To the Honorable Chas. Sumner

With the author's compts

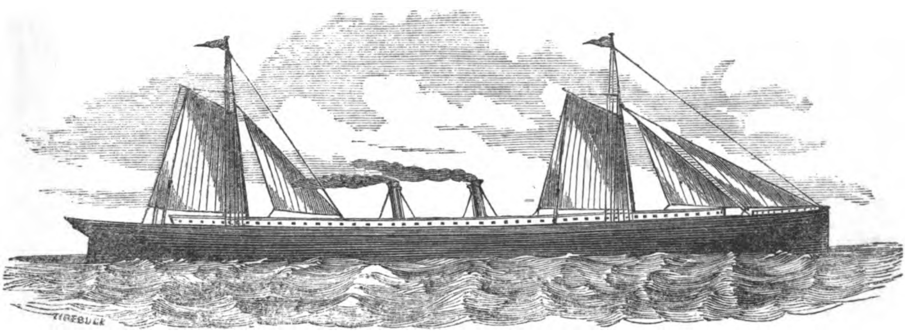
THE

SCIENCE OF SHIP-BUILDING,

CONSIDERED

IN ITS RELATIONS TO THE LAWS OF NATURE.

With Numerous Illustrations.



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INDEX

REFERRING TO PARAGRAPHS.

PREFACE.

In the following paper I have attempted to sum up the results of more than a quarter of a century of observation and thought, assisted by some limited experiments. Since 1834, when I performed for a short time the duties of Purser of a Steamer on Lake Ontario, on the banks of which I was born and brought up, I have had great opportunities of witnessing the performances of steamers and other vessels. From that time to this, I have been an almost constant voyager on the great lakes and rivers of America, or the ocean. My travels by water, made in all sorts of vessels—from a fishing boat to the Leviathan—would more than quadruple the circumference of the earth. But in endeavouring to investigate the intricate question of resistance to ships, and the best form to overcome that resistance, I have to confess myself deficient in one very desirable, if not essential, qualification, namely, a high mathematical education,—having entirely neglected those studies after leaving school. My paper, therefore, though on a scientific subject, is not a "scientific paper."

Nevertheless, my experience has enabled me, as I believe, to see where so many learned and scientific men have failed in their efforts to master some of the many important questions connected with naval architecture. Under these circumstances, I trust that what I have to communicate will be received indulgently, and serve to point the way towards greater perfection in that profession which is doing so much to civilize and benefit mankind.

My taste for ships and ship building has always led me, when opportunities afforded, to the docks and ship-yards of maritime cities, without any fixed purpose, except to gratify curiosity and give scope to my notions as to how ships ought to be built. Whenever I came to this country, during the construction of the Great Eastern, I paid occasional visits to witness her progress. But until the present occasion, I have never had the leisure and opportunity combined, to inquire into the actual progress making in the forms and construction of ships.

One of the first works on naval architecture to which I turned my attention, was the treatise of Mr. Creuze, published in the seventh edition of the Encyclopædia Britannica. But I discovered no trace in that, or any later writer, of the principles which I have endeavoured to elucidate. I found that he treated the subject as nearly exhausted, and as if little was left for future Columbuses to discover. He divides the elements of naval architecture, ex-cathedia, into two classes, namely, "those which are solely dependent on *known laws of nature*, and those of which the solution involves laws of nature which are yet imperfectly developed. The first division," according to Mr. Creuze, "embraces *by far the greater part* of those principles on which the most essential properties of ships depend; and it may be said" he continues, "the principal difficulties of these are surmounted and are familiar to the instructed naval architect."

This is not the way in which an earnest seeker after truths, deducible from experimental science, should have spoken. It has been owing to the prevalence in high quarters, in this and other countries, of such dogmatical assumptions of facts, that far greater progress has not been made in the numerous scientific details relating to naval architecture, and more especially in reference to the application of steam power. When great authorities, and (I hope I may say it without disrespect to those able and enlightened men now in control of Her Majesty's navy) more especially official authorities, take it for granted that perfection has been attained, and that no further inquiry is desirable; there is an end of improvement.

The danger now is, that the Admiralty is going to an opposite extreme. They are actually laying out millions of money on untried theories and principles, in utter ignorance of certain great laws of nature, the existence of which can no longer be doubted; when a few thousand pounds would serve, either to confirm, upset, or materially modify the systems in question. A man takes out a patent, or gets up a model and drawings for an armour-plated ship, to cost anywhere from £150,000 to £500,000. The model and drawings are got up *secundum artes*, and he goes to the Admiralty; if he knows anything of the freezing effects of official etiquette and delay, he will obtain some political backing, in order to gain early attention. If he manages his negociations cleverly, in due time, one, two, or more ships are ordered to be built on the new plan, and the lucky adventurer is appointed to superintend the building. Such, at least, are charges constantly made through the columns of leading journals.

Now, any person who will take the trouble to examine the drawings in the Patent Office, will find that by far the greater proportion of them are purely fanciful, and have no reference whatever to the laws of nature—against which they are a standing violation. One specification I examined—the patentee, by the bye, is an American,—is to secure to the fortunate inventor for fourteen years the exclusive right to build ships of a circular form in the cross-sections—that is, the shape of a cigar, with just enough cut off the upper part to form a deck. Another—and this time an Englishman—has taken a patent (and is actually building some ships accordingly) for a semi-circular formed ship,—semi-circular both ways, lengthwise and breadthwise. But these are no more fanciful than many of the absurdities with which the Admiralty is constantly pestered, to say nothing of the numerous designs got up for the mercantile community. It is not going too far, I think, to say, that nearly all those who have deviated widely from the established ideas of ships' forms, have done so in total ignorance of the laws of nature, or, at least, are unable to assign such laws in support of their theories.

I shall not attempt to refer to the various writers I have consulted on this subject, but I must express the great satisfaction with which I have read many of those valuable papers published in the transactions of the Institution of Naval Architects—to some of which I have referred in the body of my paper. I am told that the current volume* will contain a large and valuable addition to the stock of accumulated knowledge on this subject. But I cannot forbear expressing an opinion here, that the government ought to originate some new and less expensive method of acquiring that knowledge of the laws of nature, about which so much has been said, than that of trying every man's fancy drawing—or, at any rate, let there be some system about it.

I avail myself of this opportunity to quote a passage from one of the ablest, least prejudiced, and clearest writers on this subject, the Reverend Joseph Woolley, M.A. At the commencement of his very able paper, published in the first volume of the Transactions of the Institution of Naval Architects, Mr. Woolley says, "It must unfortunately be conceded that the mathematical theory of that science is in a very imperfect state, and that some of the most important and interesting problems have hitherto eluded the grasp of the geometer and physicist. One of the chief benefits to be looked for from the Institution of Naval Architects, which we are inaugurating to-day, is a more systematic inquiry into the laws of nature, on which the motions of a vessel at sea depend, than has hitherto been attempted—an inquiry that shall furnish to the mathematician satisfactory data on which he may found his calculations. The great and hitherto insurmountable difficulty has been the discovery of these laws."

It now seems to me that the greatest difficulty in the way of attaining a rapid approximation towards a really scientific system of shipbuilding, and especially in the war navies of the world, is to get rid of old and wrong conceptions. The pre-conceived ideas as to the forms, rigging, manning, propelling, and steering ships, as well as how to fight them, stand like grim giants in the paths of those entertaining more advanced views on the subject.

The proposition to do away with the sails, masts, and rigging, and thereby to dispense with sailors,—in fact, to regard a ship of

*Since writing this preface, I have received through the kind attention of Mr. E. J. Reed, chief constructor of the navy—then Secretary of the Institution of Naval Architects, the volume referred to.

war as a vast floating military engine, capable of being rapidly moved to any point required, at a velocity hitherto unknown in ships, is no doubt well calculated to shock the sensibilities of that heroic class of men who have shed immortal glory on the pages of British history. It will, perhaps, cost the nation a pang to witness the "wooden walls" departing, one by one, if not in squadrons, like "Fighting Temeraires," to their "last resting places." But the experiment made, during the current year, by the improvised Confederate steam "ram" Merrimac, demonstrates that one such powerful engine as that proposed in this treatise may, under able management, be made to do the work of a whole fleet—or in other words, will be capable of destroying a whole squadron of "wooden walls," if not of "Warriors" and "La Gloires."

I am tempted to make one more extract from Mr. Woolley's paper. "One thing," he says, "has strongly impressed itself on my mind, while engaged in this work, and I dare say it has occurred to your minds also, and that is, *how very little is really known and fixed, compared to that which is unknown and awaiting for its solution, the discovery of those natural laws which have hitherto eluded our grasp.*"

There is a growing sentiment pervading society, that the necessities of civilization require another great step to be taken towards bridging over the space and shortening the time which separate distant portions of the globe from each other. A quarter of a century ago, the successful application of steam to Ocean Navigation, reduced the voyage between Europe and America from a month to a fortnight. From that time to the present, the genius of ship and engine builders—following in the traditions of the past, has only been able to reduce the average time to twelve days. It may fairly be asserted that, since the launch of the "Himalaya," more than ten years ago, no actual advance has been made, either in the speed or economy of ocean steamers; since the speed of the "Scotia"—the fleetest ship now in the merchant service—does not exceed that of the former vessel.

In making this comparison, it must not be forgotten that the speed of the "Scotia,"—though only about the same as that of the

"Himalaya," before she came into the possession of the Government,—is obtained at a far greater outlay, both in first cost and current expenses. Although the public are kept very much in the dark as to the actual cost of building and operating such high speed vessels, enough is known to warrant the assumption, that they can only be maintained by large government subsidies. This circumstance is of itself sufficient to illustrate the unsatisfactory state in which, what is now considered, high speed ocean navigation remains.

So long as the Government of Great Britain alone pays a million of pounds pension money to support ocean steam navigation, the subject of it cannot be regarded as in a healthy condition. These subsidies must be viewed in the light of a national tax, paid to support a systematic violation of the laws of nature, which we have not even taken the means to fully comprehend. We pay more for the carriage of an ounce letter across the ocean, than the merchant does for the transit of a hundred pounds of merchandize. If Government would change the system, and allow a penny or two pence for every letter, and a half-penny for every newspaper of the minimum weight carried,—I will not say by every transient ship, but by every steamer forming part of a regularly-established weekly or fortnightly line, which will undertake to deliver such mail matter within a specified time,—then we may hope for a sounder system of ocean mail service.

I am aware that there are a great many men, at the present time, whose minds like my own have been at work in endeavouring to master the problems I have ventured to discuss, and into whose hands this little treatise may fall. Some of these may have arrived at conclusions different from my own; but I think that the tendency in the development of mechanical and theoretical science is in the direction I have pointed. At any rate, I have the large and valuable experience of the American and Canadian Lakes to fall back on in support of many of my views.

It may be remarked as a singular circumstance, that several of the most important scientific discoveries have been preceded by strong presentiments shared in by thousands of the approaching events which such impressions foreshadow. Lamartine, in alluding to the existence of such prevailing sentiments just prior to the discovery of America, says, "There seem to be ideas floating in the air—a species of intellectual miasma, which thousands of men, without concert, breathe at once."

Our present necessities demand a class of vessels that will reduce the voyage between Europe and America to an average of one-half the present time, and at a cheaper rate. I have endeavoured to indicate how, I think, this may be accomplished, and trust that my ideas may be regarded by the enterprising Merchants of this country, if not by the Admiralty, as worthy of consideration. If the thousands of intellects at work on this problem did not believe that it was susceptible of a solution, it would indicate a species of wide-spread monomania. I simply believe that the prevailing sentiment and conviction foreshadow the event.

Before concluding these prefatory remarks, I avail myself of the opportunity to acknowledge the services rendered me, in the way of valuable suggestions as well as in the preparation of the drawings which illustrate this paper, by Mr. Thomas Smith, of Glasgow, Naval Architect, in the Ship-building establishment of the eminent ship and engine builders, Messrs. Randolph, Elder and Co., of that town. I feel confident that I am not paying an undeserved compliment in expressing the opinion that he has before him a long and useful career in the important profession on which he has entered.

London, 30th March, 1863.

ERRATUM.

At page 24, line 10 from top, for immersion, read emersed.

THE SCIENCE OF SHIP-BUILDING.

1. Naval Architecture and Shipbuilding are receiving so large a share of the attention of the ablest scientific men in all Maritime Countries, that it requires a considerable amount of moral courage to approach the subject with the view of suggesting new theories, particularly when they are pretty certain to run counter to old prejudices. I am, however, encouraged to undertake the task of laying before the world the result of many years experience and observation, by the admissions of the highest authorities on the subject, that nothing has yet been definitely settled on a scientific and permanent basis, in respect to the best form for a ship, to enable her to overcome the resistance opposed to her passage through the water. Indeed, the latest and best writers are compelled to admit that the most difficult problems, connected with Naval Architecture, remain to be solved, and the solution, it is said, must be sought after in the results of scientific experiments yet to be made. Having said so much in mitigation of criticism, I trust that I may succeed in directing the attention of scientific men to some new, or at least, imperfectly understood truths.

2. As a starting point for investigation, we may inquire what is the main or primary object aimed at by

the designer of a ship. On this point there will probably be no disagreement. Every one will admit that commercial economy must ever be kept in view. This holds equally true, whether the ship is intended for purposes of war, for the carriage of freight and passengers, or either of these latter objects separately. But by economy must not be understood mere cheapness, which is often quite the opposite of economy, but a right adaptation of means to an end, at the smallest present and future outlay of money.

3. The shipbuilder has therefore to consider first what work the ship has to perform; and secondly, how she can be designed, so as to perform that work most economically. Before proceeding to discuss these propositions, I desire to make some general observations.

4. I have said that true economy does not consist in mere cheapness. On the other hand, there is much danger of running into extravagant expenditure. There must be in this, as in everything else, a happy medium, and this is the object to be sought. For instance, a ship of war must be built stronger than a merchant vessel, and her strength must be so developed as to meet the peculiar demands of Naval warfare. The merchant vessel, whether intended for freight, or for passengers, has for each class its specific requirements, and these have frequently to be combined—although ship owners are gradually arriving at the conclusion that the two classes of qualities cannot, as a general rule, be advantageously united. On the American lakes and rivers they have already become almost distinct. Though passenger steamers still carry light goods that will bear high freights, the vast bulk of freight is carried by steamers that take no passengers.

To be economical in a true sense, the passenger steamer must have high speed, whilst the reverse is most generally the case with respect to freight vessels. What is now considered the most economical speed on the Canadian lakes and rivers for the respective classes, is 15 or 16 knots an hour for the former, and 9 or 10 for the latter. It is usually assumed that the two descriptions of vessels should differ widely from each other in form, as well as in horse-power. On these points I shall have some remarks to make hereafter (76). Convenience may dictate modifications in the forms of sailing vessels, in comparison with steamers, but as this paper will be mainly confined to the subject of steam vessels, it is unnecessary for me to dwell on the distinctions.

5. The question of a ship's form, naturally leads to the study of the elements in which she is intended "to live and move and have her being." We want to know the principles of these elements, and how they sustain, resist, and otherwise affect a ship in her course through them. This knowledge embraces the laws of fluids and atmospheric air.

6. The first great problem requiring solution, is one which seems to have received little or no attention from those who have written and spoken most learnedly on the subject of ship's forms,—I refer to the law of increasing resistance opposed by water to the passage of bodies through it, as the depth of immersion increases. As far as I have been able to ascertain, all the formulæ and calculations hitherto made by scientific men, in regard to resistance and the causes and peculiarities of the rolling of ships, have been predicated on the assumption that the various kinds of resistance to be overcome are the same,

per square foot, at the ship's keel, as the surface,—or at any rate that the difference is so small as to be unworthy of being taken into account. Acting on this hypothesis, the Naval Architect estimates for horse-power to produce a given speed in the case of a vessel of 25 to 30 feet draught, the same as for one of 10 or 15 feet. Hence arise those discrepancies between the performance of vessels constructed on precisely the same principles, causing the same amount of displacement, and having the same effective horse-power, but being of different draughts.

7. Perhaps no better example of such differences can be given than that afforded by the recent experiments of the Warrior and the Black Prince.* We read in the *Times* of the 1st of September, as follows: "Under these circumstances" (referring to the cleaning of the ships' immersed surfaces, and the adjustment of the safety valve, so as to cause the same pressure of steam as in the case of the Warrior) "as the ships were built from the same drawings, and their engines were made in one shop, from one set of patterns, it might reasonably have been expected that the speed of both ships would have been as nearly as possible equal; but" (says the writer) "the result of Saturday's trial has definitely proved the Black Prince, under present circumstances, to be fully a knot an hour inferior in point of speed to the Warrior." The writer then goes on to give reasons for this difference, and alludes to her greater draught as possibly being one of the causes.

8. We find by the account of the next trial of the Black Prince, in the *Times* of the 11th September, that

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* **This paper was written in the months of September and October, 1862.**

instead of the ship having been lightened to the same draught as her consort, she had a "mean immersion of hull 8½ inches greater than the Warrior," when on her trial,—that is to say, one inch more (equal to 50 tons additional displacement) than she had on the 30th August, when she averaged 13·317 knots per hour; on the last trial (10th September) she made 13·584 knots, but "under an excess of indicated power of 540 horses over the Warrior, and also a superiority in the number of the engines' revolutions."

9. At the high speed of these ships, a difference of a mile an hour is very considerable, and may not be fully accounted for by the difference of immersion of 7½ inches, though that represents an additional displacement of about 400 tons. I think, however, when I come to state the result of my own observations, it will be found to be fully explained. It is somewhat singular, that the Black Prince on her second trial had not been lightened to the trial draught of the Warrior, instead of being deeper immersed. Such experiments ought to be conducted, at least, on principles of common sense, if the scientific world, or the Admiralty desire to profit by them.

10. There are several methods by which this important problem (of the increasing resistance in the sub-strata of water) may be solved, or by which the law may be ascertained. To some of these, I shall presently allude; meantime I may observe that the greater efficacy of the screw, as compared with the paddle-wheel, is due to this law.

11. The paddle-wheel derives its power at the surface or point of least resistance of water, the screw, from the deeper and more stable strata; but this advantage of the

screw has its drawbacks: to increase its efficacy, by adding draught to the ship, is not to be thought of, for the simple reason, that there will occur a corresponding or greater resistance to the ship's progress. There is a certain amount of immersion indispensable, otherwise, the screw would be continually rolled or pitched out of the water. Beyond this requirement there is nothing to be gained by deep draught.*

12. The law of fluids which causes them to resist the progress of moving bodies in a regular proportion to the depth of their immersion, demonstrates the desirability of so constructing ships, as to give them the least immersion compatible with other requisites—that is to say, they should have as great a breadth of beam and length for a given tonnage, with as long and level a floor as may be found compatible with other indispensable requisites and qualities.

13. That future and more minute and repeated experiments will sustain my own observations, as to the existence of a law of increasing vertical resistance, of the several kinds hereafter to be noticed, I do not doubt. My chief endeavour shall therefore be to convince the scientific world that it is worth investigating, and being recognized.

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*On reading this passage, Mr. Thomas Smith, the gentleman referred to in the preface, suggested a very ingenious and effectual method of obviating the drawback to the use of the screw in ocean vessels of light draught, not intended to navigate shallow waters, and which will add only in a small degree to the aggregate of resistance. Mr. Smith proposes to "break down" the keel from a short distance in front of the mizen post, (Fig. 2—Plate II.) so as to drop the screw as low down as it can be made to work, and thus increase its diameter as well as efficiency. The successful application of two screws placed under the ship's quarters may serve the same purpose.

My limited means of experimenting have led me to recognize resistance under three heads: first, FRICTIONAL; secondly, HEAD or POSITIVE; and thirdly, NEGATIVE, or the effort required to separate substances, or to overcome the cohesion of the particles of fluids, or masses of such particles to a ship's clearance or run, which I conceive to be different from the first. Friction is caused by the rubbing of two substances or surfaces together. Negative resistance (a term I have selected for want of a better one) is the effort of cohesion of fluids to the after surfaces of solid bodies moving through the water. The necessity for drawing these distinctions will hereafter be seen, when I come to speak of each part of a ship in detail. In the aggregate, I estimate the law of increase to be according to arithmetical progression. That is, if the resistance to a solid body, moving at a given velocity, be represented by 1 at the first foot from the surface, it will be 2 at the second, 3 at the third, and so on. This will no doubt be a startling announcement, but I hope to convince the learned world of its reality by many strong arguments, besides the assertion of my own experience. The nature of my experiments will sufficiently appear from the suggestions I purpose to make to verify the results.

14. It will now be seen that when we have established the ratio or laws of increase, all that we have to do to find out the comparative resistance offered to vessels or other bodies moving at the same speed, and having the same area of immersed cross-section, surfaces and displacement, but of different draughts, will be to compare the sums with each other.

15. To exemplify this we will take the case of the

Great Eastern, whose width, for the sake of illustration, we will assume to be, in round numbers, 80 feet; her draught, when loaded, being 30 feet. Had her beam been 100 feet, and it were possible to have moulded her lines accordingly, she would in this case have drawn only 22 feet, still offering the same area for head resistance, and the same displacement; but her weight would have been sustained by the less resisting strata of the water, or nearer the surface. The comparative resistance according to the theory I am now supposing, would in this case have been as 17 to 31, or very nearly so. At 20 feet of draught and the same immersion of cross section in square feet, it would be as 14 to 31, or less than half. After making allowance for her less fine entrance and clearance, in case of such additional breadth of beam (which circumstances must be considered in the account) the Great Eastern, with her present power, might have more than realized the expectations of her designers. At the lighter draught she would probably have reached a speed of 18 knots, which no ocean steamer has yet done, instead of barely 13. Or her side wheel engines might have been dispensed with, thus diminishing the cost and relieving her of an enormous weight, and she would still have attained 15 nautical miles—or 360 knots per day—a speed rarely achieved on the ocean. Besides, she would have thus avoided an almost insuperable obstacle to her success—namely, the danger of touching bottom when entering the greatest commercial ports, where alone she can obtain adequate business. If her owners will take my advice, they will lose no time in taking out her side wheel engines and boilers, leaving say, two sets of the latter to add to the power of the screw. She will thus be lightened of a dead weight, including coals for a round voyage of from four to five thousand tons, and a saving on each such trip of at least £4000 will be effected, whilst her additional freight capacity may be estimated at as much more. The ship will then be safer and make better speed than she now does.

16. To have carried out, in the case of the Great Eastern, the modifications alluded to, without adding to her useless tonnage, would have demanded a diminution of depth of 18 feet, or a reduction from 58 to 40 feet. This of course would have lessened her strength. But with the present knowledge of the use of iron, the architect could have found no difficulty in providing for even a greater diminution in depth.

17. Assuming the law of increasing resistance to be correctly stated, and applying the rule to the recent experiments made on the Black Prince and Warrior, it will be seen that the 7½ inches, which the former drew more than the latter, being added to a draught of 26 feet, offered approximately 26 times greater resistance than the same amount of area would have done at the surface. Hence the additional 540 horse-power, exerted on the second trial, proved insufficient to produce a speed equal to that of the Warrior's.

18. It seems surprizing that Colonel Beaufoy and the learned French Academicians, in their protracted and minute experiments for ascertaining the comparative resistance encountered by solid floating bodies of different forms and moved through the water at different velocities, should have neglected the question of depth. The well known incidents related by Whalers, long before the

periods of these experiments, respecting the exhaustion produced on the leviathan of the deep by "sounding" as the sailors term it, ought to have suggested the propriety of experimentalizing on the lower strata of water. It had also before then, been remarked by naturalists, that fish and other marine animals, accustomed to feed in and inhabit the deeper regions of the sea, were formed with greater strength, and moved with less speed than those living and feeding near the surface. Cases are related where whales, after being slightly wounded, have sounded so deep, that when they rose to the surface they have been so exhausted as to be readily approached and killed with lances without a struggle. Other cases have been related where they have been killed outright by the enormous resistance they have encountered in their rapid course through the lower depths of the sea. Nor is this surprising when we consider that the pressure on the body of an ordinary man, at a depth of 32 feet, is equal to 20,000 lbs., a pressure which only powerfully-constituted divers are able to bear.

19. Any experiments instituted to determine the ratios of increasing resistance at different velocities, should be made on a scale sufficiently large, and under circumstances calculated to afford accurate results. The great Lakes of Canada, from their depth and freedom from tidal and other currents, present unusually favorable fields for obtaining accurate data. There are often weeks together when some of these great inland seas are scarcely moved by a ripple, except when the refreshing evening breezes spring up during the hot months. Valuable experiments might be made in the following manner:—construct a flat bottomed boat of some light and strong material,

of sufficient length—say 30 feet, with a "slip" keel box, eight or ten feet long, and also a similar box placed at right angles with the keel. As considerable strain will come on these boxes, let them be supported by two upright pieces of scantling, stayed by small chains or wires, passed over cross trees at the top, and secured to the stem and stern post. These scantling will serve as slide guages for the implements to be used. Then construct a slip keel of boiler plate—say 30 feet long, so as to admit of being dropped down 20 feet below the boat's bottom. Let this thin plate of iron, made sharp at the edges to avert head resistance, be divided into a scale of inches and feet, so as to tell at a glance the amount of immersion. Attach the stem of the boat by a line to a well-constructed dynamometer, or instrument for measuring the rate of resistance, which has been made fast to the stern of a steamer. First ascertain the readings of the instrument with the sliding keel up, at different velocities. The drawings of such an apparatus as I have described, will be seen by reference to Fig 2—Plate II., It will now be easy to note the amount of frictional resistance exerted at each successive stage of immersion of the scale, and by comparing the different sums of resistance with each other, to establish the ratio or law of increase. In like manner, the law of increased resistance under different velocities, at the same depth of immersion, may be ascertained. Such experiments would require to be repeated a great number of times, and with a number of instruments, to correct each other, in order to arrive at an accurate result. Head resistance might be ascertained by means of a scale to which bodies of different forms and sizes may be attached, and immersed through the cross section box, and be towed horizontally through the water at different rates of speed and at various depths, in the same manner as described in respect to friction. There are no doubt many other devises, which an ingenious engineer, accustomed to study the subject, may avail himself of. But experiments made in the way I have mentioned will give results that will surprise those unprepared for them, particularly in respect to friction.*

20. I will now proceed to apply the law I have laid down to the rule generally used by scientific ship-builders in estimating for horse power. That rule assumes that the resistance to similar forms, is as the square of the velocity and the horse power as the cube. As to the manner in which this rule is worked out in practice, I will quote the words of Mr. Scott Russell, who is a great authority on all subjects connected with ship-building.

21. Mr. Russell says, "he had ascertained that at ten knots per hour, with a vessel of proper form (?), of

* It may be interesting to mention some experiments which I made with a small boat, which I had constructed in 1860, either to sail or row. It drew about 6 inches, light, and had a sliding keel—arranged to drop 1, 2, or 3 feet below the bottom; three feet wide, and made of thin boiler plate. I found that in smooth water, uninfluenced by wind, I could pull this boat, with the keel up, a given distance in 15 minutes. When it was one foot down, exposing on the two sides six feet for frictional resistance, I perceived a decided difference in pulling it through the water with the oars; and after many trials, I found it took me a full minute longer to pull the distance between the two marks. On lowering the keel another foot, instead of finding the time increased to 17 minutes, I discovered that fully 18 were required. With the keel fully down, exposing 18 feet on the two sides, the time was increased to 21 minutes; whereas, if each foot of immersion encountered a uniform resistance, the boat being pulled with the same amount of effort, should have been retarded only 18 minutes.

1,500 tons burthen, the head resistance of a ship could be reduced to 50 lbs. per square foot. He had also ascertained how much a similar vessel could be propelled with, by engine power alone, including the loss due to the working of the engines, and he had found that whilst the direct resistance to a ship going ten knots per hour, was only 50 lbs. per square foot of midship section, including all loss from communication by paddle wheel, air pump, and other sources, except the slip, this resistance was not more than 65 lbs. per square foot of midship section. Thus they could calculate confidently to a quarter of a knot, as he had done for years past with his peculiar shape of ship, the amount of steam power necessary to propel a given ship at a given speed—as for instance, where a speed of ten knots per hour was desired, he provided for 50 lbs. per square foot of midship section, for the resistance of that ship; and when he had to overcome the resistance of the machinery also, he made that up to 65 lbs. per square foot."

22. Now it will be seen that, without taking into account the surfaces exposed to frictional and negative resistance, and the draught of the ship and the law of increased vertical resistance, this rule must be attended with great inconvenience. If the engine power of the Great Eastern was predicted on the data obtained from a vessel of 1,500 tons, and drawing only 15 or 16 feet, her failure to realise the expectations of her designers will now be understood.

23. The law in question being established, we must endeavour to find out the cause. The increase in the density of the water by the superincumbent weight of the upper strata, can scarcely be supposed to have much

to do with it. The experiments made on this head show that water is only compressed $\frac{1}{20}$ at 500 fathoms, which would be about $\frac{1}{2000}$ at five fathoms. In case of frictional resistance, it is probably due to the increase of pressure on the ship's skin, as the immersion increases, which, as already mentioned, at 32 feet deep, is equal to 20,000 on the body of an ordinary man. Head resistance, or displacement, must, I think, be sought in the power required to raise each cubic foot of water lying in the ship's path, a certain height in a given time, according to her velocity. In the case of a steam ship going at a high speed, the work that the engines have to do, is to raise above the surface a quantity of water equal or nearly so in bulk to the whole mass lying in the way of her largest immersed midship cross-section, and to overcome the friction on her exposed surfaces, as well as negative resistance and of the engines themselves.

24. In respect to these labors, in ocean road making, the great facility with which particles of water move amongst each other, as well as the readiness with which solid substances are moved through it in any direction, or in other words, its great fluidity, has possibly led to much misconception on this point.*

*It is not many years since the doctrine prevailed, because of this facility of movement on the part of solid bodies under water, that a body surrounded by any liquid was destitute of weight, and that the particles of liquids did not gravitate on each other. The fallacy of this opinion was at length shown, by suspending an exhausted glass bottle to one arm of a balance, so that its neck was wholly immersed with weight sufficient on the other arm of the balance to keep it in equilibrium. When the water was let into the bottle by means of a stop-cock, it was found that it required the same amount of weights to be added to the opposite end of the balance to make it maintain its equilibrium, as the contents of the bottle weighed in the air. To draw a tin or

Mr. Scott Russell has so admirably described the manner in which a ship, by the power of her engines or sails, excavates for herself a passage, and has so well informed us what she does with the water, and how she fills up the passage behind her, that little can be added. I wish, however, to state what I have observed, both in deep and shallow water, and what in a small degree may be seen almost every day on the Thames, by close observation, to be the appearance of the water immediately surrounding a rapidly-moving steamer. The best point for observation is the deck of another steamer of the same speed moving in the same direction and at such a distance as to make the angle of view about five degrees. If the water is smooth and unrippled, and the steamer under view be a screw, the appearance will be very striking. The moving vessel will seem to be placed in an elongated moving basin, scooped out of the water, and she will be seen to keep her place at a fixed distance from the rim, being always nearer to the end in front of her, which her cut-water will touch. If the steamer have a very fine entrance, the edges of the basin, on the two sides will appear higher than near the ends, and the horizontal shape of the rim will be that of versed sines. See Plate II., Fig. I. This rim is formed partly of the displaced water and partly of other water acted on or pressed upward by it. The wave of translation spoken of by Mr. Russell, does not in the case of such a vessel in

iron bucket from a deep immersion in a well, or in the sea at a considerable velocity, requires more power at the commencement then when it nears the surface, that is, the power required to maintain a uniform velocity diminishes as the depth of immersion decreases. Some advantage may be gained by having this experiment nicely tested.

the open sea take a course directly ahead of her, but nearly at right angles to the water lines of her respective bows, and the rollers or waves which follow and which are the result of negative resistance form an obtuse angle to each other having its point next the ship. If, however, the vessel have a bluff entrance and a fine run, the wave of translation will be largest ahead, thereby impeding the progress of the ship, which will rise at the head and sink by the stern, and seem to be labouring up hill.

25. The remarks just made, it will be seen, have a direct bearing on the FORM of the ship, which will presently come under notice (60). Prior, however, to discussing this most important question, which is the main one to be mastered, it will be necessary to consider that of ocean waves, and their effects on ships and other solid bodies. I now speak only of waves produced by the action of the atmosphere on the surface of the sea. The wind to which they are imputed is merely an incident of the atmosphere and one of the processes by which it produces wave motion.

26. The properties of the atmosphere which enables it, when set in motion by changes of temperature acting on vast fields to produce waves, are its elasticity and weight. The qualities of water which render it susceptible of being thus acted on are its fluidity and elasticity—the latter a quality once denied by philosophers. But however small it has been demonstrated to be, there could, I think, be no wind-made waves without it.

27. We have now before us the body to be acted on and the agent ready to act, and know the peculiar qualities of each required to produce a given result—namely, ocean-waves. But there is yet another requisite,

without which there would be no result. I speak of the law of gravitation. We will now see how these combined agencies perform their work.

28. Suppose the surface of the sea to be perfectly smooth, and that a current of atmospheric air, or wind springs up, the first thing that will be noticed, will be innumerable ripples on the face of the deep. This is the commencement of wave-making—the process is begun. As the wind or elastic current of air bearing down on every square foot, with the force of nearly a ton, pushes the water up into these ripples, gravitation pulls it down again. Each time a little wave is thus raised and drawn down, it increases in size, by absorbing its lesser neighbours. It will thus be clearly perceived, that the two agents, which create the waves, are the atmosphere with its peculiar quality of elasticity acting from above and horizontally, and attraction of gravitation, acting from below on a semi-elastic fluid.

29. The waves thus commenced go on increasing in magnitude, so long as the wind increases in force, until they reach the limit imposed by the laws which create them. This law, on the part of the atmosphere, would limit their height to 32 feet, or the height of a column of water, the weight of which is equal to that of an entire atmosphere. But there is another law to be sought in the water itself, which imposes a much smaller limit on the height of waves. That law I am inclined to believe, will be found to be the extent of the elasticity of water. Great exaggeration has prevailed in respect to the altitude of ocean waves. Even learned writers, until very recently, continued to speak of their rising 40 or 50 feet high. In November, 1840, I encountered during a

voyage from New York to Barbadoes, in a small barque, one of the severest hurricanes of the present century. It was one of those great cycloidal storms, reported on by the late Colonel Reid, which swept down the whole length of the Càrribean sea, and turning with the gulf stream, followed the coast of North America to Newfoundland, and finally crossed the Atlantic to the shores of England. Owing to the ignorance and stupidity of the captain, we received the whole force of the storm for four days, almost under bare poles, when, by changing the course of his ship, he might have run out of it in a few hours (as I endeavoured in vain to convince him). When we reached the middle of the gulf-stream, where the current was three knots an hour, off the Capes of Carolina, we had the wind at its greatest force from the north, almost in an opposite direction to the current, thus raising the waves to what people delight to call, in poetic language, "Mountains high." Being a good sailor, I mounted the mast to get a better view of the terrible desolation which surrounded our little barque, and to measure the height of the waves. I was quite surprized, when I mounted about 30 feet, to find that I was on a level with the crest of the waves, when the ship was at the bottom of the "troughs." I therefore arrived at the conclusion that they never rise above 16 or 18 feet above the ocean's level when at rest. The violence of the waves was such (as we found when we came into port) that nearly one-third of the copper was torn from the ship's sides and bottom. This was the commencement of my observations on ocean waves.

30. The law of water (whatever it may be) which limits the height of waves much below the power of the

atmosphere, no doubt, limits the downward wave motion, which would otherwise extend to the bottom in the deepest parts of the sea. The complete elucidation of these interesting topics, connected with the subject under discussion, will bring to light the law which says to the sea, "thus far shall thou go, and no farther."

31. The idea that the particles of water in waves advance, is simply an optical illusion, although on the surface, there may be, and probably is, a slight onward movement, counterbalanced by a counter current underneath.

32. Although the particles themselves do not move forward, the effect of waves on ships is in many respects the same as if they did. To illustrate this fact, let a great ocean-wave encounter an unyielding obstruction, such as a rock rising out of deep water, which would prevent the undulation from passing under it, and the wave will then act in a horizontal direction, with enormous force—the force being proportioned to the velocity and size of the undulation. The bearing of this fact on our subject, will hereafter be seen (35, 36).

33. The waves thus formed are simple undulations moving in the direction of the wind, without advancing the particles which form them. These particles we have seen oscillate vertically, or as some allege, in parabolic lines or columns. As they rise and fall in long lines, or in masses, they give the peculiar forms assumed by waves —some being long regular swells and others tumulose in shape. The advancing movement of the undulations, is caused by the graduated rising and falling of these coulmns or masses of particles—the rising lines being always in advance of the falling ones. Thus all the

particles near the surface occupy alternately the crest and trough of the waves. A well drilled army of soldiers, formed in lines, might be so manœuvered, as to produce the effect of ocean waves, by causing the men to fall to their knees and rise in lines in the manner described, without moving a step.

34. A ship, or floating immersed body of any kind, displaces a certain quantity of the particles forming a passing wave. It might therefore, be expected that a ship would conform exactly to the motions and angles of the wave, where it happened for the time to be. This is certainly what happens to a perfectly flat body, floating directly on the surface, such as a detached portion of a ship's deck, or a raft made of spars or timber. In the case of a ship it is, however, different. The rising and falling lines or masses of particles, act unequally and with different forces on different parts of her, according to their depth of immersion.

35. The rolling of a ship is produced by a two-fold action of the waves: namely, first, by the rising of the particles on one side of her, whilst they are sinking at the other, or by the slope of the wave; and, secondly, by the forward motion of the undulation, which has further and faster to travel at the surface than at the ship's keel, where the motion begins rapidly to diminish.*

* Mr. Froude in his paper on "the rolling of ships," read before the Institution of N.A. (Vide Trans. I.N.A., 1861) takes quite a different view from that here expressed :—He assumes that there is no sensible difference between the parallelism of wave undulations at the surface and at the depth of immersion of even the largest vessel. Various experiments which I have made, however, sustain my opinions. Besides, it is the greater velocity of waves at the surface which causes them to break where they encounter no opposing solid body.

If, therefore, a ship sinks so deep into the water as materially to impede the passing undulations, it is obvious that she will roll more and receive a heavier shock, when a wave breaks against her, than one drawing less. Nay, more; such a ship will often *cause* a wave to break, which would have passed under her unbroken had she drawn but a little less water.

This will account for such accidents as that which befell the Great Eastern, and caused the loss of her paddle-wheels in 1861, and no doubt many a gallant ship has foundered at sea from this cause.

36. The violence of breaking waves, whether on the sloping strand, or against the more yielding sides or decks of ships at sea, is, under high velocities, enormous, and points out the danger of giving ships too deep an immersion in the less yielding strata of water, so as to interfere seriously with the passing undulations. During the great West India hurricane of 1780, cannon that had lain long buried in the sea were driven up high and dry by the waves, and were still shown when I was there in 1840.

37. A learned writer on waves (*En. Brit.*, 1840), lays down the following law with regard to the depth of wave undulations: "The depth of the water to which the agitation of a wave extends perceptibly, never bears a very large proportion to the dimensions of the wave, either in breadth or height, the motion diminishing in geometrical progression as the depth increases in arithmetical; and at a depth equal to the breath of the wave, the motion is diminished to a 534th part of that at the surface." Whether this rule be correct or not, we find a very marked difference between the motion of an

ordinary Atlantic wave, (of say 15 feet from the hollow to the crest), at the surface and at 20 feet below it. If, therefore, a ship draws more than that, she will receive a severer shock and a heavier roll than one drawing less.

38. As already observed, a flat bottomed boat or raft floating immediately on the surface, conforms more readily to the angles of the waves than a ship. But there is another peculiarity connected with the rolling of ships. It is the acceleration in the velocity of the motion.

This phenomenon consists in the gradual accumulation of angle during several successive rolls, until such accumulation reaches a maximum force, when a gradual subsidence commences, and the ship comes to rest to begin a new series of rolls. The worst rollers are those in which this peculiarity is most developed.

39. The form that will roll most—the adjustment of weights being the same—is that which approaches nearest to a circle, in the cross sections which afford the greatest amount of buoyancy, because a circular form does not widen its base at the water line as it changes position. The form that will roll least, other things being equal, such as the adjustment of weights, &c., is that of the parallelogram and angle combined, the corners being rounded in order to give a more gentle deflection to wave oscillations, as seen at Fig 6—Plate III. The reason of this is that the latter form gives less draught, and conforms to the peculiarities of waves as already described, and consequently receives their action more equalbly on the lines of flotation. It also widens its base of flotation on the least change of position.

Every one who has made a voyage in the Great

Eastern, has had to remark the extraordinary rolling of that vast ship.

When she was building, it was predicted of her that she would neither roll, nor pitch, or at least only in a slight degree.

The drawings at Plate I.—Fig 1, and Plate III.—Fig. 4, represent the great ship, and show how nearly she conforms to a circle, although she in reality has considerable level floor.

This great tendency to roll, taken in connection with the accumulation of force, is calculated to lead to serious evils, to say nothing worse, should the ship encounter a real hurricane. The danger arises, in such ships, from the accelerated roll outrunning the periodicity of the waves, so that the ship comes to act in an opposite direction to them, when she will occasionally meet the crest of a great wave half way, thereby adding to its force, and frequently causing it to break over her.

The forms of the Resistance, Defence, and the Warrior, approach even nearer to that which, according to my deductions, is the worst—though they partake of the triangle; whilst that of the Great Eastern is in the nature of a parallelogram, with the lower corners too much rounded. See Plate III.—Fig 7. By reference to Plate II.—Fig 3, the acceleration in the rolling of a ship may be traced in her different attitudes and degrees of angle, as you run your eye from right to left, the waves being supposed to be moving in an opposite direction.

But most vessels roll when running before a following sea, as badly as when going in the troughs. When the subject shall be properly brought to the test of experimental science, I think it will be found that both kinds of rolling depend on the same circumstances, and that whatever mitigates the movement in the one case, will do so to the same extent in the other. In both cases, the primary cause of a ship's oscillation, is the unequal action of the disturbed water on the lines of buoyancy or floatation. A ship running before a gale, as she rises over each wave, and pitches into the hollow of the next, is detained sufficiently long in each position, with her entrance and run deeply immersed, and her midships in a corresponding degree emersed, to cause her to incline or fall over to one side, or the other. When the wave reaches the midship sections, where the greatest buoyancy exists at the greatest distance from the axis of motion, the chief action of the water is suddenly changed from the ends to the body, and the vessel is violently righted, and carried in an opposite direction by the acquired momentum. If at this instant she has reached a similar position on the opposite slope of the wave, she will acquire an increase of angle. Should these conditions be continued for several successive waves, as I have witnessed, a ship may have her safety seriously imperilled. In such cases, a slight alteration of course, or an easing of the engines, even for half a minute, will check the evil. So very important is this question, it is to be hoped the government of some country will take it in hand, and cause a regular system to be adhered to in every public ship, with the view of collecting data, and determining the best means to obviate this unpleasant and dangerous characteristic in ships. I shall hereafter refer to the effect of the distribution of weights on the rolling of ships (66).

40. An interesting and useful experiment may be made, at a very trifling cost, to show the varying action

of waves, on solid bodies at different degrees of immersion. Take, say three small spars of the same diameters and of the respective lengths of 15, 20, and 25 feet. Attach bags or sand, or other weights to the lower ends of each, just sufficiently heavy to cause them to float vertically, leaving five feet of each above water. They will then remain immersed respectively 10, 15, and 20 feet. Then drop them into a rolling sea from a boat, or a ship stopped for the purpose, after the subsidence of the wind, and observe the effect. In a few minntes the spars will all be oscillating and swaying backwards and forwards with different periodicities. The experiment, however, will be deficient in not showing the effect of momentum possessed by ships.

41. The next quality belonging to water, and other fluids, to be noticed in connection with this subject, is friction. No accurate measurement of its power of resistance to a ship has yet been made. When a solid of any kind is immersed in water, a quantity of the particles attach themselves to every part, or as we say, it becomes wet. When the body is set in motion it is those particles which cohere to its surfaces that rub against the surrounding masses of particles, which press against the body with a force proportioned to the depth of immersion, and not the actual rubbing of those particles against the surfaces.

42. Frictional Resistance, according to the facts adduced, is at its minimum at the surface of the sea, and its maximun at the deepest parts of immersed bodies, moving parallel with the surface, and it increases in proportion to the pressure from above—that is, in an arithmetical ratio; or the same, as my limited experi-

ments have led me to ascribe to the combined Resistances from all causes (13). But as the skin of a ship can only receive one half the pressure on each square foot, or inch, I think we can only estimate for one half. In other words, referring to the experiments suggested by means of the slip keel, the pressure on the two sides must be considered in the light of a single sum. But, whatever it may be, it demonstrates the great importance of the draught of a ship, when regarded in relation to this kind of resistance.

It also demonstrates, the desirability of at once determining by experimental science, the respective degrees of friction, exerted on the surfaces of the various materials, used for forming the outer skins of ships. Those the least porous, or which absorb the least water, and which are susceptible of receiving the highest polish, will be found the best adopted to mitigate the effects of friction.

If any of the enamels invented for this purpose, prove efficacious, and are capable of resisting the effects of sea water and barnacles, a great boon will be conferred on the world.

43. I have already suggested (19) a method for ascertaining the laws of frictional resistance. The same apparatus will serve to test the best materials to be used for the outer skins of ships, in reference to the diminution of friction.

44. Some years ago I made an experiment worth recording. I was the owner of a small pleasure boat, or yacht, of less than three tons, and a severe contest having arisen between myself and the owner of another and considerably larger boat, in regard to speed, I resorted to the following

expedient. No more sail could safely be added, so I took my boat out of the water, and after she was dry, gave her several coats of marine varnish, which resists fresh water, and made her skin as hard and smooth as enamel. The next time I encountered my rival, both of us were immensely surprised, that, with precisely the same sail, I was able to beat him at all points of the wind. In a moderate breeze of six, or seven knots an hour, I found I had added at least a mile to the speed of my little boat, by this simple expedient. In a large steam-ship such an addition of speed—caused by the abatement of frictional resistance, would no doubt amount to two knots per hour, or an economization of 20 per cent. in coals. Mr. Smith, naval architect of Glasgow, has mentioned to me a case where a steamer having 500 tons displacement and 165 H.P., drawing 7½ feet, had her speed improved 1⅛ miles per hour by coating her immersed surfaces with black lead.

45. To experiment on oblique surfaces and curved lines, would require differently-constructed implements. But it will be seen hereafter (54 and 55), that for the sake of accuracy and convenience, I purpose to treat such surfaces as opposing only the same frictional resistance as those moving parallel to the ship's keel, charging the difference to the account of head resistance. Nevertheless, the ends of science would be promoted by making a large number of experiments to ascertain the *value* of curved lines, as *auxiliaries* to the power of the wedge.

46. Until the laws I have laboured to elucidate shall be correctly established by experimental science, ship-building must be regarded as deficient in some of the most important characteristics of a scientific pursuit. The

admissions of the greatest authorities, as already observed, prove that we are still in the infancy of the art. Much of what we do know must be regarded, rather as the results of happy guess work and accident, than of regular scientific investigation. At the present moment, the records of the Patent Office, and the drawings and models at the International Exhibition,* afford nothing but a vast mass of contradictory evidence and conflicting theories. Many of the most learned and scientific men are wasting their time and energies in trying to erect an edifice, by beginning at the top and working downwards, whilst others of the same class have commenced in the middle, and are working both ways, with no better chance of success. When we have begun at the bottom on a safe foundation, then may we hope to erect a permanent structure.

47. There is one other kind of resistance to be noticed. The two former, for convenience, I have termed POSITIVE, or head, and FRICTIONAL resistance. The one I now propose to consider is what I have designated NEGATIVE resistance. It is caused by the cohesive qualities of fluids, and requires a real and effective force to overcome it. Its effect may be illustrated by the effort required to lift any floating body having a flat level surface underneath—such as a board, perpendicularly from the water, when a slight lateral movement will greatly mitigate the resistance. This resistance, I think, cannot be wholly due to atmospheric pressure; because by retaining the board in a perfectly horizontal position, after it has been lifted from the surface of the

* This treatise was written in October, 1862, whilst the Exhibition was still open.

water, it will be found that quite a mass of water will continue to be suspended underneath, until by giving the board a slight tilt, it will run off in the direction of inclination.

48. If the assumption in favor of this kind of resistance can be sustained, and a distinction drawn between it and frictional resistance, it may in like manner be reduced to a law. Its bearing on the form of a ship will hereafter be pointed out (60).

49. Acting on the light of my own investigations, limited as they have been by the want of appliances, I shall venture to suggest a theory deduced therefrom, Taking the principles I have imperfectly laid down, as being well founded, we shall have something to guide us in the right direction.

50. The first question, then to be solved, is how little draught can be given a ship, without infringing other indispensable conditions and qualities; and secondly, what form will most diminish the sum of resistance? The second proposition is no doubt largely involved in the answer to the first. The form that will give the least depth of immersion, it might be argued, would do most to mitigate resistance of every kind. But as there must be some depth of immersion, and a corresponding resistance, the questions must be considered as separate propositions. The question of form is indeed, a complex one, and involves many compromises of principle, if I may so term it, as well as of power.

51. To make this clear, we will next refer to the means, by which a ship is best enabled to perform the work she has to do. That work, as I have already said, in the language of a high authority, is to excavate a

passage through the water equal in depth and breadth to her largest midship immersed cross section, and extending the whole length of her journey. To do this she is supplied with two kinds of powers—first the wedge or PASSIVE power; and secondly, the steam engine or sails, which are the active powers.

52. The wedge being the only mechanical power applicable to ocean road making, the question to determine is, what is the best shape or angle to give it? In Mechanics, the law of the wedge is, that its power increases as its angle diminishes, or in proportion to the fineness of its taper. In applying the rule to the entrance of a ship, the extent to which it can be carried, must be determined by other indispensable requisites, such as convenience, strength, and breadth of beam, which gives light draught and stability.

53. By the adoption of the hollow water line, or as it is called in this country, the wave line, a happy combination of principles is effected. But it can only be regarded as coming in aid of the wedge, which after all is the real passive, or mechanical power. I may here mention that this form has been in almost universal favor, on the Western Lakes of America, for 30 years. Those, however, who have used it, have been ignorant of the reasons of its efficacy, in economizing power. An unfounded idea exists, that it derives its efficacy from a supposed resemblance to certain kinds of waves. The simple fact is, it obtains its virtue from the convenience it affords in fining down the point of the wedge, or the commencement of the ship's entrance, to an almost minimum amount of frictional and head retistance, thereby increasing its power. The entrance of a ship is thus enabled to cleave the water to the best advantage.

The water is then deflected in a current in the direction of the increasing angle, until it reaches the widest part of the vessel, where the versed sine dies away in the straight lines of least frictional resistance. To illustrate this, let Fig 1.—Plate III., represent the entrance and run of a ship having hollow water lines, and AA., particles of water towards which it is approaching, and BB., CC., DD., EE., and GG., indicate several sections of the entrance, the exteriors of which are at the respective angles with the keel of, say, 2½, 5, 7½, 7½, and 5 and 2½ degrees. When the ship reaches the particles AA., they will be deflected two and a half degrees from the line of her keel, until she advances to BB., (we are supposing the sections to be vertical and to have straight, instead of curved lines), when they will receive a further deflection of 2½ degrees, and at CC., still another deflection of 2½ degrees, when the entire deflection from the line of her keel will have reached 7½ degrees, at which they will remain, until the progress of the vessel brings them to EE., where the angle of deflection begins to diminish. It will then continue to diminish until it dies away in the straight lines of the ship's body, at which the frictional resistance is at its minimum. By this it will be seen, that the particles of water come in contact with each approaching section at the same angle.

Or, if we suppose the ship to be at anchor in a stream, or current, the great fluidity of water, assisted, perhaps, by its elasticity, causes it to follow the curvilinear course, it is at first gently made to take, and which is gently continued, by the increasing angle of the curve or hollow line, to the ship's keel. But the wave line has its limit of efficacy, and I have seen it carried so far, on the Canadian lakes, as to cause the water to break at the rounding of the convex lines, at AA., Plate II.—Fig 3.

54. It will, I think, be obvious, in considering the *increase* of frictional resistance occasioned by oblique surfaces—whatever that increase may be in comparison with that on surfaces moving through the water parallel to the ship's keel, that it can only be regarded in the light of head resistance, or that of displacement, of which it, in fact, forms a part. It cannot therefore be treated as a separate quantity to be added to the general sum of resistances, but is in reality a part of positive, or head resistance.

55. Instead, therefore, of experimenting to find out the increase of frictional resistance, caused by different angles of the wedge, or of oblique surfaces, we must ascertain their *value as passive powers in mitigating the sum of resistances*. In fact, what we have to do, is to determine the *unit* of power of the simple wedge, by experimental science, to which must be added the value of curved lines, as far as that can be ascertained (53); that is, we must find how much a wedge of given angles mitigates or diminishes the sum of resistances when it is driven through the water at a given velocity, and then by calculation determine what the value, or power of wedges of other, or greater, or less, angles will be at the same, or at different velocities.

56. Since then, we are to regard the increase of friction arising from the oblique surfaces of a ship, as belonging to the sum chargeable to head resistance, we must treat the whole of the skin as offering only minimum ratios of friction, or, as if the whole immersed surfaces were moving in lines parallel with the ship's keel.

57. But, it may be objected to this method of dealing with the question, that it will be troublesome, if not impracticable, on account of the infinite variety of forms and curves used by ship-builders.

58. Such an objection, however, can only be regarded as a begging of the whole question under discussion, since the very object is to establish, by experimental science, what is the best form for a ship, in order to *adhere* to it, when ascertained. Like the watchmaker, who knows the exact amount of friction to be overcome, and the scientific proportions to be observed between every part of the machinery of a watch, and is thus enabled to find the necessary power to keep the whole in motion at uniform velocities, the ship-builder must learn to deduce from ascertained laws, the proper length, breadth, depth, angles, and curves—that is, such a combination as most to mitigate resistance without detriment to other necessary qualities, and then determine the horse power required to produce a given speed. Meantime, this very multiplicity of forms, brought up in objection, must be taken as a proof of what I have already remarked (46) on the unsatisfactory state of the science of naval architecture.*

* Since this work was written, I have visited a large number of the ship-building yards of the Thames, the Mersey, and the Clyde, and examined a great number of ships on the stocks and afloat, as well as the models and drawings of many of the eminent builders, and have come to the conclusion that little, or no advance has been made in the designs and forms of ships during the last ten years. In the construction of marine boilers and engines, some economization has probably been effected, as well as in the various processes of construction. In respect to the best form to overcome resistance, and mitigate rolling and pitching, we are just where we were ten years ago, when the performances of the Himalaya first excited public attention.

59. Having deduced from natural laws and principles, what is the best entrance for a ship, we will next proceed to the clearance, leaving the body to be dealt with last. Some builders have gone so far in their indifference about this part of their vessels, as to propagate a sort of axiom, "take care of your ship's entrance, and the run will take care of itself," or in other words, "find the best way to get the water out of the ship's track, and it will find its way back, without the aid of your skill." Such ideas are simply the result of ignorance of those laws I have been endeavouring to elucidate.

60. The clearance of a ship must be formed in reference to laws to be established on the subject of negative resistance, (47 and 48) and to the duties it has to perform. The same reasons that favor the wedge and the hollow, or wave line form, for the entrance, apply with equal force to the ship's clearance. But what relieves the ship-builder from the necessity of fining down the clearance of his ship to the same degree as the entrance, is the effort which the displaced water makes to regain its equilibrium. Being elevated above the surface, it falls with greater force towards the ship's wake, than that rising from below. See Fig. 1, Plate II. A current is thus formed which detaches the cohering masses. Hence the hollow or curvilinear form of clearance acts in mitigation of negative resistance, whilst a convex form, such as that given to the Great Eastern, under a wrong notion as to the replacement of water, aggravates it.* Great lean-

* A further illustration of negative resistance is to be seen in the effect produced on the wake of a ship of a very full and convex run. Such a vessel, when sailing in a smooth sea, draws after her so much water, that a small boat will almost "tow" without the aid of a line. Nevertheless, this form

ness of clearance is a fault as much to be guarded against as the reverse. By abridging the lines of flotation in this part of a ship too much, we throw a larger amount of weight on distant parts, whose strength is taxed for its support. This is particularly the case with modern "Screws," and all such formed vessels are more liable to hog, than where an opposite principle is kept in view. What is called a high run, it will thus be perceived, is not a desirable quality. A vessel with two sharp ends, resembling an Indian's bark canoe, may not be considered quite "Ship Shape," a term without any meaning, and which has led to the squandering of untold millions of money; but, nevertheless, it is surprising how soon we accustom ourselves to new forms, and ultimately find beauty in adaptation. The present generation feels a sense of pride and superiority, in comparing our graceful modern built ships of war with the "Seventy-fours" of a hundred years ago, when those vessels were regarded as models of perfection, as compared with a line-of-battle ship of the days of the Virgin Queen. An American thinks his lake, or river steamer, a marvel of elegance, whilst an "old Salt" spurns it as a mere "floating hotel." Such a clearance, as I have described, is shown at Fig. 1.—Plate III. HH., and also at Plate IV. AA.

61. We will next proceed to the "mid-ship" or intermediate portion, which has to support, not only the engines, fuel, and cargo, but frequently, from want of judgment in the builder, a large amount of unnecessary weight added to the entrance and clearance. It requires no reasoning to prove that this part of the ship, the skin

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of run still predominates in sailing vessels, as every one who visits the Docks at Liverpool or London, will perceive.

of which moves parallel wth her keel, can encounter but one kind of resistance—namely, that arising from friction.

62. A certain length of body is necessary to obtain capacity for flotation and cargo. The question then arises, in what ratio must the horse-power be increased, for each additional foot of midship, in order to maintain the same, or to obtain a higher speed? Instances are cited, where a positive gain in speed has been effected, by cutting a ship in two parts and adding to her body, without increasing the horse-power. The cases of the "Europa," "Candia," and "Alliance" are cited in proof of this observation. Where such results have followed, it affords evidence that the ship was originally too short in that part to maintain a proper proportion, or else she has, by the addition, been made to draw less water. After reaching the limit of speed, attainable with a given power, it is obvious, that in calculating for increased horse-power for additional length, we have, as already observed, to take cognizance only of frictional resistance at its minimum ratios.

63. It may be a waste of time to lay down a rule founded only on present information. I will, however, state that some American lake builders act on the hypothesis, that after a steamer has been modelled to the maximum length at midships, to attain a given speed with a given horse-power, the increased horse-power required to maintain the same speed, for any additional length put into her body, will only be in the proportion of one-fourth of that already estimated for. That is to say, if the horse-power was in the ratio of one horse to four tons, it need only be for the tonnage added to that

part of the vessel having straight fore and aft lines, as 1 to 16.

64. To still further illustrate my meaning, we will suppose that a steamer of two thousand tons, actual burthen, can afford to carry a full cargo across the Atlantic at £1 per ton, by adding 2000 tons more to her body, she can do the whole work at a cost of 12s. 6d. per ton. In making this estimate, I have not considered the additional weight of the ship. This example points out the importance, after we have gone to the expense of excavating a passage for a ship, of sending as much freight and as many passengers through it as possible.

65. We will next briefly consider the ship's beam and the shape of her bottom. And here it may be observed, that, as we proceed from one part to another, we shall discover, that each possesses an importance of its own. It is generally believed that broad vessels roll and pitch more than narrow ones. This impression, I think, is erroneous, particularly where they have a good length of floor, and has arisen from a misconception of the causes of ships' rolling. I might cite the instances of nearly all the Ocean Screw-steamers as evidence of a contrary nature. These vessels are generally built narrow and deep, in order to give immersion to their screws, and they are the worst of rollers. Where a wide vessel has been found to roll badly, it must not be charged to her breadth of beam *per se*, but we must find the reason for this in another direction. The immersed portions of a ship occupy the exact position, and are subject to the same laws as the body of water displaced, and the whole ship and cargo weigh exactly as much as the water, whose place the immersed portions of her occupy. If,

therefore, we do not wish to produce a condition of things at variance with the laws of nature, which I have so often referred to, we must endeavour to so model our vessels and adjust the weights of all kinds in them, as to make them conform to those laws.

66. The question of rolling, beyond the simple yielding to the slope or angles of the waves, is so largely affected by the arrangement of the weights of the ship and cargo or armament, that I think I may safely say, if a vessel can be so built, and have her weights so distributed, as to cause her to conform exactly to the slope of the waves, she will roll less and easier than under any other conditions. The average slope of a wave 30 feet high and 600 wide—that is, 300 from the centre of the trough to the crest—is about 6 degrees; whilst most vessels roll from 20 to 40 degrees—the "Warrior" 39. Compare the angles of roll of a flat body, shown at Fig. 4.—Plate II., with those of the ship at Fig. 3. A ship loaded with iron, stowed on her lower floor, rolls too quickly and heavily, and often endangers the masts. If the centre of gravity of the weights fall at or above the surface, she will have too little stability, if below the centre of gravity of buoyancy, too much. Now, as a wide shallow ship naturally stows a larger proportion of her cargo nearer to her lower floor than a deep narrow one, to say nothing of engines and coals, she is more likely to roll more and heavier. A wide vessel, therefore, having her weights distributed in reference to the centre of gravity of displacement or buoyancy, may be made to roll less than a narrow one. The builder should be able to inform the merchant how much of his cargo should be stowed above, and how much below

a given line, according as his vessel is partially or fully freighted. Regard must also be had to the horizontal position of the weights, for after the due stability of the ship has been secured, the nearer each ton of weight can be made to conform horizontally to each ton of water displaced, the better.

67. In this case the quantity and weight of matter that must pass the centre of motion of the ship with each oscillation, will be greater in a deep narrow ship than in a wide one, proving exactly the converse of the popular prejudice on this subject. This will appear by reference to Figs. 3 and 4., Plate III, which represent midship cross sections of ships having the same displacement. B. and B. are the respective centres of displacement and motion; AA. and CC. respectively represent equal angles, formed by the lines of the ship's inclination, with the line of gravitation when at rest; and DDDD. are the respective water lines. If we require any further evidence of the fallacy about broad vessels rolling more than narrow ones, we have only to press the *argumentum ad absurdum*. Will a plank float steadier on its edge than on its broad side?

68. Breadth of beam, therefore, at and below the water line, gives stability, due regard being paid to "trim." It follows, that the more we can widen a ship's base, the greater will be her stability, and she will also draw less water, and encounter less resistance in her passage through it, and from wave motion. But breadth of beam, like length, has its limits, which must be determined by the exercise of sound discretion. On this subjcct I shall have a few words more to say, when alluding to ships of war.

69. In speaking of rolling, the forms of ships' bottoms were incidently discussed (39), so that little is left to be said here. I remarked that the form of the parallelogram with the lower corners slightly rounded, and the lines next the keel curved downwards, in conformity with the doctrine of the hollow or wave line, which gently deflects the water, was the best to meet the peculiar action of wave motion, and to avert rolling. See Fig. 6.—Plate III.; also the cross sections in Plate IV.

Colonel Beaufoy's surface-experiments led him to the conclusion that a triangular-shaped body, moving in the direction of its largest axis, met with less resistance than any other form. This was a wrong conclusion, as will appear evident by reference to Fig. 5.—Plate III., where AAA. is an equilateral-triangle and BB. a parallelogram of exactly equal superficies, and of course having the same exterior dimensions exposed to frictional as well as head resistance. But the difference is in favor of the parallelogram, because all its parts will float nearer the surface, or place of least resistance in fluids.

70. It may be objected that such a form as I have laid down for the cross sections of a ship in the body, or part of greatest buoyancy, will not do for a sailing vessel. I reply that it is the best possible form for a sailing vessel, due regard being paid to the adjustment of weights, and the centre board, or sliding keel, being substituted for the standing keel. The hollow lines near the central part of the ship's bottom or bilge, will assist in giving efficacy to the centre board, or to a standing keel, should that, in compliance with ancient tradition, be preferred; and will help to keep the ship up to the wind, and prevent lee way. Yachtmen often designate fast

sailers having long, flat floors, "sailing machines," in contempt of a class of vessels they find difficult to beat, or rather which often beat those costly sea toys—modern yachts.

71. Vessels with centre boards, and level or nearly level floors, are better sailers in every wind than those having standing keels and triangular bilges. Whenever the wind is abaft the beam, the centre board can be wound up with the windlass or winch, and a material gain is experienced as regards friction. During the last six years, a large number of this description of sailing vessels have crossed the Atlantic, with cargoes, and have very generally beaten the ocean built ships (though the latter were twice, or thrice their size) by several days. Necessity, "the mother of invention," obliged the Canadians and Western Americans to build broad shallow vessels, with centre boards, so as to navigate their rivers and canals, and now they find them the best on the sea. The form given at Fig. III.—Plate III. is that almost universally adopted on the great lakes of America for sailing vessels. It wants the curves in the bilge to adapt it to ocean navigation.

72. In considering the comparative merits of broad shallow, and deep narrow vessels, we should endeavour to arrive at the average effect of all the forces on the immersed portions. To accomplish this, it becomes necessary to ascertain approximately the form which will represent an average of all the cross sections. It must also be borne in mind, that in order to maintain the same fineness of lines in the entrance and run, the same proportions of length and breadth must be preserved. Where these proportions are all carefully adhered to, it is obvious that

the forces acting on the several portions of the respective vessels will be equal and subject to the same laws.

73. To make myself more clearly understood, I beg to refer the reader to Plate I., showing in comparison with a midship cross section drawing of a ship marked "form of least resistance," those of several noted vessels. The dotted lines may be assumed to be approximations to the average forms of some of these ships. The other dimensions of my ship will be seen hereafter (77). But as all these ships—and more particularly the "Great Eastern," draw more water than the one suggested by me, and have so much more pared off the outer angles of their bilges, the average form of their cross sections will doubtless give sharper angles than those represented by the dotted lines.

74. If the cross sectional lines in the body of a ship approach a right-angled triangle, as they often do in yachts, and then run rapidly into the vertical, as they recede towards the two ends, it will be seen that the average effect will be something near that of an equilateral triangle. See Figs. 5 and 7.—Plate III., for an illustration. By carrying the level floor well fore and aft we not only obtain increased displacement, but we are able to preserve a better form for the support of all the weights. I might leave the subject here for more practical men to elaborate, but I feel that it would be incomplete, and that some things I have said may be mis-interpreted, unless I describe my own view of the best class of vessels to meet the demands of the laws of nature.

75. The size of a ship has much to do with economical working. But this must be made to conform to the particular trade for which she is intended. On long routes, and between great centres of commerce, perhaps the

only limits imposed are those dictated by convenience of management and strength. On the American route, steamers of six or eight thousand tons, exclusive of engines and coals, may not be found too large; and will, if built to float on the surface, instead of being deeply immersed, prove the most economical.

76. The only difference required to be observed between the form and construction of steamers intended for passengers and light freight, which require high speed, and those intended wholly or principally for freight, for which only moderate speed is required, is in the power of their respective engines. To insure safety, the hulls of both kinds must be equally strong. The shapes of the immersed portions, being designed on scientific principles, deduced from ascertained laws, cannot be varied to suit different rates of speed without a violation of those laws. Mr. Russell, who has contributed so much to the growing science of naval architecture, has, in this particular, fallen into an error. He says, "there is a form for every speed;" that is, a vessel intended to have a speed of ten knots must be made of a different form to one intended to go twelve. This would be to keep the question of form just where it is—an open question, incapable of being brought to a scientific solution. I reverse his axiom, and find there is a speed for every form. That is, the best form, with equal power and tonnage, will have the greatest speed. I think it must be admitted that the form offering *least resistance*—which is the essence of economy, at high speed, will likewise oppose *least resistance* at low speed.

77. For the American trade, which every year increases, I think steamers, 500 feet long, sixty or seventy

feet wide, and drawing from 10 to 15 feet, according as they are intended for passengers or freight, and from 20 to 30 feet deep, will be found the best. Their capacity would range from 5000 to 8000 tons. The drawings of such a steamer are given at Plate IV. Fig. 1. shows the deck, load and bilge lines. Fig 2. is a side view of a steamer 25 feet deep, drawing 15 feet, with a cargo, and coals for a voyage on board. Fig. 3 is a vertical longitudinal section, showing the "backbone" or mode by which I propose to obtain the necessary strength, and which will, at the same time, act as a counterpoise to the weight of the ship's sides, and thus cause her to conform to the centres of gravity of displacement. In using the term "centres of gravity," I am supposing the ship to be divided into a number of cross sections, to each of which the expression is intended to apply (65, 66, and 67). Figs. 4, 5, and 6, are midship transverse sections, of three classes of merchant steamers, referred to hereafter (89). The longitudinal drawings represent a ship whose entrance is 200 feet, or four-tenths of her whole length—her clearance and body being each 150 feet long, or three-tenths of her length each, at the load water line. By body, I mean that part having straight fore and aft lines, which oppose only frictional resistance.

78. This backbone may either be made of truss work, or of plates secured in the same manner as those used in the outer skin. In large ships the latter would be preferable—thus dividing the ship vertically from stem to stern, or so far as may be requisite to obtain the necessary strength, into two water-tight compartments, from the keel to the main deck. If by reason of shallowness in the hold, additional strength is required, it can be

obtained by springing an arch above the deck, in the manner shown in the drawings referred to.

79. By this method, the ship's keel will become the basis of strength for the whole structure, both longitudinally and transversely, instead of looking to the outer walls, as is now done, for the main support.

80. If we now divide the ship into four or five water tight cross sectional compartments, we shall have a combination of qualities never yet attained. The speed, strength, safety and comfort of such a ship, though only a fourth the size of the Great Eastern, will far surpass those of any now on the ocean, and it will probably not cost so much to build as ships of the "Persia" and "Scotia" class.

81. In designing so large a vessel, the architect should not overlook the importance of providing steam machinery for loading and unloading. This I have found from observation, has not been properly regarded in the "Great Eastern." No ship of any magnitude should carry grain in sacks, as I have remarked to be the case with the great ship—a method requiring from four to six times the time and expense in the handling, as when it is carried in bulk, and loaded and unloaded by steam power.

82. By adopting the backbone principle, no class of ships will gain so much as armour-plated vessels of war. In order to prevent that violent and heavy rolling ascribed to the "Warrior"—a characteristic that will be found to be common to all of the same class and build, there must be some means adopted to adjust the weights of the ship and armament more equalbly, so as to make them conform to the laws of nature bearing thereon (67). Here we have the best means, as I conceive, yet devised, because

we are at the same time enabled to add immensely to the ship's strength. I will venture to assert that the application of bilge "boards" or keels, as in the case of the "Warrior," "Resistance," "Minotaur," "Agincourt," and other ships, if any appreciable effect has been produced by them, it has only been to cause the ships to roll quicker and more violently, by interposing at a leverage distance from the keel serious obstructions to the passage of wave undulations, and the rising and falling of the columns or masses of water, which constantly act in opposite directions on the two sides of the ship. The use of the centre board in sailing vessels is only the toleration of a necessary evil; that is, we are compelled to violate a law of nature to prevent the occurrence of a greater evil—namely, leeway. In steamships, no such reason can be pleaded in extenuation of either class of keels. By the adoption of the backbone principle, which is a proposal neither more nor less, than to construct a vast iron girder on the line of the keel, we shall also avert that enormous strain which, according to newspaper reports, caused the "Warrior" on her first voyage to Lisbon to "leak at every butt." Besides, it will afford, in conjunction with proper timber mortar-beds, an immovable basis for towers (as shown in the drawings), capable of carrying and sustaining the recoil of heavier artillery than have yet been forged, and of the largest mortars. See Plate V.

83. When I commenced this treatise, it was my intention to have avoided altogether the discussion of questions connected with the peculiarities and details of ships of war. The importance of high speed in such vessels, however, is so momentous, that the question cannot be lightly passed over in any work intended to

point out the indispensable requisites to its attainment. As light draught is one of those requisites, I have ventured to suggest how the necessary strength may be obtained by the application of the back bone, or central girder principle. But light draught acts in reduction of the efficacy of the screw, as a propelling apparatus, in two ways. 1st. It limits the diameter of the screw; and, 2nd, it raises it nearer the surface, where the fulcrum against which it acts, or from which it acquires its power, is diminished, and is also more liable to be thrown out of the water by the rolling and pitching of a long and wide ship.

84. There is, however, one advantage gained which must be set off against the drawbacks referred to. The friction on the screw blades, which must be very great, is mitigated. But light draught for the ship is a gain which far outweighs the loss of power of the screw from the causes assigned (11). I submit for consideration the practicability of applying two or more screws to ships of war, as well as to merchant steamers, where high speed is sought.*

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* Nearly a month after this little work had been completed, namely, on the 8th of November, the *Times* gave an account of the complete success which had attended the double Screw Steamer "Flora." The "Flora" is 22½ feet wide, 160 feet long, and 15½ deep, and has two screws of 7 feet diameter each, placed under her quarters. Her speed, on her trial trip, was 14-16 knots per hour, with a nominal power of 120 horses. Her tonnage is 400. Several experiments of this kind were tried many years ago, on smaller vessels on the lakes of Canada, but as screws are chiefly used on these lakes for the carriage of freight, where high speed is not sought, the practice has not been followed up. Vide note to Paragraph 11.

The delay that has taken place in the publication of this paper enables me to quote a further instance of the complete success of the application of two screws. The "Kate," built by the same firm, Messrs. Dudgeon, Brothers,

85. By the adoption of two or more screws, masts, sails, and sailors may all be dispensed with. These accessories to a ship of war are her greatest drawbacks, when regarded in the light of an engine of war. If we can perform the work at present exacted partly from steam and partly from sails, *wholly* by the former, we shall do it with more unerring certainty, and vastly greater effect. When the age of iron and steam shall have fully arrived—the "jolly tars" and "wooden walls" will have passed away together, and the nation will save some millions annually thereby. We shall only want steersmen, navigators, and stokers to work our ships, and gunners and marines to fight them.

In order to get rid of pre-conceived ideas about the forms and requisites of ships of war, which hang like a nightmare on the progress of national ship-building, it is absolutely necessary that we should simply regard them "as engines of war," adapted to the indispensable requirements of navigation and rapidity of movement.

86. I have ventured to make some drawings suggestive of steam "rams," armour plated, carrying broadsides,

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of Limehouse, performed her trial trip on Saturday, the 28th February, and the *Times*, of the following Monday, says:—"The trial trip proved to be a great success, for by the working of the two screws, one each side of the dead wood, a perfect steering power was obtained, with the ship going either ahead or astern, without any assistance from the use of the rudder; and by reversing the screws—that is, working them in opposite directions—the 'Kate' turned round upon her centre as upon a pivot, after the manner of a turntable. She was also very fast under steam, with engines only a little more than one-fourth horse-power to tonnage—great capacity of hold, and light draught of water." The "Kate" is an iron vessel of 500 tons capacity of hold, is 165 long, 22½ beam, 13½ deep, and drew on trial 7 feet 2 inches; is flat in the floor, and without keel; speed not given.

and having turrets, as recommended by Captain Coles, and now so extensively used in America. The object aimed at being light immersion, great strength and high speed combined, I propose the use of four screws. Fig 1.—Plate V. shows the deck, water and bilge lines of such a vessel, intended to go in either direction. Figs. 1 and 4, at a scale of 50 feet to the inch, represent a ship 500 feet long, 70 feet wide, and 35 feet deep. Without wishing to enter into details, I have shown the manner in which the screws may be worked and the vessel steered. In so large and costly a ship, there may be two steering apparatuses (one at each end), to guard against the risk of accident. With four screws, however, a ship might be worked almost without a rudder. (See note to paragraph 84). At scales of 40 and 30 feet to an inch, these drawings (1 and 4) will represent vessels of the respective lengths of 400 and 300 feet, and 56 and 42 feet beam each. Thus, after the suggestion of Mr. Scott Russell, I propose to have three classes of war ships, which may be used as rams with turrets, or to carry broadside, or both combined.

87. Figs. 2 snd 3.—Plate V. exhibit midship cross sections of first and second classes, showing their relative sizes, and also how beds of timber may be used to mitigate the recoil of very heavy mortars and guns. It must not be inferred from the illustration, that I propose, except in extreme cases, such as the use of the 36-inch mortars at Woolwich, to fill the entire midship cross-section with baulks as suggested.

The planning of details for the construction and working the turrets are not within the scope of this paper. Fig. 4 shows a side elevation of such a ship, having both broadsides and turrets. AAAA. are gun turrets, and BB. mortar turrets. CC. are wheel houses, and DD. are lifting rudders, nearly counterbalanced by weights, so as to be easily raised into chambers, when not in use. These chambers may be so constructed, that in case of accident the rudders may be unshipped and replaced by spare ones. This, however, may be regarded as an unnecessary precaution, as their position and mode of arrangement place them almost beyond the risk of accident of any kind, whilst the vessel having them may, by a well directed blow or shot from a heavy gun, disable an enemies' rudder. A ship built on the plan I have suggested, even if she drew 20 feet, could float with her rudder down, wherever the "Warrior" can float; and if perchance she got into shoal water and her rudder touched, it would readily rise into its chamber, without injury. In such cases the vessel must be steered by her screws, which would also be available in ascending rivers or turning in emergency. The two rudders acting in aid of the four screws would give the most complete and ample control over the vessel in action, that can possibly be desired.* Another important advantage is claimed for this kind of rudder. By being placed below the ship's keel near the end, the blade of the rudder will always be acted on uniformly by the water, which must be admitted to be a very great desideratum. Fig. 5 is merely suggestive of some details, and has been supplied by a practical friend who approves of my plans.

* The reporter of the *Times* in giving a description of the performances of the "Kate," on the 28th of February, 1863, speaking of the importance of applying two screws, says, "In fact, the whole question has such an important bearing, look at it in what light we may, whether as a power of steering ships of commerce under steam, when threading tortuous rivers, or ships of

88. The question as to the best mode of applying four screws—whether so as to drive them by separate and unconnected engines, or by long shafts made to connect and disconnect at pleasure in midships, is one on which I cannot offer an opinion. In ships of great length and breadth, the rolling may so diminish the dip of the screw as to render a connection of the shafts on each side desirable, in order that when one screw is rolled or pitched partially out, the other may receive the power of both engines. The conditions of such a vessel, as I suggest, may be summed up as follows:—

1.—A displacement of 10,500 *tons* to be disposed of as under:—

Weight of Hull - - -	3,500	Tons.
Ditto of Engines, &c. -	1,300	,,
Armour Plating, &c. -	1,350	,,
Armament, Stores, &c. -	1,350	,,
Coals - - - - - - -	3,000	,,
Total	10,500	Tons.

2.—Ability to carry thirty 100 pounder guns in broad side, and six 500 pounders, or four such, and two large mortars in turrets.

war when engaged with the enemies' ships or forts, that the great interest that has been displayed by the Admiralty and many naval and scientific men, in the trials of the two vessels, the 'Flora,' in November last, and the 'Kate,' on Saturday, is fully accounted for." The drawings, exhibiting the details and mode of working lifting rudders, having received the warm approval of two experienced and practical Naval Architects—the one an English, and the other a French gentleman, have been made the subject of an application for a patent. Hence they are not here given. The principle is not claimed as new, but the mode of applying it, so as to afford the utmost degree of efficiency and command over the vessel.

3.—The power to move with equal facility and speed either end foremost.

4.—A draught of water (with full armament and stores for a year's ordinary requirements, and 3000 tons of coals, at commencement of voyage) not to exceed eighteen feet.

5.—18 Nautical miles per hour under full steam, or 432 per day, on a consumption of 200 tons of coals giving a supply for 15 days, and a run of 6450 knots. With two screws working at full power, she would make 15 knots per hour, 360 per day, consuming 100 tons of coals, and giving a run of 10,800 knots in 30 days. Under half steam, with two screws, her speed may be set down at 12½ knots per hour, 300 per day, with 75 tons consumption of coals—to last 40 days, and giving a run of 12,000 knots. One screw* at full speed, consuming 50 tons of coals per day, would give about 10½ knots per hour, (the "Great Eastern" drawing 27 feet, made 11½ knots with her screw alone), 250 per day, and coals for a run of 15,000 miles in 60 days, and under easy steam something more. These estimates are founded on the experience of Lake steamers of *light draught*, such as the "City of Buffalo."

6.—Ability, with 1000 tons of coals to ascend rivers and hold towns in subjection wherever the draught of water is 17 feet.

89. The following table exhibits the relative dimensions, power, estimated speed and economy of three classes of merchant steamers, to which is added some particulars of the "City of Buffalo," American Lake vessel.

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* The "Kate" and "Flora" steered as well with one screw in motion as with two.

		1st.	2nd.	3rd.	City of Buffalo.
Length	(Feet)	500	400	300	340
Breadth	(„)	70	56	42	40
Depth to bottom of keel	(„)	30	25	20	16
Load draught	(„)	17½	15	12½	10
Ditto to underside flat floor	(„)	15	13	11	16
Engine power	(Nominal Horse)	1250	1000	650	500
Speed (estimated)	(Knots)	18½	16½	14½	19
Displacement	(„)	10500	6100	2650	
Weight of Hull, &c.	(Tons)	3600	2750	1200	
Ditto Engines, Boilers, &c.	(„)	1150	850	600	
Freight capacity	(„)	5000	2000	500	1000
Coals per voyage, Liverpool to Quebec (2500 m.)	(„)	750	500	350	250
Time (estimated)	(Days)	6	7	8	5½
Coals per ton of freight	(Lbs.)	336	555	1600	560

It will thus be seen that 10 third class ships would be required to carry as much cargo as 1 first class, and 4 to carry as much as a second class. The "City of Buffalo" would not compare so favourably, either in speed, or economy, if made strong enough for an ocean steamer.

90. Before concluding, I wish to offer some remarks suggested by reading Mr. Andrew Murray's recent and valuable work on ship-building. At page 54, Mr. Murray sums up the preliminary knowledge which a naval architect ought to possess, as follows: "Before a naval architect lays down the lines of a vessel, he is aware of the purposes for which she is intended. He knows the armament, cargo, &c., which it is intended she shall carry. These being known as well as her weight at launching, since the specific gravity of the materials of

which she is composed is known, the first requirement is to make the total weight and corresponding displacement, when ready for sea, agree with the required draught of water.

"We know that the displacement depends on the product of the three dimensions, *length*, *breadth*, and *depth*. The naval architect therefore proceeds to form a rough design, probably in comparison with some well known ship of the same class, and he will then proceed to adopt this design, as far as practicable to his own calculations, at least as far as necessary."*

91. These suggestions, coming from a scientific architect, in the service of the Admiralty, and the author of a standard work on ship-building, in my judgment, show conclusively the necessity of another step being taken towards the establishment of scientific data, from which to deduce more certain and fixed principles respecting the designs of ships. Being thus armed, the naval architect should be able to calculate, from recognized rules, the best form and proportions of a ship of

* This method of designing a ship is according to the "rule of thumb," on which the Rev. J. Woolley, in his able paper on "the present state of the Mathematical Theory of Naval Architecture," read before the Ins. N. A., 1860, remarks as follows :—

"Construction by the rule of thumb means, I apprehend, the adoption of some approved lines, with little or no modification. Those designers who resort to this mode are pretty safe, and may generally calculate on producing a good vessel ; *but they make no step in advance of existing practice, they add nothing to existing science ; and whenever the majority of designers are of this class, and persist in all their ships in perpetuating some received model, refusing to accept improvements, because unable to judge of their real merits, the practice of ship-building must on the whole be stationary, and the country, where this state of things exists, must be content to see her ships surpassed by those of another country.*'

a given tonnage, without reference to any other ship. The best form, according to my theory, is that which opposes the least resistance, and consequently requires the least power and least expense to propel, and which also rolls the least, and this form I have endeavoured to deduce from the laws of nature, so far as they relate to the questions connected with ships.

Mr. Murray, however, proposes to deduce the forms of his ships some how or other, from "a rough design made in comparison with some other well known ship," &c.

92. Again, at page 56, Mr. Murray states that "the actual, or absolute resistance per square foot of surface, or of midship section, remains undetermined on account of our ever varying forms, given to the bodies of ships, before and abaft the midship section." Nevertheless the rule to estimate for horse-power is based on this uncertain and unsatisfactory knowledge (21). See also my remarks at 52.

93. At page 58, Mr. Murray further remarks: "It has before been shown that calculations founded on the angles of incidence at the bows of a ship, to determine the exact resistance, do not correspond with the results obtained by experimental researches, or with practice." How could this be otherwise, when such experiments have been made either in ignorance, or disregard of the most important laws of nature relating to this subject? Not even an allusion has any where, that I can discover, been made to the rapid increase in resistance of all kinds opposed to bodies (moving horizontally) at each foot—aye, each inch we descend below the surface. Perhaps I have over-rated this; but even if I have, its importance will be found to be very great.

94. "Attempts are still being made" says Mr. Murray,

"to determine the exact resistance to ships of different forms, moving at different velocities, and valuable additions to our knowledge in this respect may be looked for. But the subject is one beset with difficulties." These difficulties, Mr. Murray goes on to specify, as being the state, or qualities of the immersed surfaces, inasmuch as a vessel has been known to have her speed decreased 20 per cent. by foulness of bottom—and besides this, there will be imperceptible variations in form.

95. Mr. Murray speaks of a narrow ship as having an easier roll than a wide one—without noticing the question of centres of gravity and adjustment of weights, on which the question of rolling mainly hinges (67 and 82).

96. I have been led into making these observations on Mr. Murray's valuable work, or rather on his suggestions to Naval Architects, as to the best means of obtaining a starting point for their designs, because they embody the latest, and hence it may be presumed, most approved ideas on the subject. Mr. Scott Russell, although leading the van in the revolution that is taking place in Ocean Steam Navigation, as well as others of great eminence in scientific investigation, has made similar suggestions.

97. The present method of relying wholly on data, obtained from the results of numerous steam ships, may lead to improvements in the models and construction of future ships, *but it can never establish a new system based on scientific principles.* To do that, we must find out the laws which bear on the question, irrespective of any particular vessel already in existence. We may then avail ourselves of such acquired data for purposes of reasoning and comparison.

98. In my judgment, it remains for the governments of the great maritime nations to initiate the necessary experiments to build up a new and truly scientific School of Naval Architecture.* The saving that will thus be effected will be immense. The economization in international and other maritime commerce will lead to results as important as those produced on inland traffic by the general introduction of railways. In other words, what railways have done on the land, the more rapid and cheap navigation that will ensue from the new and improved system of ship-building and propulsion, will accomplish on the trackless paths of ocean.

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* Since the nomination of Mr. E. J. Reed to the Chief Constructorship of the Navy, it has been stated that the Admiralty, on his recommendation, have decided to constitute such a board of reference and examination, to relieve themselves of the labour of deciding on the numerous applications made by inventors and others having plans to submit. A board of this sort, properly constituted, and having for its object, in connection with its other duties, the conducting of a series of experiments to ascertain the laws of nature, as they bear on the science of ship-building, would, no doubt, prove of the utmost advantage in every way. It is submitted that the better plan will be, to have this Board attached to the Patent Office, and charged with the duty of examining all applications for patents—giving the power to reject such as are not novel, or may be merely fanciful and useless. The Board should be clothed with all the necessary powers of a Judicial Tribunal in respect to taking evidence, &c. From this "Inventor's Court" an appeal might be granted to the higher Tribunals of the country, where parties feel agrieved. In a Bill prepared by the writer for the Canadian Government—and which he hopes soon to see substituted for the present wretched patent law of the Province—he has provided the machinery for a Tribunal of this kind. The advantage of having the Board of Referees and examiners attached to the Patent office, will be that applications to other Government departments, for the adoption of new patented, or unpatented inventions, may, in like manner be referred and reported on to the proper authorities.

ADDENDUM.

The sheets containing my observations on Ocean Waves, the Rolling of Ships, &c., had gone through the press before I received the third volume of the transactions of the Institution of Naval Architects, containing some learned papers on these subjects. I do not, however, see that they add much of practical value to the previous stock of information. Still more recently I have had the pleasure of attending the meetings of that Institution, at its session for the current year.

At one of these, Mr. Scott Russell delivered a very able discourse on the Wave and Rolling questions. At the opening of his address, he alluded to the observations formerly made by Dr. Woolley, which I have quoted in the preface, respecting the want of accurate knowledge of the laws of nature, and congratulated the association on the progress since made in their discovery.

It would be presumption in me to gainsay the correctness of this assumption. Indeed, the theory respecting wave motion, to which Mr. Russell has given his adhesion, is so beautiful, and explains so much that required explanation, that I hope future experiments may fully establish its correctness. But the subject is so deep and complicated, that I shall not attempt to offer any observations on Mr. Russell's views, until his paper shall appear in print, which I hope may be at an earlier period than that to which the publication of the transactions of the Institution are usually deferred.

I will, however, venture to express the opinion, that before these questions engage any further mathematical elaboration, the suggestions I have made, and which it has been my chief object in publishing this paper to make known, should be acted on. It is, I think, undeniable, that the basis for all reasoning on these subjects, must be sought in the laws of nature; and these can only be ascertained by numerous and well-conducted experiments. On this point, I take the liberty of again quoting from Dr. Woolley's admirable paper before referred to. He says, "The mathematical expression, for the time of rolling, affords very little clue to the behaviour of a vessel. Ships in which this element is nearly, if not quite, the same, according to calculation, are as wide as the poles asunder in their actual performance at sea; so that while one, in a heavy sea, rolls with considerable ease, another is so uneasy, as seriously to endanger her masts. One cause of this may be, as has already been observed, that, in order to bring the case within the grasp of mathematical analysis, so many assumptions and limitations are necessarily introduced, as to ignore the form of the vessel, except just above the water line." Now, in view of such an important admission from a great mathematician, and seeing also that Mr. Scott Russell and Mr. Froude, two others equally great in scientific lore, "differ as widely from each other"—to use Dr. Woolley's words—"as the poles," it seems to me, that before wasting more time in these learned discussions, it will be wise to find, in the discovery of the laws of nature, a starting point that shall enable all scientific men to arrive at a common solution of every problem connected with the motion and resistance to ships.

I was rather surprised to hear Mr. Froude state his experience of the rolling of the "Great Eastern," without noticing the direction of the ship in relation to the movement of the waves which caused it. He said that the worst rolling fit she had during his voyage in her to Quebec, was in a comparatively smooth sea—a circumstance quite in accord with my own experience in the same ship. In my case, I remarked that we were running, as nearly as possible, in the direction of the waves, and the cause of this *seemingly* unnatural state of things I have endeavoured to explain at pages 23 and 24. On one of these occasions, I went down to the wheel-platform, the better to observe the height of the waves, and their action on the vessel. The undulations, which were unrippled, for we had no wind at the time, and which were scarcely noticeable from the high decks of the "Great Eastern," I estimated to be fully eight feet high, from hollow to crest. I now leave it to Mr. Froude, and the other learned writers on the subject, to say whether I have given a satisfactory solution of this phenomenon, so often noticed by ocean travellers, as well as of the best mode to check the accumulating roll. Had the ship been steaming longitudinally with the waves, or, indeed, in almost any other direction than the one she happened for the time to hold in reference to them, or had she been going faster, or slower, the synchronism which produced the rolling would probably not have occurred.

In making these observations, I must plead ignorance of the mathematical processes adopted by Mr. Froude to establish the amount of stability of ships. Much of his reasoning is locked up in a language which I once imperfectly understood, but which has, for want of practice, become Hebrew to me. But I think their value must be much lessened when we hear Mr. Scott Russell, equally learned, taking direct issue with his brother mathematician on the most prominent points of the subjects under consideration. Another more practical member of the association, no doubt, remarked, that it had always been found when theory and practice differed, the latter was right. Of course, this must be the case if the theory be merely hypothetical, or good guess work. But practical men ought not to despise science, or sneer at scientific experiments; nor should scientific men lay themselves open to the censure of practical men, by offering theories deduced from uncertain premises, which are always liable to be impugned, or overthrown.

I offer no opinion on the controversy between Captain Coles and Mr. Reed, about the comparative merits of their respective plans for fighting heavy guns in cupolas or in concentrated broadside batteries; but will simply express it as my belief, that Mr. Reed's ships building at Deptford, will be deficient in the necessary speed to make them formidable opponents. Before two years pass away, there will be many ships in foreign navies, whose speed will come up to my estimates. But I entirely concur in Mr. Russell's opinion that both Mr. Reed's and Captain Cole's plans are worthy of trial, and will produce vessels of great value for particular services, where high speed, long voyages, or heavy armaments are not required. My principles relate mainly to the conditions necessary to obtain these latter indispensible requisites as well as economy, and are applicable to every class of steam vessels—without reference to the method of armament, or manner of fighting it. High speed and ecomomy are the first and most important objects to be attained. This was fully conceded by the Naval Architects at their late meeting, and the damage done by the Alabama, against which a whole fleet of war vessels had been sent without being able to capture or destroy her, was cited in proof of it.

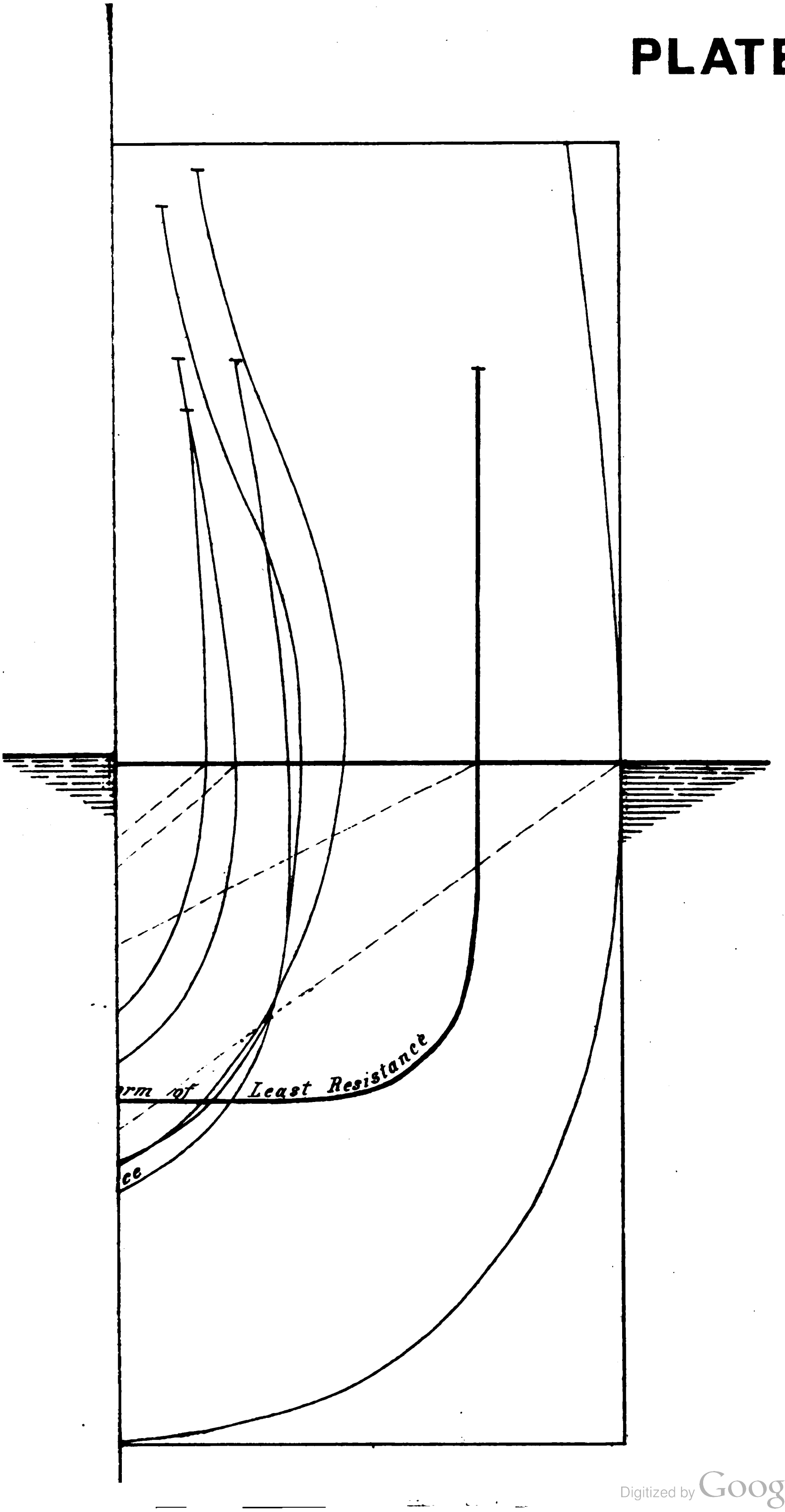
With regard to the proper position for the centre of gravity of a ship and her weights, the general opinion seemed to favour the assumption that it should be in or near the water line, though no definite reasons, or data were given for it. In the "Warrior" it was stated to be two feet below the water line; but as she rolls unusually heavy angles, in consequence of the momentum imparted by the great weight of her armour plating acting at a leverage distance from the centre of motion, no useful conclusion can be drawn from such data. The question must therefore still be regarded as an open one, to be ascertained by future experiments. In my judgment, much will be found to depend on the distribution of the weights horizontally, even in the same form of vessel, as well as in vessels of different forms. I consequently assume that the centre of gravity of vessels must be raised, or lowered within certain limits to meet the conditions imposed by the horizontal distribution of the weights, armament, and cargo, (66) and that no point can be definitely assigned, as being applicable under all circumstances.

I was unfortunately absent from the Institution when

Mr. Russell read his paper "on the education of Naval Architects in England and France," but came in in time to hear the discussion on it. The general impression seemed to favour the early establishment of a school for this purpose, at Portsmouth or Greenwich, under the auspices of the institution. This will be a step in the right direction, provided the school is placed under the control and professorship of men competent to take a large and unprejudiced view of the whole science of naval construction. Otherwise, it will only serve to perpetuate old falacies and stop the way to actual improvements. The lectures might be open on certain conditions to all who may choose to attend.

J. & I. Tirebuck, Printers & Lithographers, Monkwell Street, City, E.C.

PLATE I.



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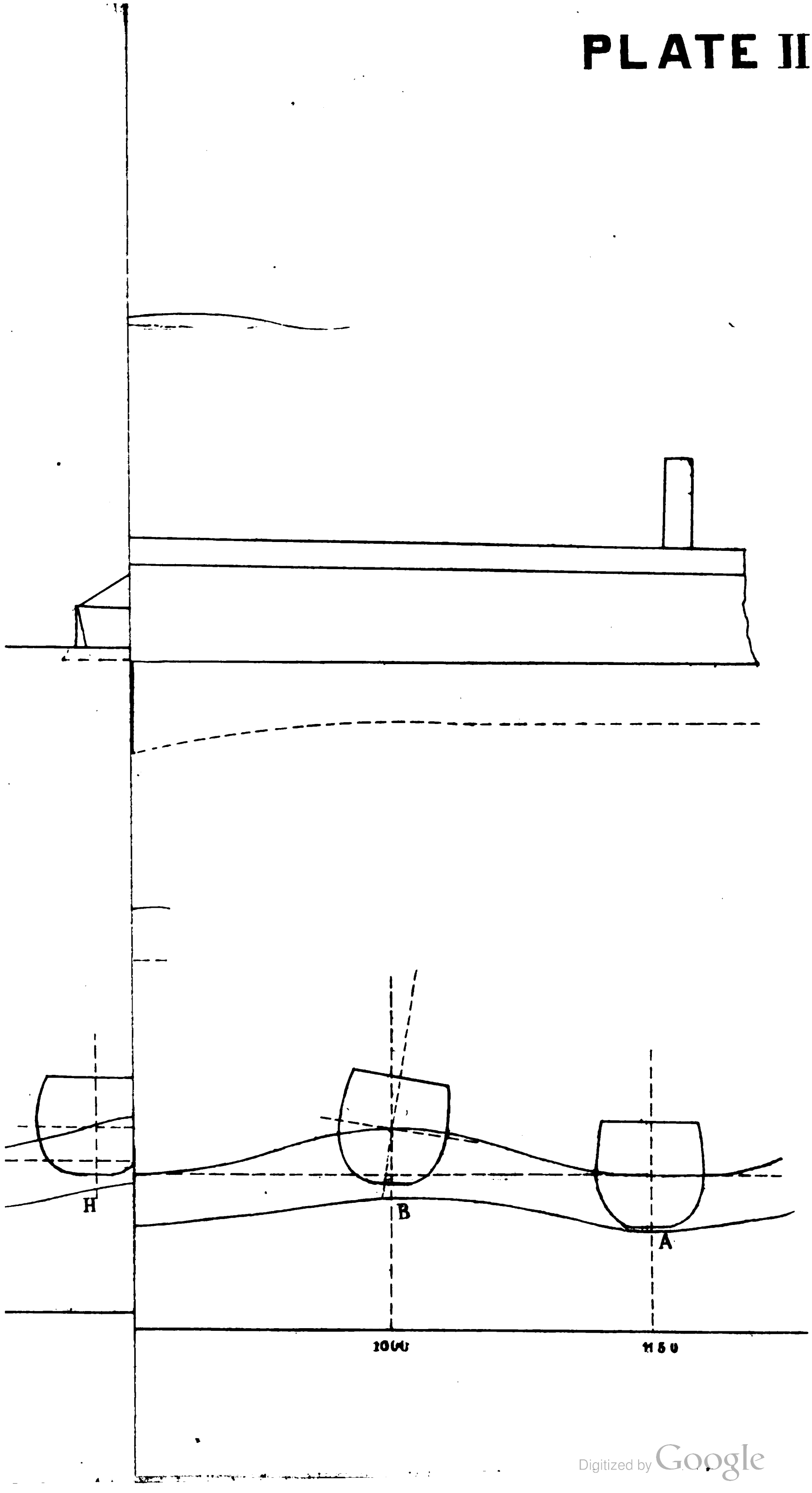

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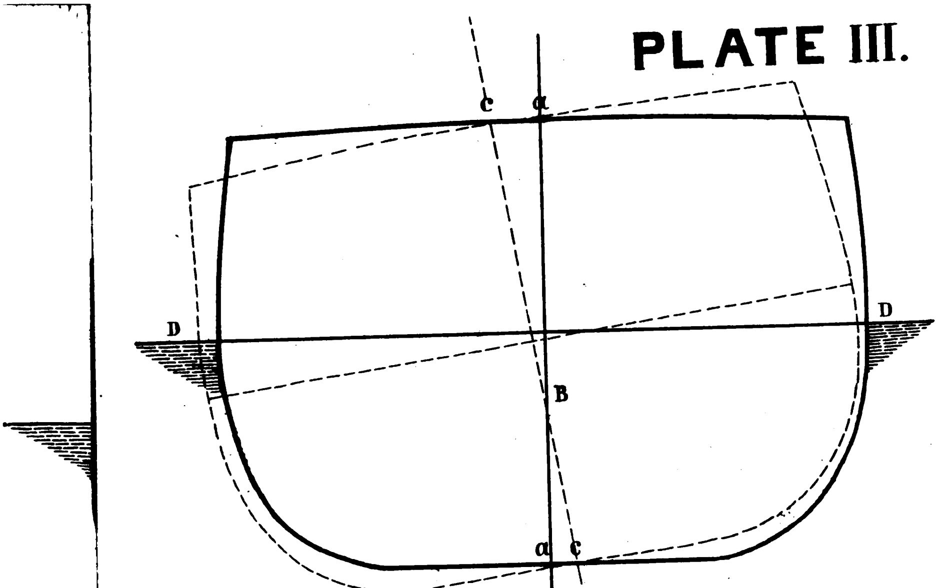

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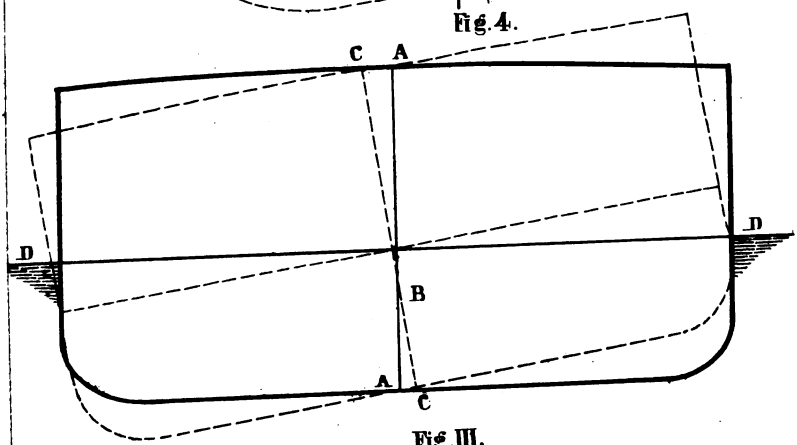

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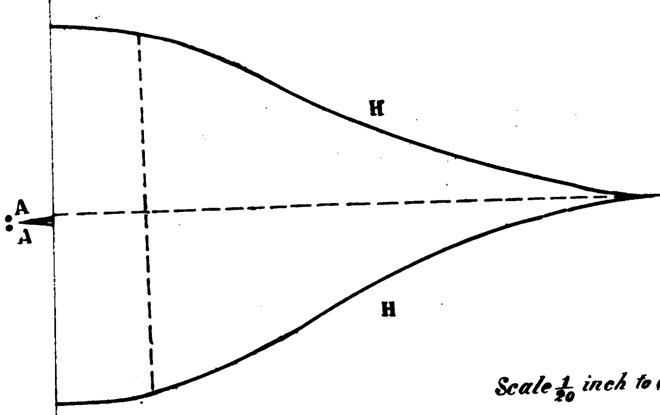

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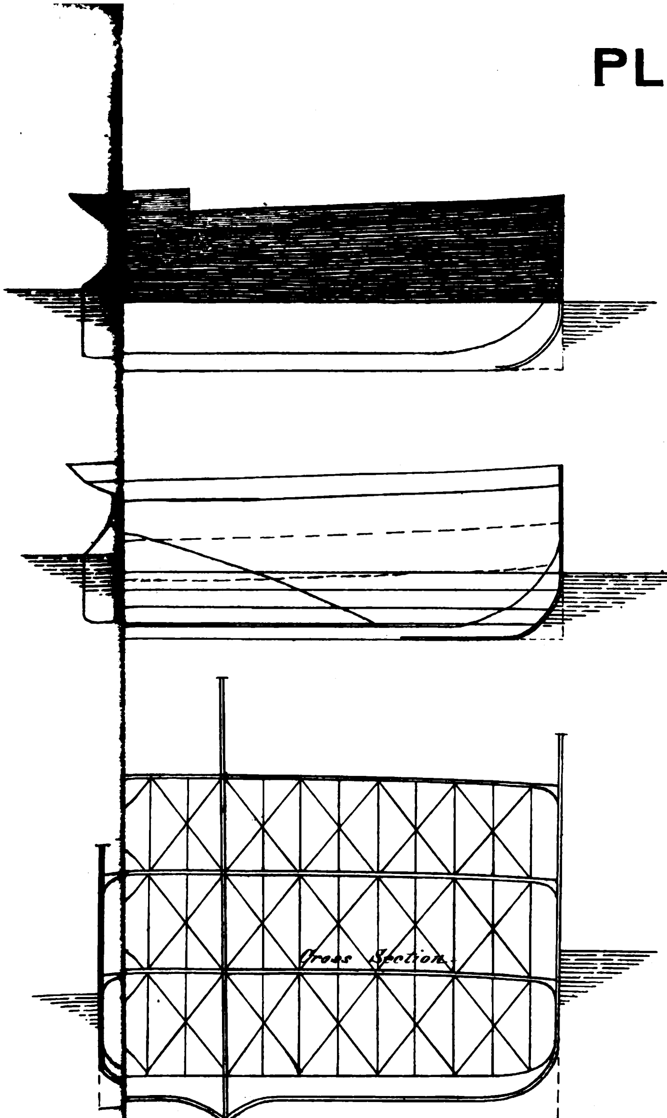

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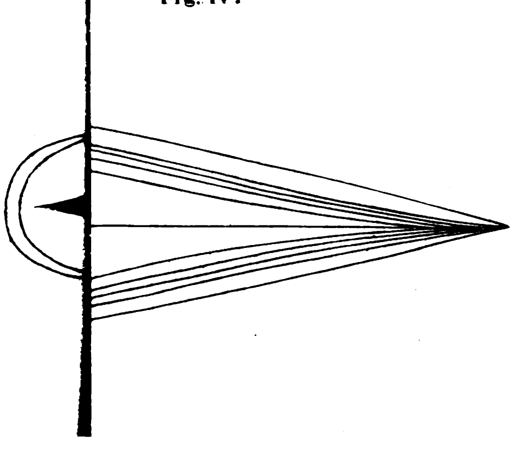

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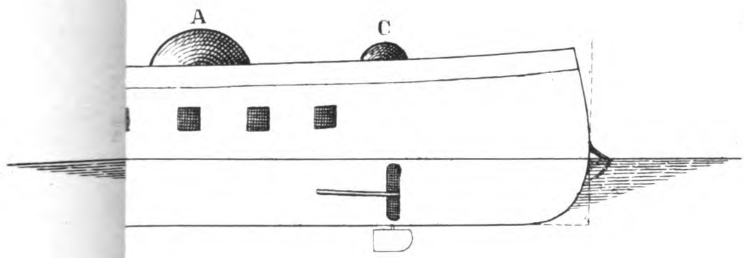

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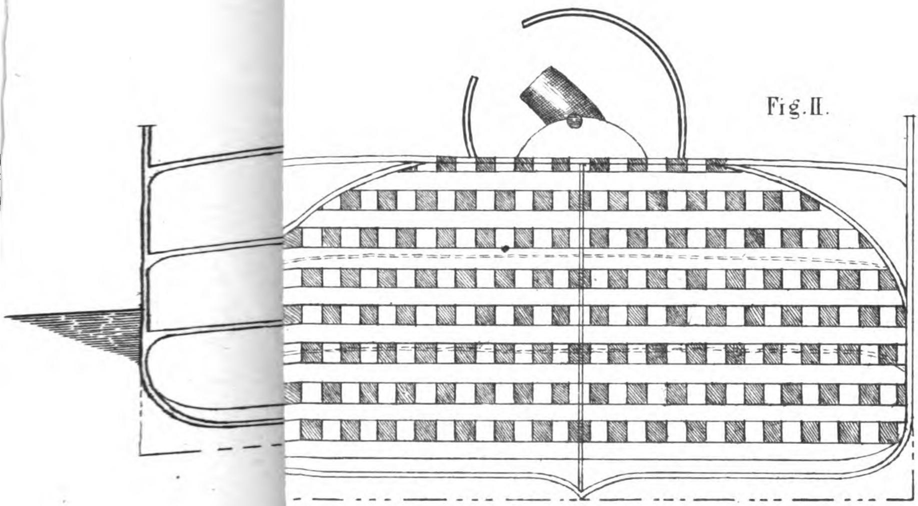

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