SWATH Ships의 저항 추정을 위한 전산 Program 개발

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Development of a Computational Tool to Estimate the Resistance of SWATH ships

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요 약

반 잠수식 저 수선면적 쌍동선 (Small Waterplane Area Twin Hull)의 총 저항 추정을 위한 새로운 전산 program 개발에 대해서 개략적으로 설명하였다. SWATH Ship의 총 저항을 조파 저항, 표면 마찰 저항, Fin 저항 및 부가 저항의 합으로 계산하였다.

개발된 program의 정확성을 확인하기 위해서 수치 해석 결과를 세 가지 SWATH모델들의 실험치와 비교하였다.

1. INTRODUCTION

A considerable interest in SWATH ships has emerged in the past one and half decades with numerous advantages clarmed for SWATH ships such as good rough weather motion characteristics, good speed performance in waves and large deck area, etc. Today this growing interest is ref-

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lected by the many reports on SWATH design which appear in worldwide technical journals.

A SWATH ship has several components below the free surface which cause complicated hydrodynamic interferences between them and accordingly, its hydrodynamic performance, in particular resistance, is very sensitive to changes in the composition or geometries of the components. With regard to this, compared to monohull ships, it is rather difficult to find an optimum SWATH ship configuration experimentally by varying the many parameters involved in the SWATH design because of time and cost. Therefore, at an early stage of the design process, the use of a reliable analytical tool to evaluate the performance of candidate SWATH ship forms is extremely important.

A number of papers have been published regarding the SWATH ship resistance problem. Chapman [1] initiated the utilization of the line source distribution along the longitudinal centreline of the submerged body and the plane source distribution over the centreplane of the surface piercing strut in order to calculate the wave-making resistance of semi-submerged ships. However, he confined the problem only to simple geometries of SWATH ship which can be expressed by mathematical formulae. Based on the same theory as Chapman and using Chebyshev coefficients and the cubic spline(piecewise continuous polynomial) curve fitting method, Lin and Day developed a computer program to predict the total resistance of SWATH geometries defined by offsets[2].

Salveson et al developed a new computational method for the design of SWATH ships[3]. In dealing with the wave-making resistance they introduced a correction term that accounts for the outlow between the strut and lower hull, but the general theory is the same as Chapman's. However, it is not clear that the line source distribution for the body can be used for the optimization example of non-circular hulled SWATH ships.

Instead of using two sets of Chebyshev coefficients as employed by Lin and Day, but employing the first kind of Chebyshev polynomial (one set of Chebyshev coefficients) and recurrence formulae for Bessel functions of integrals involved in the wave resistance formulae, Huang[4] concluded that he had simplied the computational work involved in wave resistance formulae and saved computer time. As far as computer time is concerned, however, it seems that this is not always the case. The time for calculating the wave resistance formulae is entirely dependent upon the DO-looping times which are decided by the order of Chehyshev polynomial and this is related to the accuracy of prediction.

In order to estimate the total resistance experienced by a near-surface or surface running ship, it is usual to break down the total resistance into components with the assumption that each of them is caused by a different effect and that all components are additive to give the total resistance. Although, in some cases, this is not strictly justifiable, it represents the only feasible approach to the problem in most cases. For the present study, the total calm water resistance of a SWATH ship is divided into four components : wave-making, frictional, additional resistances (form effect, eddy, viscous pressure, wavebreaking and spray) and appendage resistance.

2. WAVE-MAKING RESISTANCE

Assuming that there is no flow across the centreplane between two demihulls of a SWATH ship, a Green's function induced by a point source moving along the deep vertical wall can be used to derive the wave resistance formula of the

SWATH ship. The result is taken from the Ref. [5] without any derivation. The resisting force of two demihulls(2b distance between the centerplanes of two demihulls) which travel with a speed of U in the vicinity of the free surface of deep, inviscid and incompressible water is expressed as follows.

$$R_w = 32\pi\rho k_0^2 \int_0^{\pi/2} d\theta (I^2 + J^2) \sec^3\theta \, [1+\cos(2k_0 b \sec^2\theta \sin\theta)] \qquad (1)$$

$$I + iJ = \iint m \exp(ik_0 x \sec\theta + zk_0 \sec^2\theta) dx \, dz \qquad (2)$$

where $k_0=g/U^2$ and m is the source strength which can be determined by the boundary condition at the surface of the body and strut as well. The co-ordinate system(x, y, z) has the x-axis positive in the direction of motion of the ship, y-axis positive to port and the z-axis positive upwards. The 0-xy plane coincides with the undisturbed free surface.

A typical demihull of a SWATH ship consists of an elongated, slender body with pointed ends and a streamlined thin strut(s) with uniform thickness vertically. Hence, the well known thin ship approximation can be applied to the strut and eq. (2) becomes

$$I + iJ = -\frac{U}{2\pi}\iint \frac{df}{dx} \exp(ik_0 x \sec\theta + zk_0 \sec^2\theta) \, dx \, dz \qquad (3)$$

where f(x, z) is the geometry and for a wall sided strut, equals the half thickness, t(x).

Based on the above equation, Chapman[1] simplified the equation using the concept of the line source distribution along the centreline of the body as follows :

$$I + iJ = -\frac{U}{4\pi} \exp(k_0 h \sec^2\theta) \int \frac{dA}{dx} \exp(ik_0 x \sec\theta) dx \qquad (4)$$

Where h is the submerged depth of the body centreline from the undisturbed free surface(mean submerged depth).

According to the above equation, the wave resistance of the body depends only on the mean submerged depth of the body and on the longitudinal distribution of displacement regardless of its shape in the cross section. Therefore, the line source distribution is valid only for a circular cross sectional body since a point source generates the exact circle. As mentioned in the introduction, all computer programs developed so far are based on the above two approximations eqs. (3) and (4). In particular, when this line source distribution is applied to non-circular SWATH ships, a wrong estimation of the wave-making resistance for such SWATH ships will be obtained. Therefore, in order to predict the differences in the wave resistance of different cross sectional bodies such as circular, elliptical and rectangular cross sections with rounded corners etc, the line source distribution is not suitable. Since the designs of non-circular cross section hulled SWATH ships have increased due to some advantages over circular hulls, it was felt necessary to develop a theoretical tool to predict the differences in the resistance for the different cross section bodies. To achieve this objective a new approach utilizing a plane source distribution is derived from eq. (2).

Assuming that a uniform source strength of m(x, O, z) is distributed over the infinitesimally small surface $D_b dx$, and that the surface inclination of the body is negligible(usual for the slender and thin ship approximations), the total strength can be written as $4\pi m D_b dx$ at the section of x, where D_b is the maximum depth of the body. The boundary condition at body surface is

$$\frac{\partial \phi}{\partial n} = -U \sin\alpha \tag{5}$$

where n denotes the outward normal to the body surface and α is the angle between the tangential plane of the body surface and x-axis. If the projection of n on a plane perpendicular to the x-axis is expressed as $n' = n \cos\alpha$, the above boundary condition becomes

$$\frac{\partial \phi}{\partial n'} = -U \tan\alpha \tag{6}$$

The outward flux through the surface, cdx where c is the mean contour of the body surface for an element of length of dx, is expressed as

$$\int_c \frac{\partial \phi}{\partial n'} dcdx = -U \int_c \tan\alpha dcdx \tag{7}$$

Using the relation of $dA(x)/dx = \int_c \tan\alpha dc$ and the fact that the total outward flux must be equal to the total flux from the sources in the plane, the source strength becomes

$$m = -\frac{U}{4\pi D_b} \frac{dA(x)}{dx} \tag{8}$$

Using the above equation, eq. (2) becomes for the body :

$$I + iJ = -\frac{U}{4\pi D_b} \iint \frac{dA(x)}{dx} \exp(ik_0 x \sec\theta + z k_0 \sec^2\theta) dxdz \tag{9}$$

Now, comparing eqs (4) and (9), the difference is apparent. In order to demonstrate this, Fig. 1 shows the wave resistance variations of three slender bodies, which have the same x-directional variation of cross sectional areas, dA(x)/dx, displacements and mean submerged depths, versus Froude Number. According to the figure, the present approach gives different values for different shapes of cross section while the line source distribution gives the same results for each section. Furthermore, for the same circular cross sectional body the present theory gives values as much as 20～25% higher than the line source method depending on the submergence of the body. Above a body submergence of around three times the depth of the body, the two source distributions give nearly the same results as each other. This phenomenon is due to the fact that the contribution to the wave-making of the part of the submerged body near to the free surface is taken into account by the present plane source distribution, but not by the line source distribution. Again, this is demonstrated by the fact that the wave resistance of the horizontally elliptical body of revolution is less than that of the circular cross sectional body at the same mean draft despite its larger breadth. This proves that the present approach is successful, within the approximation, in predicting the differences in the wave resistance of different cross sectional bodies which the line source distribution can not.

Using dimensionless coordinates such as $x_1 = 2x/L_b$, $y_1 = 2y/B_b$, $z_1 = 2z/D_b$, $H_1 = 2h/D_b$ and $B_1 = 4b/L_b$ etc, where L_b is the body length and B_b the body breadth, the equations above described can be calculated numerically. Now, a geometry can be defined as :

$$y = f(x, z) \qquad -1 \leq x \leq 1 \quad \text{and} \quad -1 \leq z \leq 1 \tag{10}$$

The subscript 1 is dropped from here onwards. Any geometry may be used in calculating the wave resistance : defined either by mathematical formulae or by offsets. In order to achieve the purpose, such functions as the cross sectional area curve A(x) of the body and the strut half thickness t(x) should be described analytically either by mathematical formulae or by curve fittings from given offset tables.

Unlike the monohull ship, a SWATH ship has several components under the free surface which cause complicated hydrodynamic interference effects between its components. To account for these effects, a linear superposition technique has been used. For instance, for a tandem strut(dissimilar to each other) SWATH ship, $I^2 + J^2$ in the integrand of eq. (1) will be given by :

$$\begin{aligned} I^2+J^2 &= (I_b^2+J_b^2) + (I_s^2+J_s^2) + (I_{s1}^2+J_{s1}^2) \\ &\quad + 2\left[(I_b I_s + J_b J_s) + (I_b I_{s1} + J_b J_{s1}) + (I_s I_{s1} + J_s J_{s1}) \right] \end{aligned} \tag{11}$$

where subscripts b, s and s1 refer to body, strut and second strut, respectively. From eq. (11), it can be seen that the wave resistance of a SWATH ship consists of the resistances of the bodies and struts, plus extra resistances. These extra resistances are interference resistances between strut and body and between struts due to the existence of the wave-interaction between these components of the SWATH ship. The interference effect between the demihulls arises from the presence of the cosine term in the integrand of equation (1). This interference factor is a function of the speed and spacing distance of two demihulls for a fixed geometry, varying from -1 to 1, mathematically. Consequently, the wave resistance of a SWATH ship is at the least zero and at the most four times the wave resistance of a demihull.

Utilizing a special form of Chebyshev series and the cubic spline(piecewise continuous polynomial) curve fitting method from the given offsets of the body and strut(s) of a SWATH ship, the wave-making resistance contribution of each component of the SWATH ship can be finally written as follows :

Body Contribution

$$R_{wb} = \frac{\pi \rho k_0^2 U^2}{4} S_m^2 \sum_{m=1}^{M} \sum_{n=1}^{N} (A_{bm} A_{bn} T_{bmn} + B_{bm} B_{bn} W_{bmn}) \tag{12}$$

where S_m is the maximum cross sectional area of the body, A_m and B_m are Chebyshev coefficients, and

$$T_{bmn} = (2m-1)(2n-1)\int_{0}^{\infty} E_b^2(u)\cosh^2 u\, D(u) J_{2m-1}(\beta) J_{2n-1}(\beta) du \tag{13}$$

$$W_{bmn} = 2m2n\int_{0}^{\infty} E_b^2(u)\cosh^2 u\, D(u) J_{2m}(\beta) J_{2n}(\beta)\, du \tag{14}$$

$$E_b = \frac{1}{\frac{D_b}{L_b}k_1\cosh^2 u}\{\exp[\frac{D_b}{L_b}k_1\cosh^2 u(1-H_1)] - \exp[\frac{D_b}{L_b}k_1 \mathrm{cooh}^2 u(1+H_1)]\} \tag{15}$$

where $k_1 = gL_b/2U^2$, $D(u) = 1 + \cos(B_1 k_1 \cosh u \sinh u)$ and $J(\beta)$ is a Bessel function of the 1 st kind with integer and argument $\beta = k_1 \cosh u$.

Strut Contribution

$$R_{ws} = \pi\rho U^2 k_0^2 T_s^2 \sum_{m=1}^{M}\sum_{n=1}^{N}(A_{sm}A_{sn}T_{smn} + B_{sm}B_{sm}W_{smn}) \tag{16}$$

where T_s is the maximum thickness of the strut, T_{smn} and W_{smn} are that E_b and β in eqs. (13) and (14) are replaced by E_s and β_s, respectively, and

$$E_s(u) = \frac{1}{k_0\cosh^2 u}[1-\exp(-h_s k_{1s}\cosh^2 u)] \tag{17}$$

where $h_s = 2h_s/L_s$ (L_s is the strut length and h_s the strut depth) and $k_{1s} = gL_s/2U^2$.

Body and Strut Interference

$$R_{wsb} = \pi\rho U^2 k_0 S_m T_s \sum_{m=1}^{M}\sum_{n=1}^{N}(A_{bn}A_{sm}T_{sbmn} - A_{bn}B_{sm}TW_{sbmn} + B_{bn}A_{sm}WT_{sbmn} + B_{bn}B_{sm}W_{sbmn}) \tag{18}$$

where

$$T_{sbmn} = (2m-1)(2n-1)\int_{0}^{\infty} E_s(u)E_b(u)\cosh^2 u\, D(u) J_{2n-1}(\beta) J_{2m-1}(\beta_s) du \tag{19}$$

$$TW_{sbmn} = 2m(2n-1)\int_{0}^{\infty} E_s(u)E_b(u)\cosh^2 D(u) J_{2n-1}(\beta) J_{2m}(\beta_s)\, du \tag{20}$$

$$WT_{sbmn} = (2m-1)\, 2n\int_{0}^{\infty} E_s(u)E_b(u)\cosh^2 u\, D(u) J_{2n}(\beta) J_{2m-1}(\beta_s)\, du \tag{21}$$

$$W_{sbmn} = 2m2n\int_0^\infty E_s(u)E_b(u)\cosh^2u\ D(u)\ J_{2n}(\beta)\ J_{2m}(\beta_s)\ du \tag{22}$$

Fore and Aft Strut Interference

$$\begin{aligned} R_{ws12} = \ & 2\pi\rho U^2 k_0^2 T_s T_{s1} \sum_{m=1}^{M}\sum_{n=1}^{N} (A_{sn}A_{slm}T_{sslmn} + B_{sn}B_{slm}W_{sslmn} \\ & + B_{sn}A_{slm}WT_{sslmn} + A_{sn}B_{slm}TW_{sslmn}) \end{aligned} \tag{23}$$

where

$$\begin{aligned} T_{sslmn} = \ & (2m-1)(2n-1)\int_0^\infty E_s(u)\ E_{sl}(u)\cosh^2u\ D(u) \\ & J_{2n-1}(\beta_s)\ J_{2m-1}(\beta_{sl})\cos(\beta_s C_s - \beta_{sl} C_{sl})\ du \end{aligned} \tag{24}$$

$$\begin{aligned} W_{sslmn} = \ & 2m2n\int_0^\infty E_s(u)E_{sl}(u)\cosh^2u\ D(u) \\ & J_{2n}(\beta_s)\ J_{2m}(\beta_{sl})\cos(\beta_s C_s - \beta_{sl} C_{sl})\ du \end{aligned} \tag{25}$$

$$\begin{aligned} WT_{sslmn} = \ & -(2m-1)\ 2n\int_0^\infty E_s(u)E_{sl}(u)\cosh^2u\ D(u) \\ & J_{2n}(\beta_s)\ J_{2m-1}(\beta_{sl})\sin(\beta_s C_s - \beta_{sl} C_{sl})\ du \end{aligned} \tag{26}$$

$$\begin{aligned} TW_{sslmn} = \ & 2m(2n-1)\int_0^\infty E_s(u)E_{sl}(u)\cosh^2u\ D(u) \\ & J_{2n-1}(\beta_s)\ J_{2m}(\beta_{sl})\sin(\beta_s C_s - \beta_{sl} C_{sl})\ du \end{aligned} \tag{27}$$

where C_s and C_{sl} are the distances between the centres of the body and fore strut and aft strut, respectively. When two struts are identical to each other, eqs. (26) and (27) cancel each other so that the result can be calculated simply, without calculating eqs. (24) and (25), by multiplying the resistance of the strut given by eq. (16) by the factor $\cos[\beta_s(C_s - C_{sl})]$.

3. SKIN FRICTIONAL RESISTANCE

Since a SWATH ship has several components which are different in length from one another, the skin frictional coefficient for each component is first calculated using the ITTC'57 formulae where Reynolds number is calculated based on the individual lengths of the strut(s) and body.

Then, the skin frictional resistance for each component is calculated by multiplying the coefficient by the factor 0.5 $\rho U^2 S$, where S is the wetted area of each component. Finally, the total skin frictional resistance coefficient of a SWATH ship is obtained by dividing the sum of the skin frictional resistances of all components by the factor 0.5 $\rho U^2 S_T$, where S_T is the total wetted area of a SWATH.

A correlation factor, $C_A = 0.0005$, which accounts for the roughness allowance for full scale ship, is used as most publised SWATH resistance data and programs used this value.

4. ADDITIONAL RESISTANCES

In order to account for the difference between the measured residuary and calculated wave-making resistances, empirical form factors known for streamlined shapes and foil sections have been separately applied to the each component of a SWATH ship in the published programs. For example, in SWATHGEN [3], form factors of 0.17 and 0.10 for strut and body, respectively, are used which fall into the range of two-dimensional airfoils and bodies of revolution similar in proportion to typical SWATH struts and bodies.

If there are many exprimental data on various SWATH configurations, a form factor accounting for the difference between the residuary and wave-making resistances can be directly derived. In order to try this direct approach, a large number of experiments on 21 individual configurations were carried out in the Department of Naval Architecture and Ocean Engineering, Glasgow University, U. K. [6~10]. Based on these experimental results, the differences between the residuary and calculated wave-making resistances for each configuration were plotted as a function of Froude number(Fn), and curves are then drawn through the data. Due to the scatter in the data, careful consideration was given before finally drawing two curves as shown in Fig. 2 (one is for circular hulled SWATH ships and the other for rectangular hulled SWATH ships). These form resistance coefficients vary depending on the component shapes of SWATH ships. Therefore, these curves should be used to SWATH ships similarly shaped to SWATH models used for the present study, but when the components of a SWATH configuration do not depart greatly from these models, these curves can be used without a serious error.

It is worthwhile noting that the form resistance has been found to be almost constant with the spacing between two demihulls which means that the cross flow between them is negligible. The form resistance coefficient decreases as the draft increases. Therefore, the form resistance coefficients are taken at the most probable draft range of 1.5 and 2.0 times the diameter of body.

5. APPENDAGE(FIN) RESISTANCE

Basically, the resistance of a controllable fin may be assumed to consist of five components :

$$R_{APP} = R_P + R_I + R_{HAI} + R_{TI} + R_W \quad (28)$$

where R_P is the profile drag, R_I the induced drag, R_{HAI} the hull-appendage interference drag, R_{TI} the tip drag and R_W the wave-making drag due to the presence of free surface.

Utlizing the flat ship theory, it has been proved[10] that the wave-making resistance contribution of controllable fins to the total resistance including the interferences with the other components of a SWATH is negligible in the range of the draft of practical SWATH ships. Therefore, instead of the complicated formulae including interferences with other components, an approximation to wave making resistance of the foil is employed, as given by [11] :

$$R_W = \frac{1}{2Fn^2} C_L^2 \exp\left(-\frac{2h_f}{cFn^2}\right) \frac{1}{2} \rho U^2 S_{PI} \qquad (29)$$

This is an equivalent vortex line approximation to the wave effect of the foil and Froude number should be calculated based on the chord. S_{pl} is the plan form area and the lift coefficient for the foil is given by [12] :

$$C_L = \frac{dC_L}{d\alpha_a} \alpha_a \qquad (30)$$

where α_a is the angle of attack. For a symmetrical foil section and small angle of attack(up to around 6 degrees), the gradient term in the above equation(so called lift slope) becomes 2π.

The profile drag is composed of flat plate friction plus form drag(sometimes referred to as pressure drag). For fins, the following empirical formula is used [3] :

$$R_P = 2C_f \left[1+2\frac{T_m}{c} + 100 \left(\frac{T_m}{c}\right)^4 \right] S_{PI} \frac{1}{2} \rho U^2 \qquad (31)$$

where c is the mean chord and T_m is the maximum thickness. The frictional coefficient is calculated based on the local Reynolds number[13].

The induced drag is calculated by the formula[14, p. 7~3] :

$$R_I = C_L^2 \left(\frac{1+K}{\pi AR}\right) \frac{1}{2} \rho S_{PI} U^2 \qquad (32)$$

where the AR is the effective aspect ratio and C_L the lift coefficient for the foil given by eq.(30). The factor K accounts for the increase in induced drag due to nonelliptic spanwise loading of the foil. At higher speeds and in the vicinity of free surface, this factor can reasonably be approximated to, as given by[11, p. 38] :

$$K = \frac{AR}{AR + 12(h_f/c)} \qquad (33)$$

where h_f is the submerged depth to the fin centre.

For the interference drag of a lifting surface intersecting a flat plate, the hull-strut interference drag is calculated using the formula from Hoerner[14, p. 8~10] :

$$R_{HAI} = \left[0.75\left(\frac{t_m}{c}\right) - 0.0003\left(\frac{c}{t_m}\right)^2 \right] \frac{1}{2} \rho U^2 t_m^2 \qquad (34)$$

The tip drag for each appendage can be estimated by the following formula, as given by Hoerner〔14, p. 6～4〕:

$$R_{TI} = 0.075\left(\frac{t_m}{c}\right)^2 \frac{1}{2}\rho U^2 c^2 \qquad (35)$$

where it is assumed that the tips are blunt and the lift coefficient is zero

6. COMPARISON WITH EXPERIMENTAL RESULTS AND CONCLUSIONS

In order to verify the accuracy and applicability of the computer program, the numerical results are compared with experimental results using three SWATH models. Table 1 shows the principal dimensions and coefficients of the SWATH 1, SWATH 2 and SWATH 3 models. The SWATH 1 and SWATH 2 are both tandem strut configurations and the SWATH 1 has circular cross section hulls and SWATH 2 has rectangular cross section (with rounded corners) hulls. The SWATH 1 tandem strut model was converted by inserting a parallel section between the maximum chord of the fore and aft struts on the demihull to make a continuous, smooth strut and designated as SWATH 3.

Fig. 3 to 5 show comparisons between the estimated wave-making and measured residuary resistance coefficients of the three models as well as demonstrating how each component of the models contributes to the total wave-making resistance. Theses figures also show the interference components such as between body and fore strut, between body and aft strut, between struts and between two demihulls. It can be easily understood from Fig. 3 and 4 that a very large hump at around Fn=0.31 for the SWATH 1 and SWATH 2 models is due to the large wave-making resista-

Table 1, Principal Dimensions and Coefficients for SWATH 1, SWATH 2 and SWATH 3

Model	SWATH 1－C5	SWATH 2－C3	SWATH 3－C1*
Length of Model, L_b	1.51	2.265	1.51
Body	Di_b=0.0892	Depth, D_b=0.0975 Breadth, B_b=0.15	Di_b=0.00892
Length of Strut, L_s	0.4	0.6	1.155
Maximum Beam of Strut, t_m	0.05	0.075	0.05
Draft, T	2.0 Di_b=0.1784	2.0D_b=0.195	0.1784
Depth of Strut, D_s	0.0892	0.0975	0.0892
Wetted Ares, S	1.0251	2.14394	1.1008
Displaced Volume, ▽	0.02175	0.06992	0.0261
C_p of Body	0.9	0.909	0.9
C_w of Strut	0.665	0.665	0.884
B_1=4b/L_b	0.762	0.762	0.762

Note : All units are in metres. *C5, C3 and C1 mean the condition numberings of model test series nce contribution of the struts coupled with the interferences between the other components, which cannot be expected in single strut SWATH ships as seen in Fig. 5. The difference between the two curves for wave-making and residuary resistances is generally called form resistance which accounts for the additional resistances described in the foregoing sections. In general, it is known that the quantity of the difference oscillates with speed about zero with a maximum amplitude of $\pm 1.0 \times 10^{-3}$. The main reason for the measured resistance having lower than the computed values at lower speeds might be due to the fact that no turbulence stimulation devices were used in the model tests. The form resistance of the rectangular hulled model is larger than that of the counterpart circular hulled model, in particular, at higher speeds due to its non-streamlined shape in trim.

Using the form resistance coefficient given in Fig. 2 and fin resistance formulae described in section 5, the total resistance of the SWATH 1 model with a pair of fins(NACA 0015) is calculated and compared with the experimental results (see Fig. 5). For the calculation, the angle of attack of the fins is assumed to be 2 degrees. It can be seen that the present estimations give excellent correlation with the experimental results.

In conclusion, the present computational tool gives very excellent correlation with the experimental results on the various SWATH configurations and hence, it can be used with good confidence for parametric and optimum studies of SWATH ships with regard to resistance.

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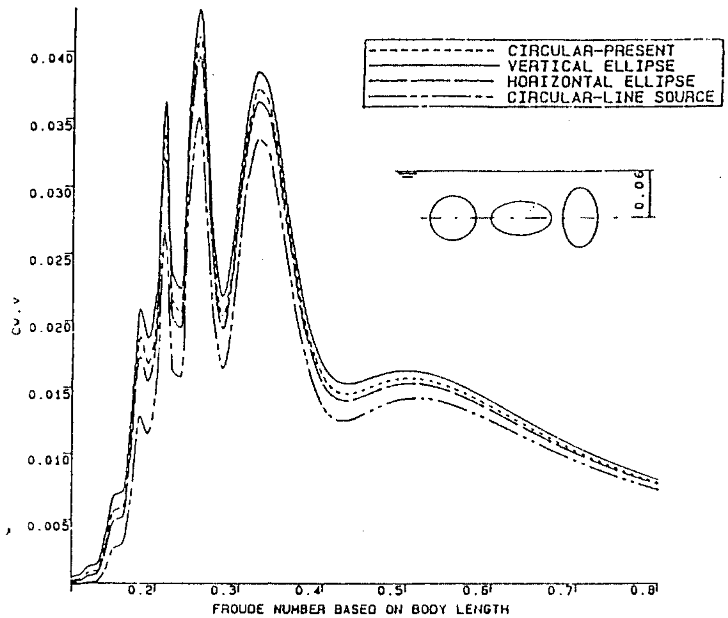

Fig. 1 Wave Resistance Coefficient Variations of Three Submerged Bodies of Various Cross Sections at the Fixed Submerged Depth to Body Centreline.

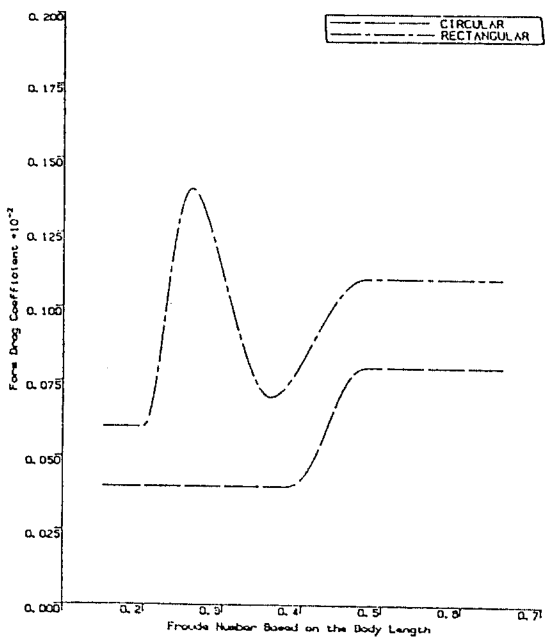

Fig. 2 FORM DRAG COEFFICIENT AS A FUNCTION OF FN

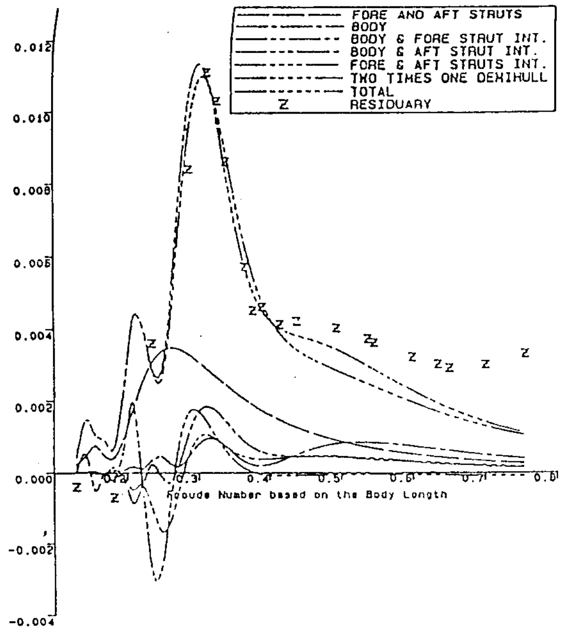

Fig. 3 Wave Resistance Coefficients of SWATH1-C5 and its Component Variations together with Residuary Rosistance Coefficient as a Function of Froude Number

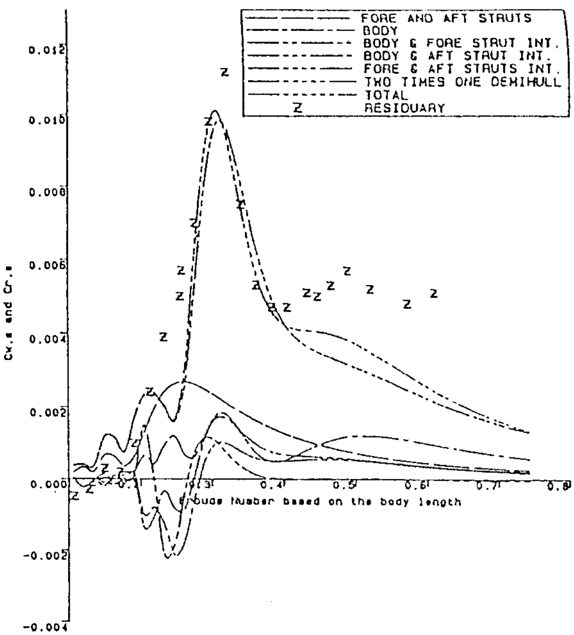

Fig. 4 Wave Resistance Coefficients of SWATH2-C3 and its Component Variations together with Residuary Resistance Coefficient as a Function of Froude Numnber.

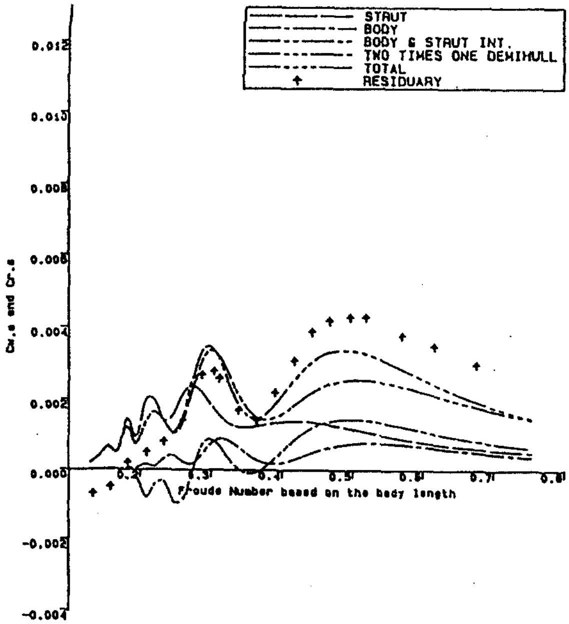

Fig. 5 Wave Resistance Coefficients of SWATH3-C1 and its Component Variations together with Residuary Resistance Coefficient as a Function of Froude Number.

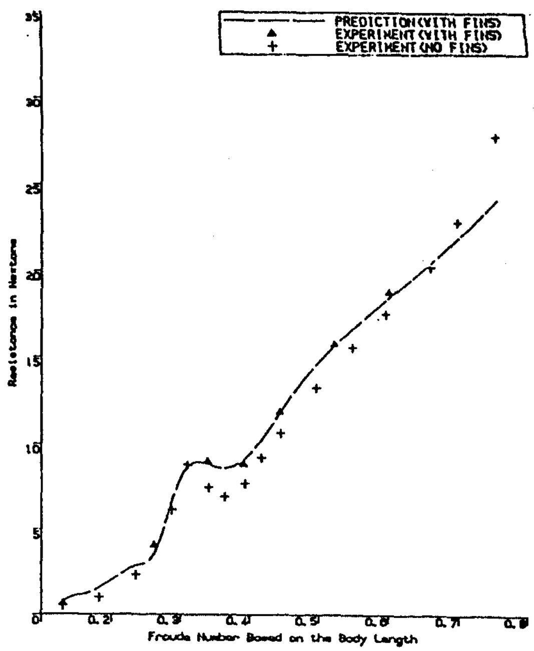

Fig. 6 Comparison of Estimated and Measured Total Resistancee of SWATH1-C4 with a pair of Controllable Fine