Wave Resistance Minimization of a Simple Form Ship with Protruded Bow by Rankine Source Method

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Introduction

Ship hull forms with minimum wave resistance obtained through a series of iterative calculations by wave resistance theory in conjunction with optimization technique (nonlinear programming) have been presented, e.g., by Higuchi et al.(1979), Hsiung (1981) and Suzuki et al.(1981,1985). They are based on Michell integral formula or low-speed theory for evaluating the wave resistance. To improve the calculation accuracy, Kim (1989), Janson et al.(1994) and Mifune et al.(1995) adopted Rankine Source Method for the minimum wave resistance problem. However, unplausible hull deformations can be often seen in the published optimum forms. This can be avoided by expressing the hull form with protruded bow by simple mathematical functions such as polynomial functions whose coefficients are the design variables in the optimization technique (Yasukawa 1995). By such a treatment, optimized hull forms can be obtained without unplausible deformations in short computation time.

As first step of the study, this paper deals with the wave resistance minimization for a fine ship such as a Wigley hull. Then, the ship wave resistance is evaluated by Rankine Source Method (Dawson 1977).

Simple Mathematical Expression for Hull Form

Taking the origin of the coordinate at bottom of aft perpendicular (A.P.), the ship hull is assumed to be separated into 2 parts: one is the main hull and the other the protruded bow (bulb), Fig.1.
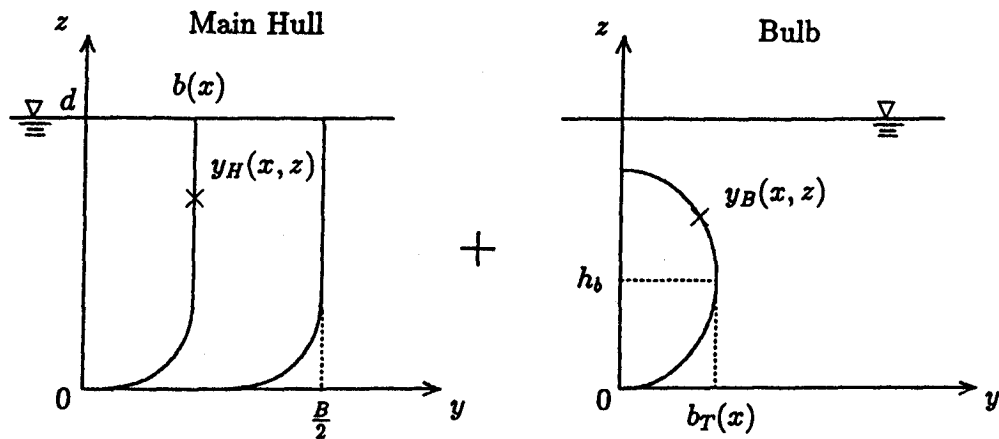

Fig.1: Simple mathematical expression of main hull and bulb

The main hull part $y_H(x, z)$ is expressed for a combination of straight line and bilge circle as:

$$
\left.
\begin{aligned}
y_H(x, z) &= b(x) & (r \le z \le d) \\
y_H(x, z) &= b(x) - r\,(1 - \sin\theta(z)) & (0 \le z < r)
\end{aligned}
\right\}
\tag{1}
$$

where

$$
\theta(z) = \cos^{-1}\left(1 - \frac{z}{r}\right), \quad b(x) = \frac{A(x) + r^2\left(1 - \frac{\pi}{4}\right)}{d}
\tag{2}
$$

$A(x)$ is sectional area, $b(x)$ the half breadth of the load water line, d the ship's draft and r the radius of bilge circle. Note that r changes smoothly near the fore and aft parts.

The bulb is expressed as ellipsoidal in sectional shape and profile. The frame line of the bulb part $y_B(x, z)$ is expressed as:

$$y_B(x, z) = 0 \qquad\qquad (2h_b \le z \le d) \left.\right\} $$
$$y_B(x, z) = b_T(x)\left(1 - \sin\varphi(x, z)\right) \qquad (0 \le z < 2h_b) \left.\right\} \qquad (3)$$

where

$$\varphi(x, z) = \cos^{-1}\left(1 - \frac{z}{b_T(x)}\right), \quad b_T(x) = \frac{A(x)}{\pi h_b} \qquad (4)$$

h_b is the height of the bulb and $b_T(x)$ the maximum half breadth of the bulb. The frame line of the ship can be calculated by the sum of $y_H + y_B$ which are determined so as to be equal to the given sectional area $A(x)$ as a function of x. $A(x)$ is assumed to be expressed as 5 powers polynomial function.

In summary, the parameters for the protruded bow (bulb height, protruded length, sectional area at F.P.) and the coefficients of the mathematical function for the sectional area curve are the design variables in the optimization technique.

Wave Resistance Minimization for a Modified Wigley Hull

A package routine of the optimization technique with External Penalty Method is employed to treat the design constraints and Hooke-Jeeves' pattern search method is adopted for local search of the solution (Parsons 1954). The solution algorithm in this method is quite simple because the derivatives of the objective function with respect to the design variables are not necessary.

As design constraints, we employ constant displacement volume, constant length perpendicular, constant breadth and constant draft. In addition, the sectional area of the ship has to increase/decrease gradually at fore/aft part in x-direction. The ship hull form with minimum wave resistance is obtained at the design point of $F_n = 0.3$ where F_n is Froude number based on ship length. Optimizations are carried out for a modified Wigley hull, Table 1.

Table 1: Principal particulars of a modified Wigley hull

	Modified Wigley
L/B	10.0
L/d	16.0
C_b	0.533
C_m	0.800

L, C_b and C_m are ship length, block coefficient and midship coefficient respectively. Optimizations are carried out for the cases without bulb and with bulb of $h_b/L = 0.025, 0.030$. Further, the protruded length of the bulb is assumed to be $5\%L$ because otherwise an extremely long length might be chosen as an optimum solution.

Fig.2 shows the comparison of wave resistance coefficient curves C_w which are nondimensionalized by $1/2\rho L^2 U^2$ for original and optimum forms. About 30% reduction of C_w is obtained at $F_n = 0.3$ for an optimum form in the case without bulb against the original form. Due to the bulb attachment, further, about 50% reduction of C_w is obtained. The effect of the bulb on the wave resistance reduction is considerably large. As for the bulb height, the lower (deeper immersed) bulb is better. Fig.3 shows the comparison of sectional area curves for original and optimum forms. An optimum sectional area curve in case without bulb is the symmetrical shape

with swells at both fore and aft parts which is similar to the solution based on minimum wave resistance theory. The sectional area shifts from S.S.$1\frac{1}{2}$ and $8\frac{1}{2}$ to S.S.$3\frac{1}{2}$ and $6\frac{1}{2}$ to make the swell the fore and aft parts. A parallel part appears in the optimum curve, which is not found in the original form. An optimum sectional area at F.P. for case with the bulb ($h_b/L = 0.025$) is about 23%. The tendency of the optimum sectional area curve at aft part is the same as the optimum form for the case without bulb. Fig.4 compares body plans and stem profiles for original and optimum forms. The optimum form for the case with bulb ($h_b/L = 0.025$) has a large protruded bow and is considerably different from the original form.
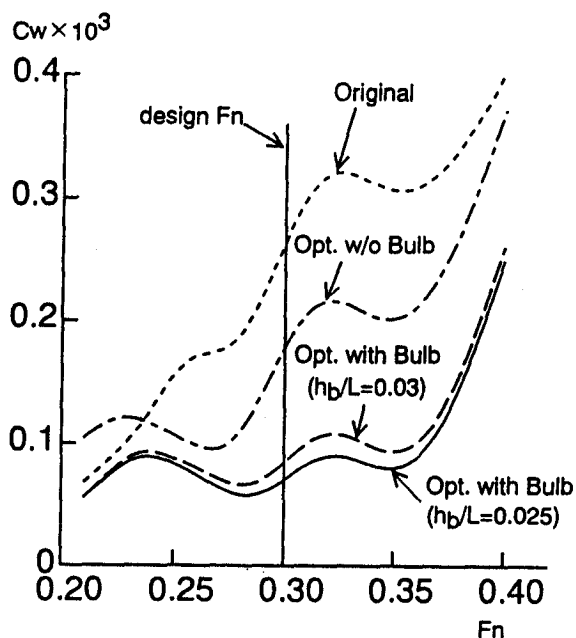

Fig.2: Comparison of wave resistance coefficient curves for original and optimum forms
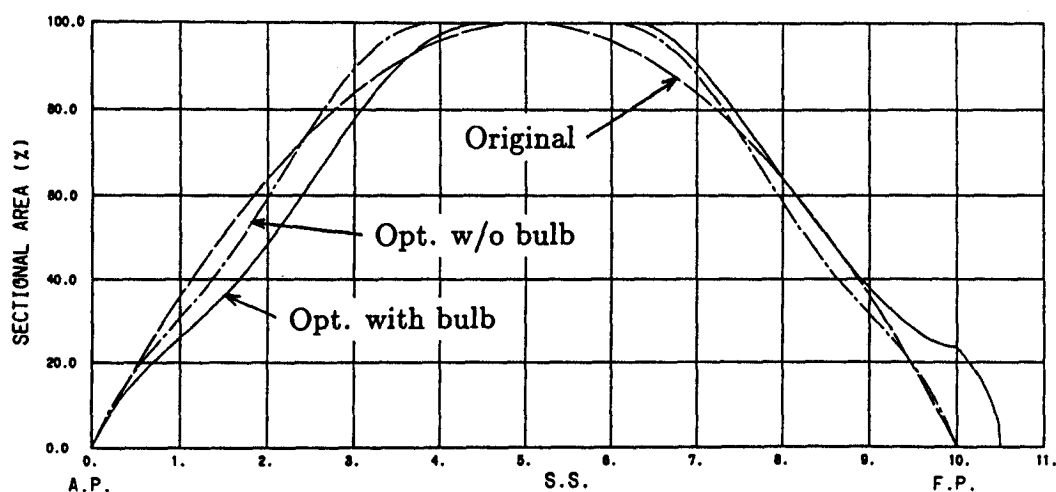

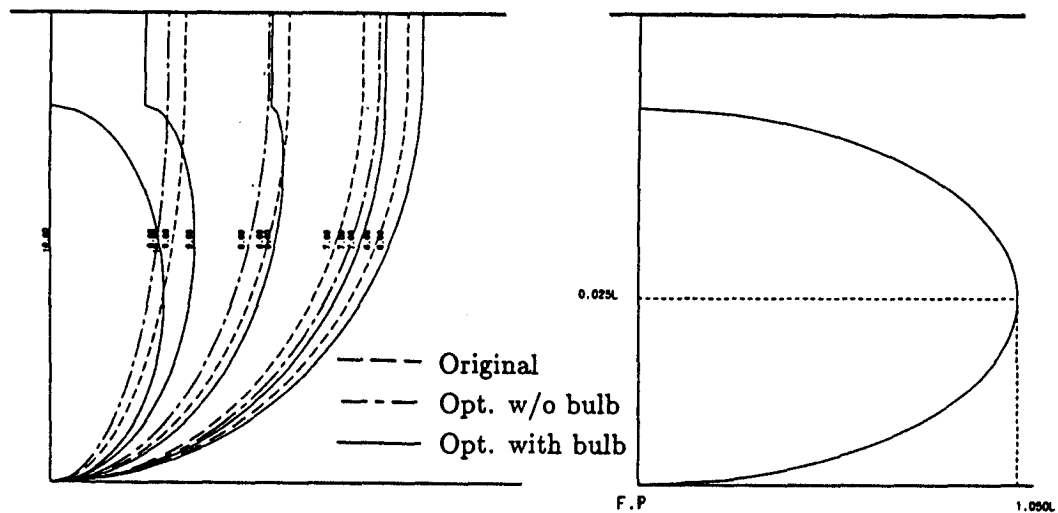Fig.3: Comparison of sectional area curves for original and optimum forms

Fig.4: Comparison of body plans and stem profiles for original and optimum forms

At the workshop, I should be able to present further applications of this approach to more realistic hull forms.

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DISCUSSION

Hsiung: When the bulbous bow is suppressed by constraints, for optimal forms side bulbs may occur. Would you like to study the effect of side bulbs on wave resistance?

Yasukawa: It is essentially possible to obtain an optimum hull form with side bulbs by the proposed method. Then, we need to express the side bubs using simple mathematical functions similar to the case of the protruded bow.