*D3R3. .* . To the speeds of model and ship thus related it is conven­ient to apply the term “ corresponding speeds. ” For example, sup­pose two similar ships, the length, breadth, depth, &c.,of which were double one of the other. Then, if at a given speed (say 10 knots) the resistance of the smaller ship were ascertained, we may infer that at a speed of √2×10=14·14 knots in the larger ship there would be a resistance 8 times as great as in the smaller vessel.

This law is in accordance with the old rule that the resistance varies as the square of the velocity, and also as the area of the surface exposed to resistance. It takes into account both the resistance due to surface friction (subject to some correction) and the formation of deadwater eddies. The passage of the ship through the water creates waves which are dependent for their character upon the proportions and form of the ship. These con­stitute also an element of resistance. They are due to differences of hydrodynamic pressure inherent in the system of stream-lines which the passage of the ship creates. These wave-configurations should be precisely similar when the originating forms are similar and are travelling at speeds proportional to the square roots of their respective dimensions, because the resulting forces will be in that case as the square of the speeds. For example, if the surface of the water surrounding a ship 160 feet long, travelling at 10 knots an hour, were modelled together with the ship, on any scale, the model would equally represent, on half that scale, the water surface surrounding a ship of similar form 320 feet long, travelling at 14·14 knots an hour ; or again, on 16 times that scale, the water surface surrounding a model of the ship 10 feet long, travelling at 2 1/2 knots. Experiment has abundantly con­firmed this proportion as to the similarity of waves caused by similar forms travelling at corresponding speeds. The resistance caused to these forms respectively by the development of the waves would therefore also be proportionate to the cubes of the dimensions of the forms and would follow the law of comparison stated above. It is necessary, however, to observe that, in dealing with surfaces having so great a disparity in length and speed as those of a model and of a ship, a very tangible correction is necessary in regard to surface friction.

The vessel tried by Mr Froude for confirming the law of com­parison was H. M. S. “ Greyhound,” of 1157 tons. She was towed by H.M.S. “ Active,” of 3078 tons, from the end of a boom 45 feet long, so as to avoid interferences of “ wake.” It was found to be possible to tow up to a speed of nearly 13 knots. The actual amount of towing strain for the “Greyhound” was approximately as follows:—at 4 knots, 0·6 ton ; at 6, 1·4 tons ; at 8, 2·5 tons ; at 10, 4·7 tons; and at 12, 9·0 tons.

Comparing the indicated horse-power of the “ Greyhound ” when on her steam trials and the resistance of the ship as determined by the dynamometer, it appears that, making allowance for the slip of the screw, which is a legitimate expenditure of power, only about 45 per cent. of the power exerted by the steam is usefully employed in propelling the ship, and that the remainder is wasted in friction of engines and screw and in the detrimental reaction of the propeller on the stream lines of the water closing in around the stern of the vessel.

We may describe in Mr Froude’s own words the system of ex­periment now regularly carried out for the Admiralty, a system which has been successfully copied in other countries and also by a private shipbuilding firm, Messrs Denny of Dumbarton :—

“That system of experiments involves the construction of models of various forms (they are really fair-sized boats of from 10 to 25 feet in length), and the testing by a dynamometer of the resistances they experienced when running at various assigned appropriate speeds. The system may be described as that of determining the scale of resistance of a model of any given form, and from that the resistance of a ship of any given form, rather than as that of searching for the best form, and this method was preferred as the more general, and because the form which is best adapted to any given circumstances comes out incidentally from a comparison of the various results. We drive each model through the water at the successive assigned appropriate speeds by an extremely sensitive dynamometrical apparatus, which gives us in every case an accurate automatic record of the model’s resistance, as well as a record of the speed. We thus obtain for each model a series of speeds and the corresponding resistances ; and, to render these results as intelligible as possible, we represent them graphic­ally in each case in a form which we call the ‘ curve of the resistance’ for the particular model. On a straight base line which represents speed to scale we mark off the series of points denoting the several speeds employed in the experiments, and at each of these points we plant an ordinate which represents to scale the corresponding resistance. Through the points defined by these ordinates we draw a fair curved line, and this curve con­stitutes what I have called the curve of resistance. This curve, whatever be its features, expresses for the model of that particular form what is in fact and apart from all theory the law of its resistance' in terms of its speed ; and what we have to do is if possible to find a rational interpretation of the law. Now we can

at once carry the interpretation a considerable way ; for we know that the model has so many square feet of skin in its surface, and we know by independent experiments how much force it takes to draw a square foot of such skin through the water at each indi­vidual speed. The law is very nearly—and for present convenience we may speak as if it were exactly—that skin resistance is as the area simply, and as the square of the speed. Now, we have so many square feet of immersed skin in the model, and the total skin resistance is a certain known multiple of the product of that number of square feet and of the square of the speed. Now, when we lay off on the curve of resistance a second curve which represents that essential and primary portion of the resistance, then we find this to bo the result : the curve of skin resistance when drawn is found to be almost identical with the curve of total resistance at the lower speeds ; but as the speed is increased the curve of total resistance is found to ascend more or less, and in some cases to ascend very much above the curve of skin resistance. The identity of the two curves at the lower speeds is the practical representation of a proposition which the highest mathematicians have long been aware of, and which I have lately endeavoured to draw the public attention to, and to render popularly intelligible, namely, that when a ship of tolerably fine lines is moving at a moderate speed the whole resistance consists of surface friction. The old idea that the resistance of a ship consists essentially of the force employed in driving the water out of her way, and closing it up behind her, or, as it has sometimes been expressed, in excavating a channel through the track of water which she traverses,—this old idea has ceased to be tenable as a real proposi­tion, though *prima facie* we know that it was an extremely natural one. Wo now know that, at small speeds, practically the whole resistance consists of surface friction, and some derivative effects of surface friction, namely, the formation of frictional eddies, which is due to the thickness of the stem and of the sternpost ; but this collateral form of frictional action is insignificant in its amount unless the features of the ship in which it originates are so abruptly shaped as to constitute a departure from that necessary fineness of lines which I have described ; and we do not attempt to take an exact separate account of it. Thus we divide the forces represented by the curve of resistance into two elements,—one ‘skin resistance,’ the other which only comes into existence as the speed is increased, and which we may term ‘ residuary resist­ance. ’ And we have next to seek for the cause and governing laws of this latter element. Now when the passage of the model along the surface of the water is carefully studied, we observe that the special additional circumstance which becomes apparent as the speed is increased is the train of waves which she puts in motion ; and indeed it has long been known that this circumstance has important bearings on the growth of resistance. It is in fact certain that the constant formation of a given series involves the operation of a constant force, and the expenditure of a definite amount of power, depending on the magnitude of those waves and the speed of the model ; and, as we thus naturally conclude that the excess of resistance beyond that due to the surface friction consists of the force employed in wave-making, we in a rough way call that residuary resistance ‘wave-making resistance.’

“ Perhaps I had better say a few words more about the nature and character of these waves. The inevitably widening form of the ship at her ‘ entrance ’ throws off on each side a local oblique wave of greater or less size according to the speed and to the obtuse­ness of the wedge, and these waves form themselves into a series of diverging crests, such as we are all familiar with. These waves have peculiar properties. They retain their identical size for a very great distance with but little reduction in magnitude. But the main point is that they become at once dissociated from the model, and after becoming fully formed at the bow, they pass clear away into the distant water and produce no further effect on her resistance. But, besides those diverging waves, there is pro­duced by the motion of the model another notable series of waves which carry their crests transversely to her line of motion. Those waves, when carefully observed, provo to have the form shown in detail in fig. 1. In the figure there is shown the form of a model which has a long parallel middle body accompanied by the series of these transverse waves as they appear at some one particular speed with the profile of the series defined against the side of the model ; only I should mention that for the sake of distinctness the vertical scale of the waves has been made double the horizontal scale, so that they appear relatively to the model about twice as high as they really are. The profile is drawn from exact and careful measurements of the actual wave features as seen against the side of the model. It is seen that the wave is largest where its crest first appears at the bow, and it reappears again and again as we proceed sternwards along the straight side of the model, but with successively reduced dimensions at each reappearance. That reduction arises thus :—in proportion as each individual wave has been longer in existence, its outer end has spread itself farther into the undisturbed water on either side, and, as the total energies of the wave remain the same, the local energy is less and less, and