|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Change of Speed. | Corresponding Change in E.H.P. | | Corresponding Index of Speech | |
| Types (1) and (6). | Type (1). | Type (6). | Type (1). | Type (6). |
| 14-16 knots | 245 E.H.P. | 273 E.H.P. | 3∙1 | 3∙0 |
| 22-23 ,, | 760" | 650 „ | 5∙3 | 4.9 |
| 25-26 „ | 890 „ | 820 „ | 4∙o | 4∙1 |

The variation of the rate of growth of I.H.P. (or E.H.P.) with the speed is a result of the interference of the bow and stern wave systems, and is dependent upon the speed-length ratio *(vide* “ Wave Resistance,” above). A good illustration is afforded by taking the case of a vessel such as a torpedo-boat destroyer, which is run over a con- siderable range of speed. Fig. 37, Plate 11, shows, for such a vessel, three curves plotted to a base of speed, the ordinates being respectively— I H P 1 H P

I.H.P., ~~(specdp (speed~~p, The second of these is of course a curve of resistance, and the rapid rise and fall of the rate of growth of resistance manifests itself in this resistance-curve by a very marked hump

I H P between 15 and 25 knots speed. The third curve, that of

is interesting as affording, by its slope at different points, a very good indication of this rate of growth. Up to about 13 knots this curve is not far from being horizontal, indicating that till then the resistance is varying about as the square of the speed. The rate of growth increases from this point till it reaches a maximum of 15 knots, and then falls off till at about 20 knots the resistance once more varies as the square of the speed. From this point onward the resistance increases at a less rate than the square of the speed.

It has been previously noted that the skin friction part of the E.H.P. does not obey the law of comparison; this is on account of variation of *f* with length, and the index of the speed being different from 2. The coefficient *f* varies much more rapidly at the smaller lengths, and hence for these the skin friction correction is more important for a given change in length. For such lengths as are dealt with in ships, *e.g.* 100 ft. and upwards, and such lengths as we should deal with in applying the data that are now given, it has been found possible to express the correction for skin friction very accurately by the curves in fig. 38, Plate II. These indicate the absolute correction that must be applied to the E.H.P. deduced for the given displacement from the standard curves when interpreted by the law of comparison, and are drawn for a series of displacements on a base of speed; the correction for any odd displacement can be easily interpolated. An addition must be made for displacements under, and a deduction for displacements over, the standard 1000 tons.

The following example illustrates this point and the method of using the standard curves:—

A vessel 320' ×35⅛' X13' ×2 135 tons is being designed ; to construct an E.H.P. curve, for speeds 11-22½ knots. The proportions (Beam/Draught ratio and block coefficient) of the design are most closely approximated to by type 2, group A (320’ being the immersed length). First find the length *l* for a similar vessel of 1000 tons displace­ment; ≈24θ,5 ft., and then from fig. 41 read off

ordinates representing E.H.P. for the given speeds of the 1000-ton standard ship. These figures are converted into those appropriate for the design, by the law of comparison. If *v* and *e* are the speed and E.H.P. for the 1000-ton ship, and V and E corresponding quantities for the design, then ^=(2-135^ = 1-135; and ^ = (2∙135)t=2∙424 ; using these ratios we get a table thus:—

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| As read from the Standard Curves at a  Length = 248∙5Ft. | | As converted by Law of Compari- son for 2135-Tons Design. | | Correction to  Col.4 for Skin Friction: read from Figure. | Col.4-Col.5 = E.H.P.  Corrected. |
| **Col.** i×(i∙ij5≡-) | **Col. 2×(2∙424\*~)** |
| Knots. | E.H.P. | Knots. | E.H.P. | E.H.P. | E.H.P. |
| 10 | 150 | 11.35 | 364 | 16 | 348 |
| 12 | -275 | 13∙62 | 667 | 29 | 638 |
| 14 | 475 | 15∙89 | USt | 42 | 1109 |
| l6 | 740 | ι8∙16 | 1794 | 55 | 1739 |
| I? | 940 | 19∙3o | 2278 | 61 | 2217 |
| l8 | 1285 | 2o∙43 | 3115 | 67 | 3048 |
| 19 | 1825 | 21∙56 | 4423 | 74 | 4349 |
| 20 | 259θ | 22∙7o | 6278 | 80 | 6198 |

The curve shown in fig. 39, Plate II. results from plotting col. (6) to a base of speed given by col. (3). Since the propulsive coefficient varies with the speed, it is preferable to take the E.H.P. from the curve and convert to LH.P., using an appropriate coefficient, than to use a common coefficient by plotting a curve of I.H.P.

3. At high speeds, when a considerable portion of the resistance is due to wave-making, the total resistance diminishes at depths lower than the critical depth, and is frequently less in very shallow water than in deep water.

4. The “ humps ” in the curves of resistance on a base of

In the results hitherto recorded the depth of water has been sup­posed sufficient to prevent the disturbance attending the motion of a vessel on the surface from extending to the bottom ; in these circumstances the resistance is unaffected by a moderate change in the depth. Conditions, however, frequently arise in which vessels are run at high speeds in comparatively shallow water; and a marked alteration is then observed in the resistance and power corresponding to a particular speed. An investigation of the effect of shallow water on resistance is therefore of importance and interest; and a brief account of this part of the subject is here appended.

The change from deep to shallow water modifies the shape of the stream lines, many of which in deep water are approximately in planes normal to the surface of the hull; those in shoal water tend to lie more nearly in horizontal planes, owing to the reduced space under the bottom of the ship. In consequence, the velocity in the stream tubes in the vicinity of the ship is increased, and the changes of pressure and the “ statical ” wave heights are exaggerated. This causes an increase in the frictional resistance as the depth of water becomes less; but the effect on the residuary resistance is more complicated.

Firstly, the length *l* of the waves corresponding to a speed *υ* is increased from that expressed by

2TΓ to be in accordance with the formula c2=⅛tanh 2τ which applies to shallow-water waves for a depth *h.* When the *υ⅛*

depth *h* is equal to -, the length of wave is infinite, and the wave becomes of the type investigated by Scott Russell in canals, and termed a “ solitary wave ” or a “ wave of translation.” When the *υ^*

depth of water is less than ~ no permanent wave system of speed *υ* can exist. These changes in the wave length considerably affect the wave pattern and alter the speeds at which interference between the bow and stern systems has a favourable or unfavourable effect on the efficiency of propulsion.

In the second place the amount by which the speed of travel of the energy of the wave falls short of the speed of the ship is expressed by *υ ∕* 47rZt∕Z ∖

∖ sinh4T√

In deep water this difference of speed is in shallow water it diminishes, becoming zero at the critical depth producing a wave of translation.

Thirdly, the local disturbance immediately surrounding the ship is increased in shallow water, theoretical investigation showing that, at the critical depth above referred to, it becomes indefinite or is only limited by its own viscosity and eddying resistance. In still shallower water, the amount of disturbance is reduced as the departure from the critical depth becomes greater.

Finally, the increase of the frictional resistance due to the higher velocity of rubbing is further modified by the large dimensions of the wave accompanying the ship; the particles of a wave in very shallow water are moving appreciably in the direction of travel, which might lead to a reduction in the frictional resistance.

From these considerations it appears impossible to obtain, a priori, the net effect of shallow water on the resistance, owing to the divergent character of the component effects producing the final result. This difficulty is confirmed by the inconsistency of the readings frequently obtained during experiments in shallow water, pointing to instability in the conditions then existing. A number of experiments have been carried out in shallow water with both ships and models; the most important are those by Constructor Paulus *(Schleswig- Holstein District Club,* 1904), Captain Rasmussen, Mr Yarrow, Herr Popper and Major Rota, many of which are recorded in the *I.N.A. Transactions.* A summary of the conclusions drawn from them is appended:—

1. The minimum depth of water that has no appreciable influence on the resistance increases with the speed and, in some degree, with the dimensions of the ship.

2. At constant speed the resistance is, in general, greatest at the critical depth of water (ø . It is concluded, thcrc- fcre, that the increase of resistance due to the enhanced dimensions of the wave then accompanying the ship is more than sufficient to counteract the gain resulting from the diminished drain of energy from the wave system astern.