A Simplified Estimation of the Disturbance Due to the Waves of Ships: Studies of Turbulent Boundary Layers of Ships, Part V

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https://doi.org/10.5109/7160675

出版情報：Reports of Research Institute for Applied Mechanics. 3 (12), pp.176-179, 1955-03. Research Institute for Applied Mechanics, Kyushu University
バージョン：

Reports of Research Institute for Applied Mechanics
Vol. III, No. 12 March, 1955

A Simplified Estimation of the Disturbance Due to the Waves of Ships

(Studies of Turbulent Boundary Layers of Ships, Part V)[1]

By Jun-ichi OKABE

1. In the series of our studies we used to assume up to the present that the boundary layer, usually turbulent, of a ship or of her model, remained undisturbed by the free surface of water. In other words, as we have been treating the ships with an infinite draft, each particle of water was assumed to move in a horizontal plane. This is, however, of course, not the case with the actual flow taking place on the side of a ship, for the streamlines near the free surface deviate more or less from the horizonal plane owing to the irregularities of the surface of water. The following is a short account of a procedure to estimate the disturbance from the waves of the ship, that is to say, the deviations of the boundary layer characteristics from the normal condition of two dimensions, when the ship is advancing with a uniform velocity, U say, on water with the free surface which would be calm otherwise.

2. Since the waves generated accompany the ship, the flow is stationary when observed in reference to the coördinate system x, y and z, moving with the velocity U, where x is the distance measured horizontally from the bow along the curve of the ship or approximately along her central line, and z is directed upwards, y perpendicular to both of them. However, since the problem as it is is still too complicated, we should content ourselves with a crude approximation.

Now take the particular streamline which is the intersection of the hull and the surface of water. The pressure being uniform along that streamline, we can evaluate the speed of a particle of water at the point specified by s, the curve length measured from the bow along that streamline, from the following formula:

$$\frac{1}{2}u_1(s)^2 + g\zeta(s) = \frac{1}{2}U^2, \tag{2.1}$$

where $u_1(s)$ is the speed of a particle where the surface elevation is denoted by $\zeta(s)$.

Since the surface elevation (or depression) is not so marked compared with the length of the ship, we may put approximately $s = x$, and the usual method of calculating

[1] Part I of these studies was embodied in "A Simple Method of Finding the Point of Separation of the Turbulent Boundary Layer on a Surface of Revolution," *Zosengaku Kenkyu* (Studies of Ship-building), No. 2 (1947).

Part II appeared under the title "A Contribution to the Theory of the Frictional Resistance of Ships," *Reports of Research Institute for Fluid Engineering (RIFE)*, vol. 4, No. 2 (1947), with its English abstract, *Reports of RIFE*, vol. 6, No. 2 (1950).

Part III was published as "Measurement of the Wave-making Resistance of a Ship by Means of an Electric Analogy," *Zosengaku Kenkyu*, Nos. 5–6 (1949). Its English summary, *Reports of Research Institute for Applied Mechanics*, vol. 1, No. 4 (1952).

Part IV is "On the Waves of Ships," *Reports of RIFE*, vol. 7, No. 1 (1950), a joint paper with T. Jinnaka and written originally in English.

the turbulent boundary layer can be applied along that particular streamline. Furthermore, u_1, which we may identify with the speed of the flow just outside the boundary layer, being not very different from U, the well-known formula due to Millikan will be suitable for our purpose,[2] viz.

$$\delta^{5/4} = 0.2983\, \nu^{1/4} u_1^{-115/28} \int_0^x u_1^{27/7}\, dx\,, \tag{2.2}$$

where δ is the thickness of the boundary layer and ν the kinematic viscosity of water. This expression is probably valid approximately up to the Reynolds number $= 3 \times 10^6$.

3. Let us take an example to explain the procedure. In the paper titled "On the Waves of Ships,"[3] Shigematsu measured the wave profiles on the side of the model ship

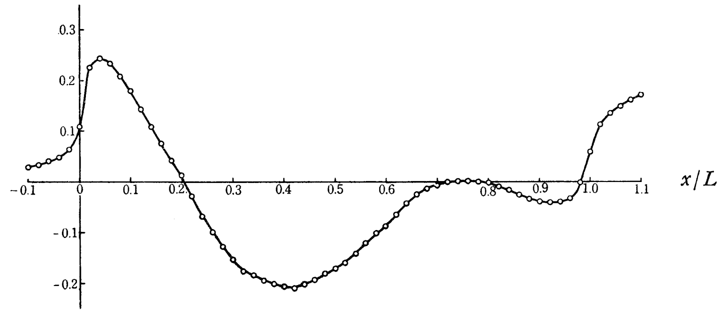

Fig. 1. Surface Elevation

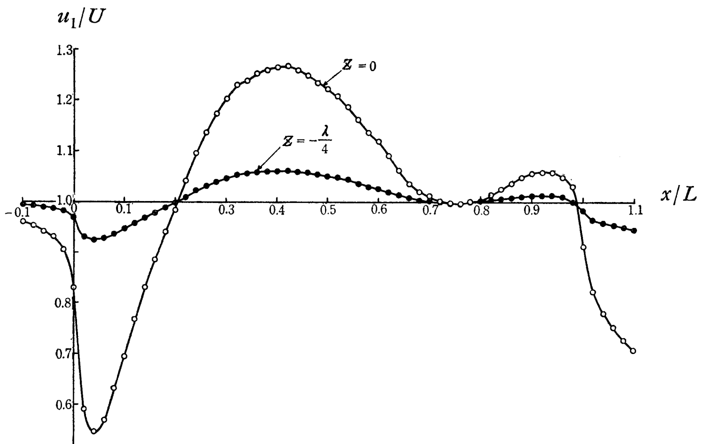

Fig. 2. Velocity Distribution

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[2] J. Okabe, A Contribution to the Theory of the Frictional Resistance of Ships, *ibid.*

[3] *Sempaku Shikenjo Kenkyu Hokoku* (Reports of the Experimental Laboratory of Ships), No. 5 (1942).

5 m in length, 1.2 m and 0.9 m in draft for the speeds of advance of 2.608 m/sec and 2.599 m/sec respectively, Fig. 8, p. 237, *loc. cit.* The surface elevations of these two cases are almost the same, and we may suppose the wave profiles to be produced by a model of an infinite draft will not be different very much from these two results. So let us assume for simplicity that the mean curve between these two series of points corresponds approximately to an experiment with an infinite draft. The mean curve

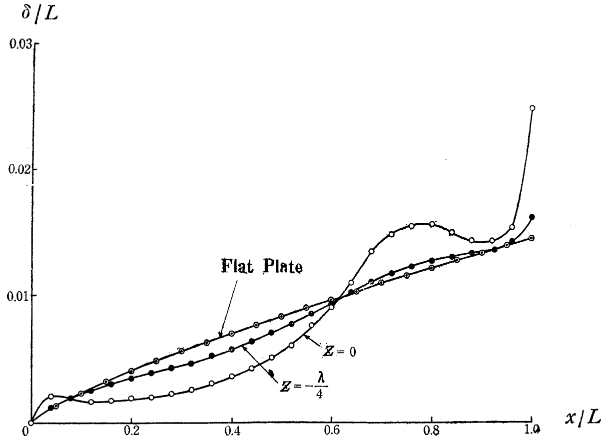

FIG. 3. Thickness of Boundary Layer

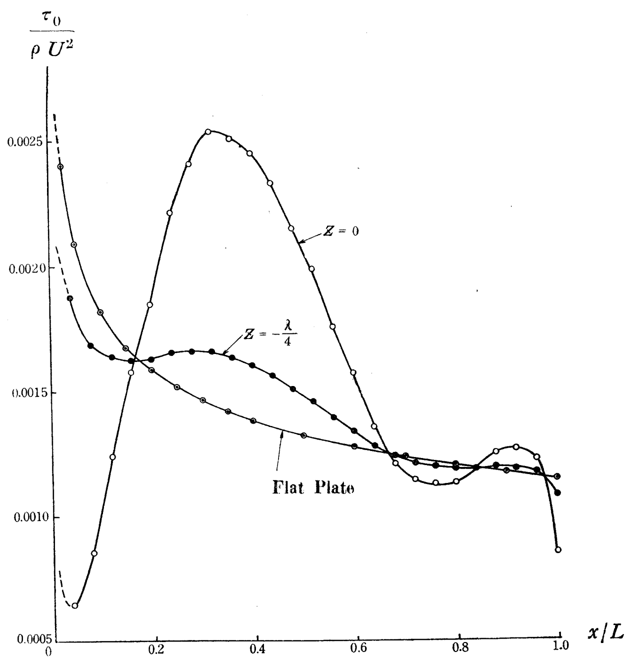

FIG. 4. Surface Traction

obtained in this way is reproduced in Figure 1. The ordinate of the figure shows the surface elevation in metre, and the abscissa represents the non-dimensional distance x/L where L is the length of the model; $x/L=0$ and 1 correspond, therefore, to the bow and the stern respectively. By reading this curve, u_1/U can be readily calculated from (2.1); see the curve denoted by $z=0$ in Figure 2. Finally by means of (2.2), δ/L can be integrated numerically and the result is shown in Figure 3, by the curve $z=0$.

Finally from the formula

$$\frac{\tau_0}{\rho U^2}=0.0232\left(\frac{UL}{\nu}\right)^{-1/4}\left(\frac{u_1}{U}\right)^{7/4}\left(\frac{\delta}{L}\right)^{-1/4}, \tag{3.1}$$

we can estimate approximately the intensity of the frictional resistance of the ship, where τ_0 denotes the surface traction.[4] Figure 4 embodies the result of this computation.

4. The question that next arises is this: how rapid this disturbance dies out when we go down in the water? It is well-known that the particle motion of a train of simple harmonic waves diminishes in the ratio $\exp(2\pi z/\lambda)$ as we go downwards, where λ is the wave-length. Let us assume first that this rule holds good, at least approximately, also for the surface elevations generated by ships. In the second place, because the pressure is uniform on the free surface, the Bernoulli's equation was found to be very simple as shown in (2.1) When we are not on the free surface, this simplification is not necessarily permissible. But if we should content ourselves with a crude estimation, it would not be far from being safe to ignore the pressure gradient along that streamline running on the side of the ship which at an infinite distance lies on the horizontal plane $z=$ constant, say z_1.

As an example let us put

$$z_1=-\lambda/4, \tag{3.2}$$

where λ is the average wave-length. According to the two assumptions mentioned above, u_1 and U are related to each other by the following formula:

$$\frac{1}{2}u_1^2+e^{-\pi/2}g\zeta=\frac{1}{2}U^2, \tag{3.3}$$

ζ being the deviation of the streamline from the horizontal plane. The rest of the calculation is completely the same as in the preceding section. In Figures 2, 3 and 4 the curves denoted by $z=-\lambda/4$ were constructed in this way. In Figures 3 and 4 the curves marked as "Flat Plate" corresponds to the case $\zeta=0$, i.e. $u_1=U$.

(Received October 1, 1954)

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Reports of Research Institute for Applied Mechanics

Vol. III, No. 9, 1954

Page 45, footnote, add a comma after "Yamada."

Page 47, line 7, add "for $0<x<L$" after "ζ_u at $y=0$."

(*J. O.*)

[4] J. Okabe, A Contribution to the Theory of the Frictional Resistance of Ships, *ibid.*

[5] H. Lamb, *Hydrodynamics*, 6th edition (1932), chapter IX, p. 368.