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APPLICATIONS OF THE THEORY OF THE WAVE-MAKING RESISTANCE TO FULL SHIP FORMS

by M. Bessho (*Defense Academy*)

This is a summary of approaches to the problem of the resistance of recent full shaped ships by making use of the wavemaking resistance theory.

It is understood that Michell-Havelock's theory of the wave-making resistance is valid only for thin ships and not for such full ships but there is a possibility of the successful application to this case too.

1. Direct Application

The calculated wave-making resistance by Michell integral is very high and sinusoidal compared with the experiment so far as we know in low speed range, it is also true that the theory explains well the wave-making phenomena.

Hence, direct calculations of Michell's integral of some models in the J.S.R.A. systematic series as follows[3]:

a) Ship lines are represented by 6th order polynomials respectively in three parts, fore, middle and aft body.

b) Frame lines are approximated by straight lines as the sectional area does not change.

c) Michell integrals are evaluated by the asymptotic expansion.

d) Michell integral is applied in the doublet form as follows:

$$R_w = \frac{4\rho g^4}{\pi V^5}\int_0^{\pi/2} |F(K_0 \sec\theta, \theta)|^2 \sec^5\theta \, d\theta \qquad (1)$$

$$F(K,\theta) = \int_{-d}^{0}\int_{-L/2}^{L/2} H(x,z)\, e^{Kz - iKx\cos\theta} dx dz \qquad (2)$$

where ρ is the water density, g the gravity constant, V the speed, $K_0 = g/V^2$, H the half breadth, the x-axis forwards positive, the z-axis upwards positive and the origin at midship on the still water surface.

An example is shown as Fig. 1. The qualitative

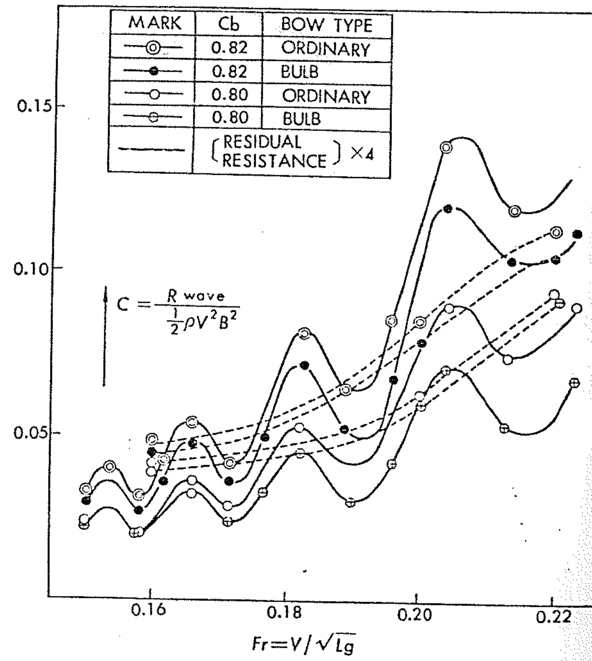


Fig. 1. Calculated wave-making resistance

correspondence between the theory and the experiment is very good but the calculated values are three or four times larger and very much sinusoidal than those of the experiment.

The one difficulty of these calculation lies on the curve fitting of the ship lines by polynomials in the x-coordinate and it may be preferable to be fitted by trigonometric functions with the weight function $1/\sqrt{(1-x^2)}$.

The other difficulty is that the representation of the frame line's small variation like the bulbous bow shape is very complex. This may be solved by the introduction of the influence function.

2. Influence Function

The formula (1) is written as the next form

$$R_w=\int_{-L/2}^{L/2}\int_{-d}^{0} G(x, z)H(x, z)\,dxdz \qquad (3)$$

$$G(x, z)=\frac{4\rho g^4}{\pi V^6}\int_0^{\pi/2} e^{K_0(z+z')\sec^2\theta}\cos(k\,\overline{x-x'}\sec\theta)\sec^5\theta d\theta$$

$$\times\int_{-L/2}^{L/2}\int_{-d}^{0} H(x', z')\,dx'dz' \qquad (4)$$

and its variation is

$$\Delta R_w=G(x, z)[2\Delta H(x, z)\Delta x\Delta z] \qquad (5)$$

Namely, the influence function G is a resistance variation per unit volume for small volume variation $2\Delta H\Delta x\Delta z$[3].

Fig. 2 is an example of a ship with $C_b=0.8$ of which water line consists of parabola and straight line[1]. This figure shows clearly the effectiveness of the bulbous bow and Youkevich form. From this calculation, the huge bulbous bow is considered to be effective and the experiment for the practical ship lines is carried out and it is verified[1,2].

However, the same calculation for the practical ship lines as shown in the above paragraph shows that the huge bulbous bow does not so effective as in the experiment.

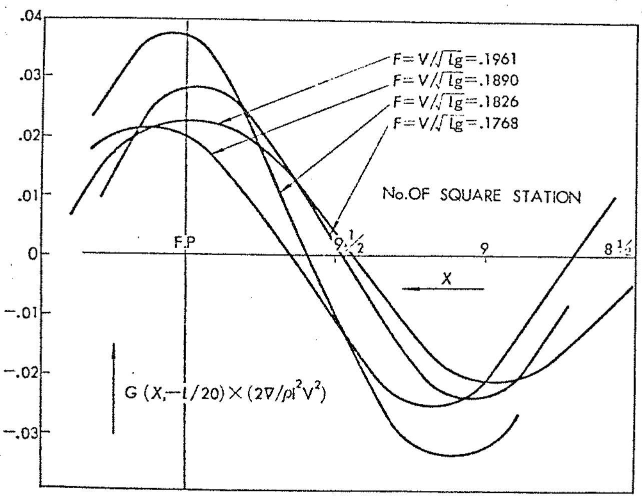


Fig. 2. Influence function at bottom of stem

3. Minimum Form

The other cause to prefer a bulbous bow or a round cylindrical stem lies on the result of the theory that the infinitely long strut which has the minimum wave-making resistance has large round endings.

Hence, the experiment is carried out as shown in Fig. 3, being rounded the stem of the practical ship cylindrically[3]. The result is so remarkable that ships with huge cylindrical bow and fullness have nearly the same resistance as the ordinary bow ship, but this is also not explained by the theory.

MARK	MODEL	DIA.OF STEM	L w.l. (m)	B (m)	d (m)	V (Kg)
○	No. 1	0.09 (m)	2.042	.3005	.1152	56.98
∘	2	0.06	2.057	.3005	.1152	57.06
●	3	0.03	2.070	.3005	.1152	57.09
•˙	4	0.004	2.082	.3005	.1152	57.09

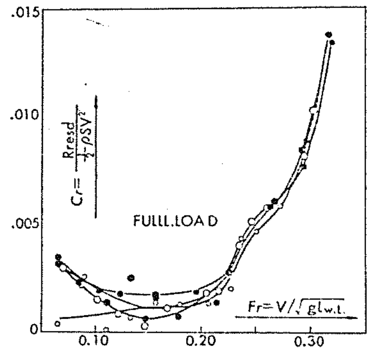


Fig. 3. Residual resistance

4. Wave-Free Transformation

The method to attack the frame line problem other than the influence function is the wave-free transformation, which is a method to change the ship lines, mainly its frame lines, without change of its wave-making resistance.

Now, if there is a function H represented as

$$H(x, z)=X(x)\frac{d}{dz}Z(z)-\frac{1}{K_0}Z(z)\frac{d^2}{dx^2}X(x) \qquad (6)$$

with the boundary conditions

$$X(\pm L/2)=\frac{d}{dx}X(\pm L/2)=Z(0)=Z(-d)=0 \qquad (7)$$

it has no wave-making resistance by the calculation of the formula (1).

Therefore, the resistance does not change if such function multiplied by an arbitrary factor is added to or subtracted from any ship lines. It is easy to see that such function has no volume and moment about midship.

A simple example shown as Fig. 4 is confirmed by the resistance test[4]. As seen from this example, this transformation keeps the sectional area curve nearly unchanged.

MARK	MODEL	∇ (Kg)	S (m)	L_{pp} (m)	B (m)	d (m)
	ORIGINAL	35.15	.6714	1.8	.2452	.0995
	TRANSFORMED	35.15	.6536	1.8	.7941	.0995

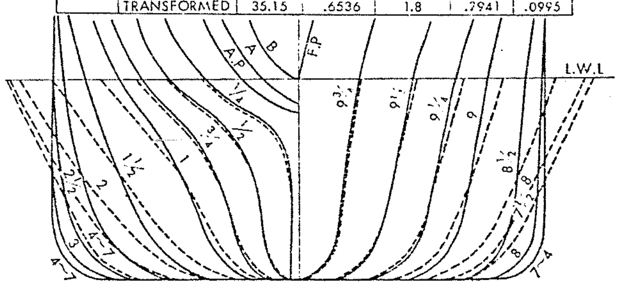


Fig. 4. Body plan

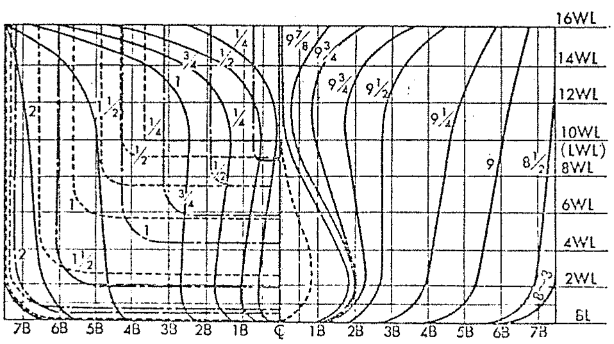
5. Ships of the Submerged Type

All appropriate functions H represented as the equation (6) with the boundary conditions (7) except $Z(-d)$ have the wave-making resistance equivalent to that of the submerged body on its keel line, because its integral (2) is converted into a simple integral on the keel line.

S-type model is Fig. 5 is a ship of such type drawn for Froude number $V/\sqrt{gL}=0.147$ so as to obtain a large but practical size bulbous bow. The resistance tests are carried out with other two models as shown in Fig. 6.

The total resistance of S-type model is very large but the residual resistance curves of three models are nearly equal. This is confirmed also from the direct measurement of the wave-making resistance by Ward's X-Y method at full load condition[5,6].

As seen from the figure, the calculated value is the same order of magnitude as the residual resistance.



$L=2.00$ M $B=0.30$ M $d=0.10$ M $C_b=0.80$ M
—— S-Type —·— R-Type --- T-Type

Fig. 5. Body plan

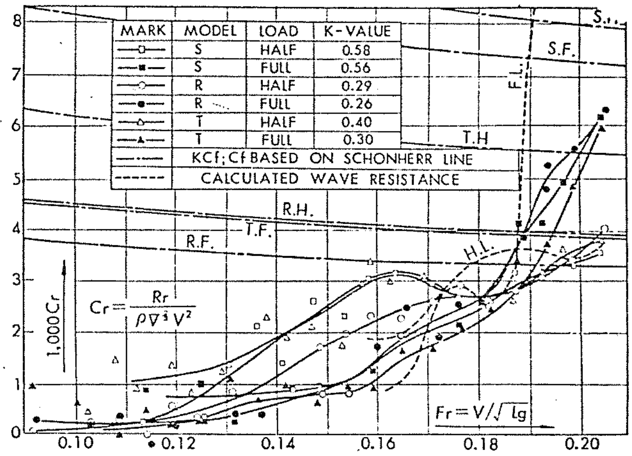


Fig. 6. Residual resistance.

Of course, many things must be done in future but these experiences encourage us to make use of the theory to full shaped ships as the powerful tool by which their resistance may be reduced and predicted more accurately.

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AN APPRAISAL OF THE THEORY OF MINIMUM WAVE RESISTANCE

by H. Maruo (*National Univ. of Yokohama*)

1. Introduction

In recent years, naval architects begin to show their interest in the application of the wave resistance theory to the practical field of ship building. One of the possible ways is to design the ship form in such a way that the theoretical value of the wave resistance becomes minimum. The theory of the ship form of minimum wave resistance has been studied by a number of scientists since Weinblum published his notable paper in 1930. In spite of many achievements in the theoretical side, however, the existing data for the experimental proof of its validity are comparatively few.

Recently a series of resistance experiment has been conducted at the Yokohama University tank about a number of ship models which are designed so as to conform to theoretical ship forms of minimum wave resistance. According to the theory, there is an optimum value of prismatic coefficient by which the wave resistance is made minimum at a given Froude number. The relation between the Froude number and the optimum prismatic coefficient was determined by the theory for ships of infinite draft and for slender ships. An experimental proof of the theoretical prediction was published