

sider the two substances identical. Treated with hydrate of potassium, this nitrile is converted into an acid which M. Merz describes under the name of *naphthaline-carboxylic acid*. The opinion expressed by this chemist, that his acid might be identical with the one observed by myself, I am inclined to adopt, although there are still some few discrepancies in our observations to be elucidated. M. Merz states that the fusing-point of his acid is at 140° , whilst the acid examined by myself fuses at 160° . In order to remove, if possible, this discrepancy, I have, since I saw M. Merz's paper, again and repeatedly taken the fusing-point of menaphthoxylic acid, but always with the same result. Possibly the fusing-point of the acid prepared by means of a sulphonaphthylate may be found somewhat higher when the compound is carefully purified by repeated crystallization from alcohol.

- II. "On the Relation of Form and Dimensions to Weight of Material in the Construction of Iron-clad Ships." By E. J. REED, Chief Constructor of the Navy. Communicated by Prof. G. G. STOKES, Sec. R.S. Received March 3, 1868.

(Abstract.)

The object of the Paper is to show that the proportion of length to breadth in a ship, and the form of her water-lines, should be made in a very great degree dependent upon the weight of the material of which her hull is to be constructed—that an armour-plated ship, for example, should be made of very different proportions and form from those of a ship without armour, and that as the extent and thickness of the armour to be carried by a ship are increased the proportions of length to breadth should be diminished, and the water-lines increased in fulness.

It is highly desirable that this subject should receive the attention of men of science, not only because it bears most directly upon both the cost and the efficiency of future iron-clad fleets, but also because it opens up a theoretical question which has hitherto, I believe, received absolutely no consideration from scientific writers upon the forms and resistances of ships, viz. the manner in which the weight of the material composing the hull should influence the form. Prior to the design of the 'Bellerophon,' the forms of ships were determined in complete disregard of this consideration; and even the most recent works upon the subject incite the naval architect to aim always at approaching the form of least resistance. The investigations given in the Paper show, however, that the adoption of a form of least resistance, or of small comparative resistance, may, in fact, lead to a lavish outlay upon our ships, and to a great sacrifice of efficiency; while, on the other hand, the adoption of a form of greater resistance would contribute in certain classes of ships to greater economy and to superior efficiency.

In order to indicate clearly, but approximately only, the purpose in view, the author first considers the hypothetical cases of a long and a shorter ship, both of which are prismatic in a vertical sense. The length of the long ship is seven times its breadth, and its horizontal sections consist of two triangles set base to base; the length of the short ship is five times its breadth, the middle portion being parallel for two-fifths of the length, and the ends being wedge-shaped. It is assumed also that at a speed of 14 knots the long ship will give a constant of 600, and the short ship a constant of 500 in the Admiralty formula,

$$\frac{\text{speed}^3 \times \text{mid. section}}{\text{indicated horse-power}}.$$

The draught of water is in each case 25 feet, and the total depth 50 feet.

It is taken for granted that the form of the long ship has been found satisfactory for a ship of such scantlings that we may consider her built of iron of a uniform thickness of 6 inches, the top and bottom being weightless.

Now, let it be required to design a ship of equal speed, draught of water, and depth, but of such increased scantlings (whether of hull proper or of armour) that the weight shall be equivalent to a uniform thickness of 12 inches of iron, the top and bottom being weightless as before. First, the new ship has the proportions of the long ship given to her; and secondly, those of the shorter ship. In each case the engines are supposed to develop seven times their nominal horse-power, and to weigh (with boilers, water, &c.) 1 ton per nominal H.P. The coal-supply in each case equals the weight of the engines, so that both ships will steam the same distance at the same speed. But as the equipment of the smaller ship will be less weighty than that of the larger ship, we will require the larger ship to carry 2000 tons, and the smaller 1500 tons additional weights.

Assuming the breadth extreme in each case to be the unknown, we can, from the Admiralty formula given above, deduce an expression for the Indicated Horse-Power; thence, under the assumed conditions, the weights of engines and coals can be found; and these being added to the weights of hull (calculated on the assumption that the sides are of 12-inch iron), and to the weights carried, give an expression for the total displacement, in tons, of each ship. Another expression is found for this displacement by finding the weight of water displaced. The two expressions are equated, and a quadratic equation is formed, from which the breadth extreme is determined; and from it all the other values can be found.

The accompanying Table shows the results obtained by this method for the two classes of ships:—

	Long ship.	Shorter ship.
Length extreme	581 feet.	342 feet.
Breadth „	83 „	68½ „
Nominal horse-power	1350 H.P.	1337 H.P.
Indicated „	9450 „	9359 „
Weight of hull	12570 tons.	7576 tons.
„ engines	1350 „	1337 „
„ coals	1350 „	1337 „
„ carried	2000 „	1500 „
Total displacement	17270 „	11750 „

It will therefore be seen that, by adopting the proportions and form of the shorter ship, a ship of the required scantlings and speed will be obtained on a length of 342 feet and a breadth of 68½ feet; whereas if the proportions of the long ship are adopted, the ship, although of the same scantlings and speed only, will require to be 581 feet long and 83 feet broad, the steam-power in both cases being as nearly as possible the same.

Considerations of this character, worked out more fully, led the designer of the ‘Bellerophon’ to depart so considerably from the form and proportions of the ‘Warrior.’

The next part of the investigation is based upon the official reports of the measured mile trials of the ‘Minotaur’ and ‘Bellerophon’ when fully rigged, and upon calculations made from the drawings of those ships. It is assumed that a prismatic vessel having the same mean draught as each of these ships, and having the same form and dimensions as the mean horizontal section (which equals the mean displacement in cubic feet, divided by the mean draught of water), will give the same constant as the ship herself, at the assumed speed of 14 knots, which, as nearly as possible, equals the speed obtained by both the ‘Minotaur’ and ‘Bellerophon’ on the measured mile. For each ship the weight of the armour and backing is supposed to be uniformly distributed over vertical prismatic sides of the dimensions of the armoured sides; and the weight of hull is similarly distributed over vertical prismatic sides of the dimensions below water of the mean horizontal section, and above water of the armoured side. The actual weights carried by the ships are thus transferred to what may be termed representative prismatic vessels, having the same constant of performance as the ships. The detailed calculations in the Paper show that the weight per square foot of the material in the hulls of the two ships, when distributed over the sides of the representative prismatic vessels, is very nearly the same for both; and the same holds with respect to the weight per square foot of armour and backing. The ‘Minotaur’ is rather heavier in both respects; but, for the reasons given in the Paper, the means of the values found for the two ships are taken, and are found to be

Weight per square foot of hull = .152 ton.

„ „ „ armour and backing = .11 ton.

The questions next considered are these: presuming it to be necessar

to build another ship, which shall also steam 14 knots, carry the same proportionate supply of coal to engine-power and proportionate quantities of stores, but shall have her armour and backing of double the weight of armour and backing of the 'Bellerophon' and 'Minotaur,' then (1) what will be the size, engine-power, and cost of the new ship of the 'Minotaur' type, and having the same mean draught and depth of armour? and (2) what will be the size, engine-power, &c., if built on the 'Bellerophon' type, and having her mean draught and depth of armour?—this condition implying, of course, that the same constants of performance as before will be realized in each case. On account of the great disproportion in size between the two types of ship, it is obvious that the smaller one will require much less weight of equipment. It is assumed, therefore, that the additional weights of the smaller ship (exclusive of engines, boilers, and coals) amount to 700 tons, and those of the larger ship to 1000 tons. The developed power of the engines, proportionate supply of coal, and the weight of engines &c. are taken exactly the same as in the hypothetical case first given.

By proceeding with the investigation for each case in a way similar to that sketched for the hypothetical ships, only treating the breadth extreme of the mean horizontal sections of the new ships as the unknown, the following results are obtained. The new ship of the 'Minotaur' type which fulfils the required conditions will be nearly 490 feet long, 72½ feet breadth extreme, and have a total displacement of 14,253 tons; while the new ship of the 'Bellerophon' type will be 380 feet long, 71 feet breadth extreme, and have a total displacement of 10,950 tons. It thus becomes obvious that a correction is needed in the weight per square foot of hull in the new ship of the 'Minotaur' type, as her length has been so greatly increased: it is considered that an increase of at least 10 per cent. is required; and this is the allowance made. On the other hand, the new ship of the 'Bellerophon' type is still shorter than the 'Minotaur' herself, and the displacement is not much greater than the actual displacement of the 'Minotaur'; so that no correction is needed in her weight per square foot of hull. When the correction has been made for the new ship of the 'Minotaur' type, the final results in round numbers are as follows for the two classes of ship:—

	New ship of 'Minotaur' type.	New ship of 'Bellerophon' type.
Length	510 feet.	380 feet.
Breadth	75 "	71 "
Tonnage	13770 tons.	8620 tons.
Nominal horse-power	1080 H.P.	1080 H.P.
Indicated "	7560 "	7560 "
Weight of hull	7100 tons.	4460 tons.
" armour and backing ..	5190 "	3630 "
" engines and coals	2160 "	2160 "
" stores carried	1000 "	700 "
Displacement	15450 "	10950 "

Taking the cost per ton at £55 (which is the average cost per ton of tonnage for the hulls of armour-clad ships), the saving made by adopting the new ship of the 'Bellerophon' type would amount to £283,250, or considerably more than a quarter of a million sterling. It must also be considered that the ship of the 'Bellerophon' type would cost less for maintenance and repair, and be much handier in action.

The last investigation in the Paper is purely theoretical, and consists of a determination of the dimensions which would be required in two ships of which the horizontal sections are curves of sines, and which are prismatic vertically, if they were built with the same weight per square foot of hull (say 1 ton) as the 'Bellerophon,' but carried twice the weight of armour per square foot (say $\frac{6}{25}$ ton). In these cases the bottom is taken to have weight as well as the sides; the speed for both is 14 knots, the draught of water is 25 feet, and the depth of the armoured side 24 feet. One of the ships is seven times her breadth in length, and the other is five times. Professor Rankine's rule for the calculation of horse-power and speed is employed; and the same conditions of engines &c. are assumed as have been indicated previously. The larger ship carries 1350 tons additional weights, and the smaller 900 tons.

The results obtained for these ships are as follows, when expressed in round numbers:—

	Larger ship.	Smaller ship.
Length	585 feet.	425 feet.
Breadth	84	85
Nominal horse-power	1267 H.P.	980 H.P.
Indicated "	8890	6860
Weight of hull	7586 tons.	5540 tons.
" armour and backing ..	6124	4470
" engines and coals	2540	1960
" carried	1350	900
Displacement	17600	12870

These results are very different in detail from those obtained in the cases based on the actual trials of the 'Bellerophon' and 'Minotaur.' The 2000 H.P. which is needed by the larger ship above the power required by the smaller ship, is principally due to the difference between the immersed surfaces of the two ships, and is spent in overcoming friction. The immersed midship sections, it will be remarked, only differ by a very small amount.

This last investigation serves to show that, the theoretical best form of ship being taken, and the most recent rule being applied in the calculations, the speed of 14 knots can be obtained in the short type of ship at a surprisingly less cost and size than the long type requires; and this result agrees with that of the preceding investigation based on actual trials.