the bow, which is bad. The appearance of this obstacle to progress shows exactly where there is an expenditure of undue force, and it is this undue force and unnecessary resistance which deranges the centre of lateral resistance of the ship, and shifts it forward. Its tendency to do so increases with the velocity of the ship. It is to meet this shift of pressure and to counteract it that the centre of effort of the sails must follow it forward. But no one can tell precisely beforehand how much any deviation from truth in the form of a ship will remove the centre of resistance, and therefore it is impossible to say what change in the centre of effort may be required to correct it. Unluckily, also, the deviation arising from incorrect form varies with the speed, so that the difference which will restore the balance is not the same for all speeds.*

There is another curious cause of deviation between the centres of effort and resistance. If a ship has a long, straight middle body, she will have a tendency to ardency, arising from length alone.† Even if the two ends be perfect wave ends, a long, straight middle body will have this tendency to disturb their balance. Of this singular phenomenon of deviation arising from length of middle body, an exact measure can scarcely be given; but the explanation is believed to be that a long ship, by the mere progress of its sides through the water, drags with it and puts into motion, by adhesion merely, so great a quantity of the water in its neighborhood that at the last, when near the stern, the water has ceased to offer any lateral resistance, because it has already received the same motion as the ship itself. At the stern, therefore, there is little left to resist the ship; and so, from lack of stern resistance, the after part loses power to

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* No certainty, therefore, is to be obtained on this point, except by the preservation of the absolute truth of the "wave" form.

† It is probably on this account that many of the long vessels of the navy are found unable to carry any after sail without a great excess of weather helm.

Fig. 26

BODY PLAN

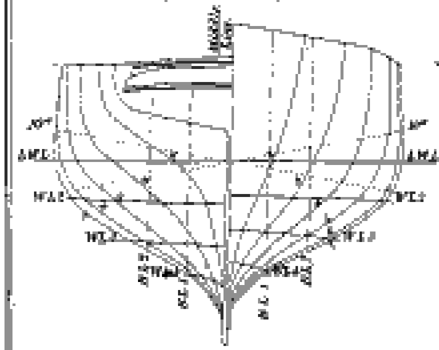
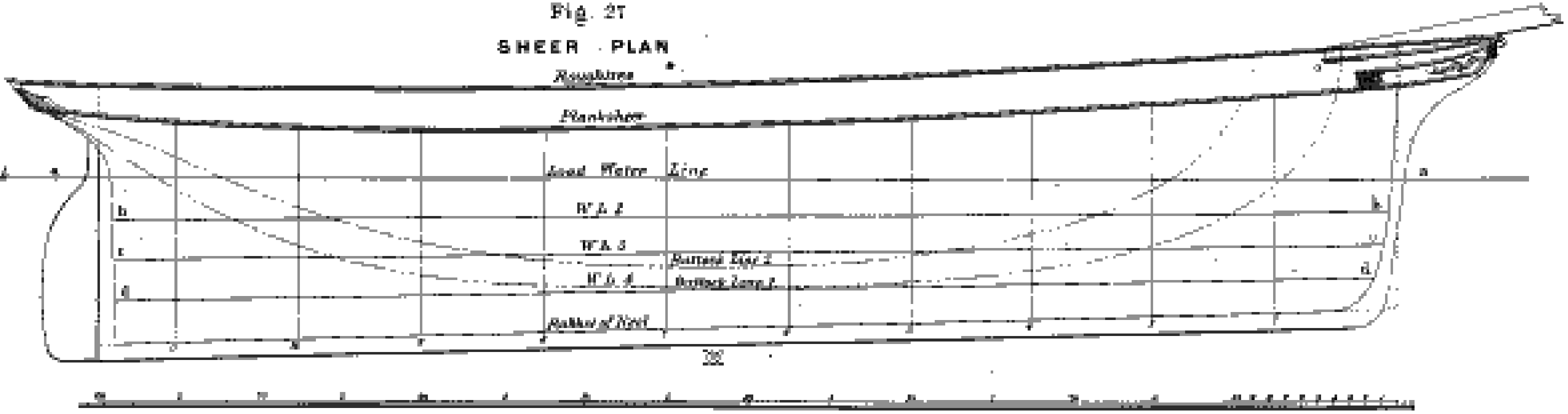


Fig. 27

SHEER PLAN



SCHOONER YACHT

165 TONS.

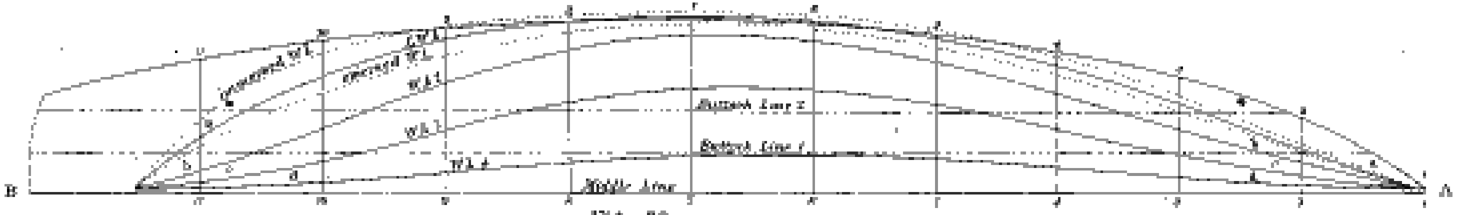


Fig. 28

HALF BREADTH PLAN

[illegible] Lith Philadelphia

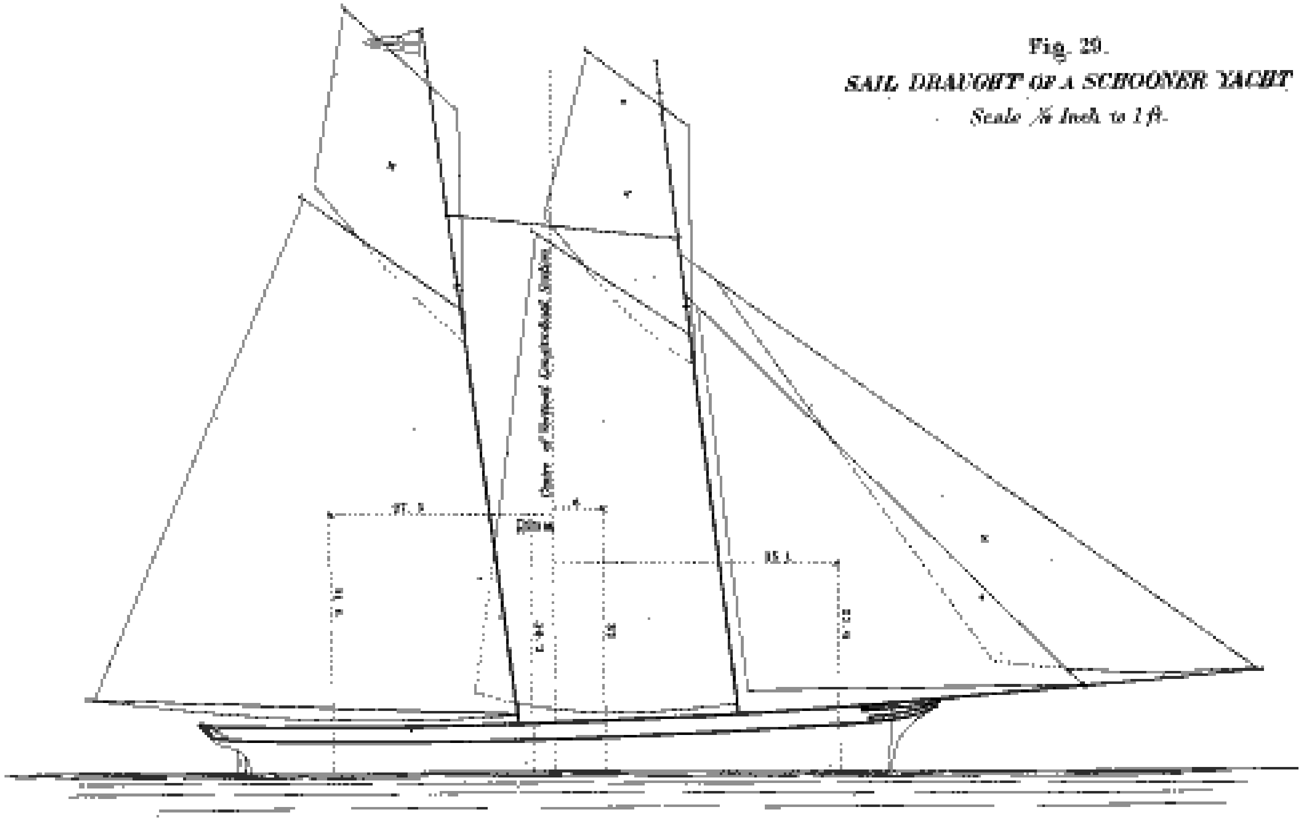


Fig. 29.

SAIL DRAUGHT OF A SCHOONER YACHT

Scale ⅛ Inch to 1 ft.

Fig. 38

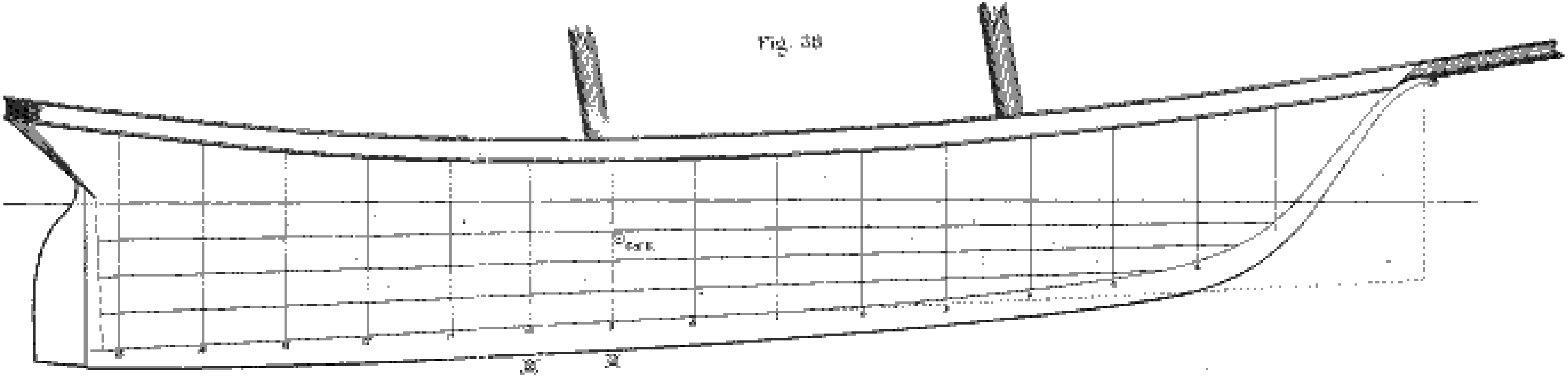
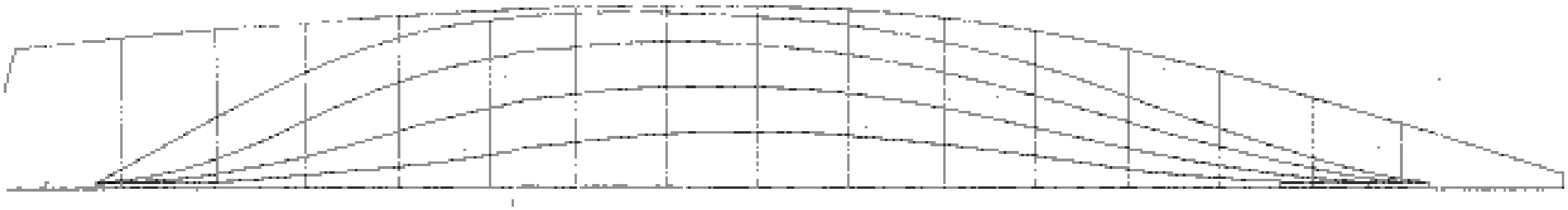


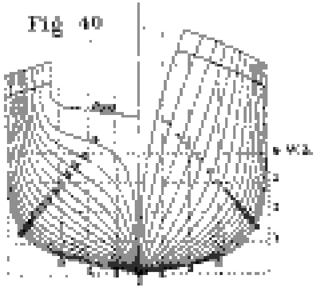
Fig. 39



DRAUGHT OF AN IRON SCREW STEAM SHIP.

BODY PLAN

Fig. 40



Dimensions

	feet
Length between perpendiculars . . .	290
Breadth extreme . . .	41
Depth amidships (from top of keel) . . .	29
Burthen in tons 1873 14/94 B.M.	
Horse power (nominal) 450	

Scale of Displacement

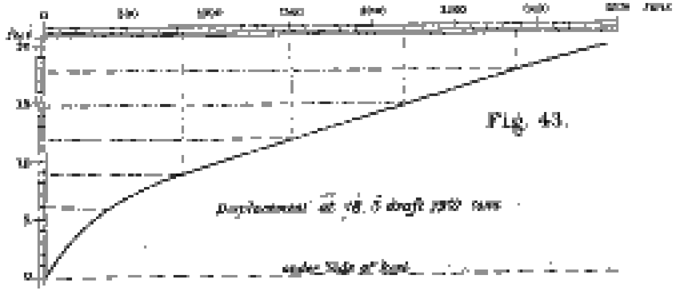


Fig. 43.

Fig. 41.
SHEER PLAN

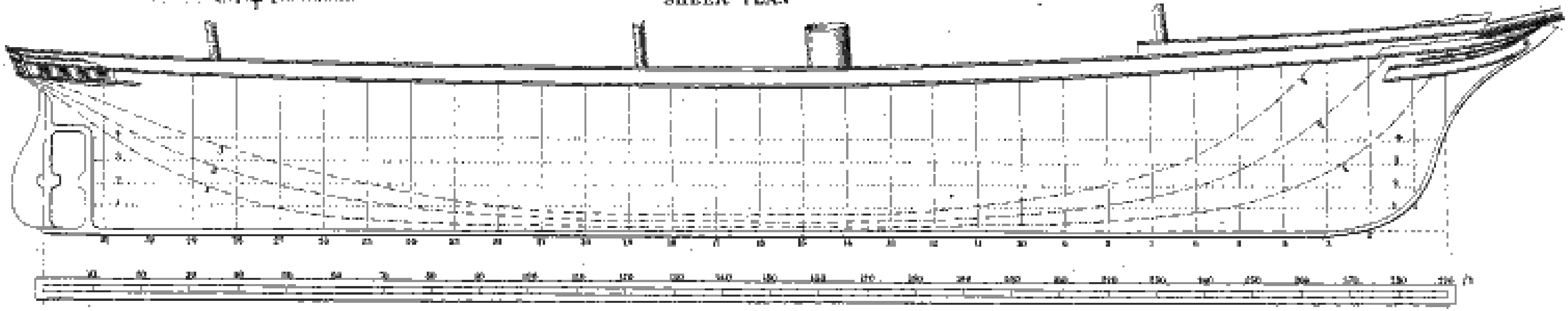


Fig. 42.
HALF BREADTH PLAN

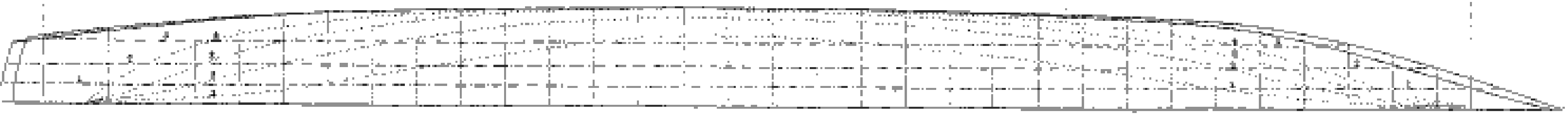
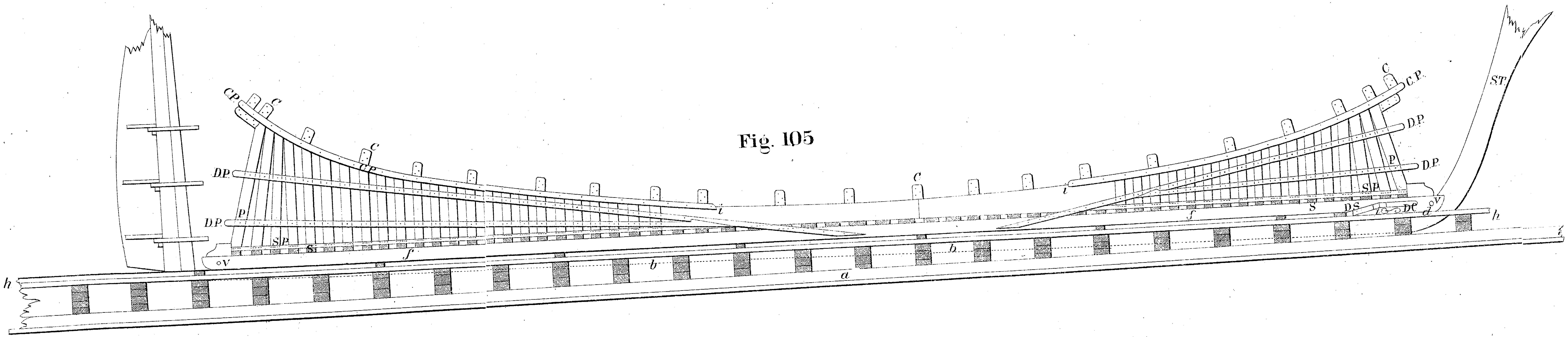


Fig. 105



Scale 1/8 of an Inch to a Foot.

T. Sinclair's lith. Philadelphia.

CHAPTER XIX.

EXAMPLE OF GENERAL DIRECTIONS FOR BUILDING A SIDE-WHEEL MAN-OF-WAR STEAMER OF THE FIRST CLASS, LIKE THE "POWHATAN" OR "SUSQUEHANNA."

KEEL.—To be of *white oak,* sided 1 foot 6 inches, and laid straight, without any curve; to be made of two depths—viz., the *upper* or *internal* keel, and the lower keel, but may be in one depth if the timber will work.

The upper keel in depth, 1 foot 2 inches.

The lower keel in depth, 1 foot.

The *rabbet* to be cut on the upper keel; the lower edge of the rabbet being 4 inches above the lower edge of the upper keel. The number of pieces in the upper keel not to exceed six (6), and in the lower keel not to exceed seven (7).

Scarphs to be in length 10 feet, to be plain without *jogs,* and four (4) *coaks* in two rows let in. Coaks, in width, 3½ inches; in thickness, 2½ inches; in length, 16 inches. The ~~*tips*~~ nibs of scarphs to be fastened with 2 copper bolts ¾ inch in diameter, to be *riveted* (*i. e.,* clinched) on; in length, three times the thickness of the *nib.*

The scarphs to be further fastened with 4 copper bolts in each, in diameter 1 inch; to be driven in the spaces between the floor timbers and riveted. Between the upper and lower keel the *joint* to be *fair,* and two rows of coaks to be let in; coaks 18 inches long, 4 inches wide, 3 inches thick and 30 inches asunder.

The upper and lower keels to be fastened together with copper bolts, about 5 feet asunder, ⅞ inch in diameter. The upper keel to be bolted athwartships, near the lower edge, about 5 feet asunder, and the lower keel in the same manner, about 7½ feet asunder, with copper bolts in diameter ⅞ inch.

False keel, in thickness 2 inches; fastened to the main keel with copper bolts 12 inches in length, ⅝ inch in diameter. Whole depth of keel and false keel, clear of rabbet, 1 foot 6 inches.

Deadwood, forward and aft, of *live oak,* sided 1 foot 6 inches. The *stern-post knee* of *live oak,* to be *fayed* on the keel and to the fore side of the *stern-post.* Over this knee the deadwood is to be built, keeping the shortest pieces below and coaking them to each other and to the keel.

Stern-post knee-bolts of copper, in diameter 1⅜ inches, in number 4; of which 2 will be driven through the lower end of the stern-post, and 2 through the after end of the keel. Care must be taken that these bolts do not interfere with those of the deadwood.

Deadwood.—The 7 main bolts of the after deadwood—that is, the 4 last in the keel, and the 3 first in the lower end of the stern-post—to be in diameter 1¾ inches. The remaining bolts in the post and the four next in the keel to be in diameter 1½ inches.

From which to the after square frame they will be driven 2 feet asunder, in diameter 1¼ inches.

When the deadwood is not more than 7 inches deep, the bolt will be in diameter ¾ inch, gradually increasing in size as the depth becomes greater; but they will not in any case, between the aftermost and foremost square frame, be of greater diameter than 1 inch.

These bolts for drawing the deadwood to the keel will be in length about 2⅓ times the depth of the piece through which they are first driven, but when this is within 4 inches of the lower side of the lower keel, let the bolts go through and be clinched as all others.

The *forward deadwood bolts,* before the forward *square frame,* to be about 20 inches asunder, and in diameter 1¼ inches.

The *deadwood knee* to be *fayed* on and coaked to the deadwood; bolts of copper, about 20 inches asunder, and in diameter 1⅜ inches.

The bolts in the *arm* to go through and clinch; those in the *body* to be in length 2½ times the depth of the piece through which they are driven.

Stern-post, of *live oak,* sided at the rabbet 1 foot 6 inches; moulded at the height of *cross seam,* clear of rabbet, 1 foot 3 inches; moulded at the *heel,* clear of the rabbet, 2 feet 4 inches, to keep its full siding on the aft side down to the cross seam, from which it will taper at the heel, on aft side, to 10½ inches.

The rabbet to be cut near the middle of the *main piece* of stern-post, or in that part most free from defects.

The aft side of the rabbet, at the height of the cross-seam, to be kept 11 inches abaft the front of the post, and at the keel from 12 to 16 inches, as the piece will work best.

The deficiency in the main-post to be made up by a *false* or *after-post,* coaked to the *main-post,* each piece having one or two tenons in the keel, according to the size.

Main transom, sided and moulded, 1 foot 8 inches; cross-seam to be 9 inches below top of transom, fastened to the stern-post with three bolts, in diameter 1¼ inches; the remaining *transoms* to side, 1 foot, fastened with two bolts in each, in diameter 1¼ inches.

Stem, of *live oak,* sided 18 inches; scarphs *hooked* (tabled) about 2 inches, and fastened with bolts, in diameter 1¼ inches; the *nibs* secured with bolts, in diameter ¾ of an inch; the rabbet of the stem, if the size and quality of the timber will admit, is not to be cut close to the aft side, but to be so situated that the aft side of the stem may be at or near the *bearding-line.*

Apron, of *live oak,* sided 1 foot 6 inches; moulded at head, at the after corner on a square from the plank, 9 inches; fastened to the stem with bolts of copper and iron about 2 feet asunder, in diameter 1¼ inches.

Timber and Room.—Floor timbers to side from 12 to 14 inches; *first futtocks* to side from 10 to 12 inches; *second futtocks, third futtocks, fourth futtocks, top timbers* and *stanchions,* for a length amidships of 100 feet, to side 11 inches; for the next 40 feet forward and aft to side 10 inches; for the next 35 feet forward and aft these timbers to side 9 inches.

Moulding of the floor timbers in the throat, 18 inches; moulding size at the floor head 12 inches; moulding of frame at the *portsill* or *planks,* 2 feet above the *upper deck,* 7½ inches. The intermediate sizes to be ascertained by a curved diminishing line, and these are the moulding sizes; the timbers are to *hold* on the *square* when ready for planking inside and outside.

The heels of *cant timbers* to have 2 inches left on the inside, to let that much into the deadwood, with a *jog* of 12 inches from their heels, and to be secured by two copper bolts in each pair, in diameter 1⅛ inches.

Frame-bolts in each scarph, asunder 30 inches; those below the third futtock-head to be 1⅛ inches; those in the floor timbers to be copper; those above the third futtock-head to be 1 inch in diameter.

Keelson to be of *live-oak plank,* in thickness 7 inches; to be *five* planks in height, the planks composing the keelson to be *butted* together and not scarphed; the lower plank to be coaked to the first futtocks; the whole to be coaked together with two rows of seasoned *live-oak* coaks, 10 inches long, 3 inches square and 15 inches asunder.

Bolts for drawing plank to each other to be copper, ¾ inch; two copper 1¼-inch bolts to be driven through the keelson and each floor timber.

Bolts through the *stemson* and keelson to be of the same size, and clinched outside before the false keel and *gripe* are put on. After the bolts are driven and the corners of the keelson *chamfered,* there will be a *capping* of 3-inch live-oak plank to fill the width between the chamfers nailed to the top of the keelsons, into which the heels of the berth-deck stanchions may mortise.

Knight-heads and *hawse-pieces,* of *live oak,* sided 14 inches; bolted into the apron and into each other with 1⅛ *iron* bolts; asunder about 2 feet 6 inches.

The spaces between the frames to a *level line,* fore and aft, as high as halfway between the first and second futtock-heads, amidships, to be *filled in* solid and *caulked;* the upper ends to be cut off level.

Before the *clamps* and *inside plank* are put on, the frames to be secured by *diagonal braces* of iron, in breadth 4 inches, and in thickness ¾ inch, over which the plank will be fitted; and in each timber to be a bolt through the plate 1⅛ inches diameter, to be clinched before the *outside plank* is put on; the upper ends of these plates to be 5 feet asunder, under the upper strake of *gun-deck clamps,* the lower end being under the strakes at the first futtock-heads; the upper bolts to be 1¼ inches, and go through the clamp and outside plank; the alternate bolts above the copper fastenings to go through the outside plank; the holes to be drilled and *counter-sunk* amidships; the heads of two braces to come on the same frame, the *heels* reaching forward in the *fore body* and aft in the *after body* at an angle of 45°.

Hawse-holes in clear of leads and pipes 16 inches.

Running plank of bottom, of *white oak,* in thickness 5 inches.

Wales, of *white oak*, in thickness 6 inches; in width about 8 inches, to gradually and fairly *diminish* in thickness till they fall in with the *bottom plank* and strake under the *plank-sheer*, which is in thickness to be 5 inches; the five strakes of wale plank below the plank-sheer, three opposite the gun-deck clamps, three at the third futtock-heads and two at the second futtock-heads, to be 1¼ inches thicker, and *jogged* that much over the frames; the plank to be put on with *fair edges*, without *hooks* or *jogs*.

Garboard strakes, in thickness next the keel 10 inches; in width, 12 to 15 inches. To allow for thickness, the timbers will be taken off on a level with the top of the deadwood or upper keel, which will be made up in the thickness of the plank next the *garboard*, falling gradually and fairly in with the bottom plank. These strakes to be fastened edgewise through the keel and each other with 1-inch copper bolts 5 feet apart, and into the timber as the other plank with 1-inch bolts. All the fastenings going through to be of *copper*, to a line 19 feet above the lower edge of the rabbet of the keel; from that line upward, *iron* to be used. The plank to be square, fastened from the keel to the plank-sheer; that is, there will be two *through-bolts* in each strake in each frame (except where a *knee-bolt* will answer the purpose) and two short fastenings. The short fastenings to be in diameter ¾ inch; the through fastenings, which are to be clenched below, ⅞ inch.

In each *butt* there will be one through-bolt and one fastening, except the *hood-ends*, where both will go through if practicable. The length of the short fastenings to be twice and one-third the thickness of the plank through which they are driven, taking care that the bolts shall not go through the timber.

Engine or *bilge keelsons*, to be of *white oak*, sided 17½ inches; made or fastened as the main or centre keelsons.

Inside strakes at first and second futtock-heads in number at each butt, three of *white oak*, in thickness 6 inches, fastened with ¾-inch bolts.

Berth-deck clamps, to be of *white oak;* six strakes on each side; thickness, 6 inches. The three upper strakes to jog over the timbers, 1¼ inches, the plank being that much thicker (namely 7¼ inches), fastened with ⅞-inch bolts. *Seams* to be fair without hooks or jogs, and to be bolted edgewise about 5 feet asunder, with *iron* $\frac{15}{16}$-inch bolts.

Berth-deck beams, of *yellow pine,* sided 12 inches, moulded 14 inches; to have a *spring*[*] of 6 inches in 45 feet, the ends *not* to be *snaped.*

Berth-deck knees: to the ends of each beam there will be one *lodge* and one *lap* and *hanging knee,* each sided 8 inches, fastened with 1⅛-inch bolts.

Carlings, or fore-and-aft pieces, of *yellow pine,* square, 7 inches, in three ranges; that is, one in the middle of the deck, and the others midway between the middle range and the side of the ship.

Ledges, of *yellow pine,* sided, 5 inches; moulded, 6 inches.

Berth-deck plank, of *yellow pine,* in thickness 3½ inches, in width, about 8½ inches, fastened to the beams with *iron spikes* (plugged); in length 7 inches. *Spikes* to be 6 inches long in the ledges. The beams and ledges of this and other decks to have two (2) spikes in each strake.

Water-ways, of *yellow pine;* deck edge, in thickness, 6½ inches, of which 1 inch will jog over the beams; next the water-ways will be two strakes of *yellow pine,* in thickness, 6½ inches, which will likewise jog over the beams and ledges 1 inch. The inner edge of these strakes to be chamfered to the thickness of the deck plank; these strakes to be bolted through the water-way and side of the ship, with *one* bolt in each frame, in diameter 1 inch. The edge of the water-way will be *chined* in 2 inches, the wood taken off thence in a straight line across to the thickness of the spirketing, which is 6 inches. The *thick strakes* and deck edge of water-way to be fastened with ⅝-inch bolts, 11 inches long.

Spirketing, to be of *white oak,* 6 inches; the spirketing and side edge of water-way to be fastened with ⅞-inch bolts.

Coamings and *head-ledges* to be of *yellow pine;* in width, for the coaming, 14½ inches, in thickness, 6½ inches; *chined* on 1½ inches to show 5 inches; height above the deck, 4 inches; to be fastened with ⅞-inch bolts.

Coamings for scuttles, same height above deck, but sided 1 inch less; bolts ¾ inch.

Abreast the *crank hatchway* the *half beams* will side 10 inches.

Beams moulded at the side of ship the same as whole beams, and continue that size 1 foot; from thence they will taper to the coamings of the hatchway to 7 inches; kneed to coamings with *lodge*

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[*] Or round-up.

knees, sided 5 inches, and to the side with lodge and lap knees, sided 7 inches.

The lower edges of beams, ledges and carlings to be rounded.

Stanchions under the berth-deck beams, to be of *white oak,* square, 9 inches; chamfered 1 inch on each corner to within 9 inches of the head and heel, and let into *caps* under the beam.

Breast-hooks, to be of *live-oak,* and all fayed to the timber, sided 12 inches. The *throat-bolt* and the next on each side, in diameter 1⅝ inches; the remaining bolts, 1¼ inches.

The *hooks* (*i. e.,* crutches) aft to be of the same size and secured in the same manner.

Gun and deck clamps, to be of *white oak,* in thickness 6 inches. The two upper and two lower strakes to be 1¼ inches thicker, and jog that much over the timbers. The whole to have fair edges and be bolted edgewise with 1-inch bolts about 5 feet asunder and clear of the *air-ports;* fastenings to be, in diameter, ⅞ inch.

The *air-ports* to be between the *second* and *third* strake, there being no *air-list;* the clamps will reach the spirketing.

Gun-deck beams, of *yellow pine,* sided 13½ inches; moulded 15 inches; to *spring* 6 inches in 45 feet.

Gun-deck knees: to the ends of each beam there will be one lodge knee, one *dagger knee* and one hanging knee.

Lodge and dagger knees, to be sided 8 inches; hanging knees, 9 inches.

Bodies of hanging knees to reach the lower-deck water-way; *arms* to be 5 feet in length. *Knee-bolts* to be 1¼ inches.

Deck, or stern-hook knees, to be sided 9 inches; bolts 1¼ inches. *Knees* to be *white oak* or *live-oak.*

Stanchions on the *berth deck* to be *white oak,* in diameter 8 inches.

Ledges, of *yellow pine;* one (1) between every two beams, except in the range of the hatches, where they will be 2 feet, average distance, asunder; sided 5½ inches, moulded 7 inches.

Coamings and head-ledges of hatches, in height above the deck 10 inches; to be 1 inch thicker than those on the deck below, and fastened with 1-inch bolts.

Gun-deck plank, of yellow pine, in thickness, when planed, 4½ inches; width not to exceed 8 inches, to be fastened with *iron* spikes and *plugged;* spikes in the beams to be 9 inches long, and in the ledges 8 inches long. To have two strakes next the water-way 9 inches in width, each; jogged over the beams and ledges 1½ inches, in thickness 6 inches.

Water-ways, of *yellow pine;* side edge 5 inches thick; deck edge 6 inches thick; of which 1½ inches jog on the beam; the deck edge to be chined in 2 inches; the wood taken off thence in a straight line to the thickness of the spirketing, 5 inches.

The thick strakes to be bolted edgewise through the water-ways and side of the ship, with one 1$\frac{1}{16}$ bolt in each frame, if practicable.

Side edge of the water-way to be fastened with ¾-inch bolts.

Spirketing to be of white oak, 5 inches thick. The midships part, when practicable, to be 1¼ inches thicker, and jog that much over the timber, where the thickness will be 6¼ inches, and to be fastened with ¼-inch bolts, as in the outside plank.

Plank-sheer, of *white oak*, 6 inches thick; every other timber to come through; scarphed edgewise and bolted into the water-ways, through the spirketing and into the outside plank with ¾-inch bolts. Height of the top of the plank-sheer above the deck to be 2 feet.

Partners of fore and main masts to be of *live-oak*, 15 inches in breadth, 9 inches thick, and framed to admit wedges of 3 inches. To be kneed, as well as those on the berth deck, with lodge and lap knees, sided 6 inches, fastened with ⅞-inch bolts. Those of the *mizzen-mast* to be of live-oak, 12 inches in breadth, 8 inches thick; knees to be sided 5 inches, bolts to be ¾ inch.

*Guard beams** to be of *yellow pine*, sided 20 inches; moulded 26 inches. To be made in two thicknesses, the pieces coaked together and secured with *screw-bolts*. To be kneed with hanging knees at each end; that is, two inside, sided 8 inches. The lodge knees, as the other beams, all to be fastened with screw-bolts, sided 8 inches.

Cable (i. e., *riding*) *bitt*, to be of *live-oak;* square at the head 18 inches, bolts 1¼ inches.

Bowsprit bitts to be of *live-oak*, 14 inches square at the head, 1⅛-inch bolts.

Catheads of *white* or *live-oak*, sided, 15 inches; moulded 17 inches, bolts 1⅛ inches.

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* Or paddle-box beams.