a narrow range of tasks relating to resistance proper, now the attention of the Committee is attracted to more general problems of the flow around the hull as well. The list of the basic problems alone includes a number of fundamental studies and methodological work.

At present the most important are the following two problems: the two-dimensional viscous flow and potential flow around the hull. Although both the problems were initially associated with viscous and wave resistance tasks, the importance of the flow-near-the-hull studies is beyond the problem of resistance and is of no less interest in solving the tasks dealt with by the Propeller, Cavitation, and Performance Committees

Valuable results in the boundary layer studies have been recently given by the semiempirical theory of three-dimensional boundary layer. Reasonable quantitative data were obtained for the shallow boundary layer. Worthy of notice are the comparative calculations of the boundary layers of ships, which were undertaken on the initiative of the Committee and the Swedish Maritime Research Centre. They show that until now the quantitative estimates of the layer behaviour at the aft end have not been accurate enough and much effort will be needed in the future to improve the semiempirical methods of computation. Alongside with the questions listed in the Committee Report, which are still to be clarified, it is essential that the determination of the potential flow characteristics needed for starting the boundary layer calculation should be more accurate, " the laws of resistance " in way of the after end and the turbulence model should also be improved. The next step in this direction will be preliminary accumulation of detailed information on the real flow. In this connection the Committee's proposal on carrying out joint comprehensive experimental studies of the boundary layer for various shapes of ships should be encouraged. In the course of further development of work in this direction it is advisable to combine and co-ordinate the efforts of all the Committees concerned in the solution of the primary tasks of improving the methods for the determination of flow parameters.

The second problem, which is potential flow around the hull, is directly concerned with the determination of the wave resistance of ships. A great contribution in this area was made by the Committee and the DTNSRDC who organized and carried out discussions of the results of wave resistance calculations for a number of ship types. The results showed that further development of computational methods for the determination of wave resistance under linearized boundary conditions would be unreasonable. The primary emphasis should be placed on the development of algorithms for the calculation of wave resistance within the nonlinearized boundary conditions. The principal object of this work should consist in the accumulation and analysis of test results, which subsequently would provide an unambiguous answer to the question of the possibility of practical application of wave resistance theory. In this respect further work under the cooperative program for 4 models of various types of ships should be appreciated.

Despite a number of studies where attempts are made to find wave resistance with consideration for the viscous effect of fluid, no reliable numerical data have been obtained so far. Consequently, studies on the theory of wave resistance in viscous fluid should also be continued.

It should be desirable to consider the

possibility of using some conclusions and theoretical results for the solution of such problems as elaboration of mathematical methods for hull form design and assesment of changes in propulsive performance due to deterioration of the hull and propeller surfaces.

The aforesaid and the very interesting report by the Committee show that the future Committee will be faced with the tasks which are serious and very important from the practical point of view.

V.S.SHPAKOFF - **Krylov Shipbuilding Research Institute, Leningrad, USSR**

ON CONSIDERATION OF SERVICE CONDITIONS IN THE INVESTIGATION OF VELOCITY FIELD IN A PROPELLER DISC AND SHIP RESISTANCE

The Resistance Committee report submitted for discussion at the 16th ITTC provides a thorough analysis of the present-day state of the theory and experimental facilities used to investigate the components of ship resistance and characteristics of flow around the ship hull.

It seems useful to touch upon two items related to the corresponding sections of the Committee's report, namely, on the investigation of the velocity field behind the hull and of the effect of roughness on ship resistance.

I. In recent years consideration of service factors in solving the practical problems of ship design has been used on an increasingly wide scale. This is dictated by the increased requirements for ship economical efficiency, reliability and habitability.Therefore, when speaking of velocity field characteristics behind the hull which provide important initial information for propeller design, calculation of ship propulsive performance and prediction of unsteady hydrodynamic loads on shafting and hull plating, it appears that today by the above characteristics should be implied ones which correspond to real conditions of ship operation. Here are meant, mainly, long-term operating conditions such as motion in a seaway which causes the ship oscillations, travelling in shallow water or in the water-ice two-phase medium . As yet, theoretical approach to this problem has been fairly difficult, also rather complicated is the experimental procedure involving the measurement of instantaneous values of flow velocities near the hull. Nevertheless, in the recent years The Krylov Ship Research Institute and, judging by publications, Japanese investigators have obtained a number of interesting results of practical importance characterizing the mechanizm of velocity field variation in course of ship oscillation, which gives rise to considerable fluctuation of unsteady hydrodynamic loads in the propeller-shafting system. The same thing can be said of the shallow water conditions whose influence on flow non-uniformity in the propeller disc places certain requirements upon the stern form, especially that of inland vessels.

Some rather unusual results of the model study of propeller-nozzle system operating conditions due to interaction with ice, when, as the results of self-propelled tests in ice basins and full-scale observations show, its thrust characteristics drastically decrease, and vibratory loading on propeller blades increases, have also been obtained recently and are given in the Papers of our Institute, prepared for this Conference.

The above can, to a degree, serve as an illustration of the importance of the

ITTC Executive Committee suggestions regarding a more close coordination of the efforts of the Technical Committees in solving the problems which are on the junction of their scientific interests.

2. The review of published papers given in the Committee Report indicates the attention which is given to the problem of investigating and taking into account the effect of hull roughness upon its resistance. One can distinguish two main trends aimed at solving this problem:

- determination of roughness allowance directly on the basis of ship full-scale trials in various stages of operation;
- determination of roughness function on the basis of experimental sample tests with subsequent extrapolation to full scale conditions.

In shipbuilding practice the results of tests carried out under item I in the form of various empirical formulae have been already used to determine roughness allowance. On the contrary, the lack of identity in the geometry of roughness of the test specimen and in that of the full scale hull becomes a serious hindrance to practical use of the results of tests carried out under item 2.

The investigation into hydrodynamical manifestation of roughness function seems to be more promising as more understandable physically and offering to obtain not only integral but also local flow characteristics in proximity to the ship hull. In the above-mentioned Papers of the Institute some findings on this problem are also given. Here I would like to note only that to avoid the main difficulty - the reproduction of real geometry of hull roughness - test specimen manufactured in the form of circular discs were painted according to the scheme accepted in shipbuilding practice and then kept in the conditions identical to those existing during ship outfitting afloat. Roughness functions obtained on the basis of experimental specimen tests relate to the same scheme of painting, that is their change depends only upon the time of specimen being in water. Also records of geometry statistical parameters were made after the tests on determination of roughness function were carried out. The measurement data indicate that during the time when test specimen are in water, not only the height parameters of the roughness but also roughness geometry structure are changing.

Future investigations of the Institute in this aspect suggest further study of the roughness characteristics and their effect for service conditions.

T.TACHIBANA - Instituto de Pesquisas Tecnológicas do Estado de São Paulo S.A. - IPT, Brazil

INVESTIGATION OF SHALLOW WATER EFFECTS ON SHIP

A Sinkage Prediction Method

This theoretical investigation has been developed in São Paulo Model Basin on gasdynamics theories, as suggested by Prof. H. Maruo of Yokohama National University.

Maruo (2) presents the following expression:

$$\frac{\partial \bar{u}}{\partial x}+\frac{\partial \bar{v}}{\partial y}=\frac{1}{gh}\left(\bar{u}^{2}\frac{\partial \bar{u}}{\partial x}+\bar{u}.\bar{v}\,\frac{\partial \bar{v}}{\partial x}+\bar{u}.\bar{v}\,\frac{\partial \bar{u}}{\partial y}+\bar{v}^{2}\,\frac{\partial \bar{v}}{\partial y}\right) \quad (1)$$

Considering a slender body with small relative angles in a uniform stream where discontinuities (like shock waves) are sufficiently weak and undisturbed velocity ($v+\phi_x$), then when $\bar{u}=\phi_x$, $\bar{v}=\phi_y$, $\bar{u}_x=\phi_{xx}$, $\bar{v}_y=\phi_{yy}$, $\bar{u}_y=\phi_{xy}$, $\bar{v}_x=\phi_{yx}$ it follows that :

$$(1-F_o^2)\,\phi_{xx}+\phi_{yy}=F_o^2\,(3\,\phi_x.\phi_{xx}+\phi_x.\phi_{yy}+2\,\phi_y.\phi_{xy}) \qquad (2)$$

where $F_o^2 = g.\frac{h_o}{v^2}$

In order to solve equation (2), jump conditions of discontinuities for quasi-linear systems expressed by conservation laws (Courant & Hilbert) are introduced:

$$\left[(1-F_o^2)-3F_o^2\,\frac{u_1+u_2}{2}\right](u_1-u_2)^2+(V_1-V_2)^2=0 \qquad (3)$$

where: u_1, v_1 : upstream shock velocity

u_2, v_2 : downstream shock velocity

And as boundary conditions:

a) $\left(\frac{\partial\phi}{\partial y}\right)_{y_2}-\left(\frac{\partial\phi}{\partial x}\right)_{y_2}=0$

b) $\phi_y(x,0)$ = F' (x) inside body

c) $\phi_y(x,0)$ = 0 outside body

Then a solution for shallow water is expressed by

$$\phi(x,y)=\frac{1}{\pi\beta}\int F(\zeta)\,\frac{x-\zeta}{(x-\zeta)^2+\beta^2y^2}\,d\zeta+$$
$$+\frac{K}{2}\cdot\frac{1}{2\pi\beta}\iint_{-\infty}^{\infty}\frac{x-\zeta}{(x-\zeta)^2+\beta^2(y-\eta)^2}\,u^2(\zeta,\eta)\,d\zeta\,d\eta \qquad (4)$$

where $\beta^2 = 1 - F_o^2$

For correlation of theory and experiment Inui's Mathematical models were used and sinkage and trim were calculated using the following expressions :

$$s/L = FN^2\,(h/L)\,\frac{CF-CM\cdot CA}{1-CA\,.\,CB}$$

$$t/L = FN^2\,(h/L)\,\frac{CM-CB\cdot CF}{1-CA\cdot CB}$$

where

$$CF = -\frac{\int u\,(x,y)\,.\,B\,(x)\,.\,dx}{\int B\,(x)\,.\,dx}$$

$$CM = -\frac{\int u\,(x,y)\,.\,x\,.\,B\,(x)\,.\,dx}{\int x^2\cdot B\,(x)\cdot dx}$$

$$CA = -\frac{\int x\cdot B(x)\cdot dx}{\int B\,(x)\cdot dx}$$

$$CB = -\frac{\int x\cdot B\,(x)\cdot dx}{\int x^2\cdot B\,(x)\cdot dx}$$

h = water depth

$FN^2 = \frac{U^2}{gh}$

s = sinkage

t = trim

B_o = ship breadth

L = ship length

d = ship depth

and

$$u(x,y)=u_L+\frac{K}{2\beta^2}\,\frac{u^2}{2}-\frac{K}{\pi\beta}\iint\frac{u^2}{2}(\zeta,\eta)\,\frac{(x-\zeta)^2+\beta^2(y-\eta)^2}{[(x-\zeta)^2+\beta^2(y-\eta)^2]^2}\,d\zeta\,d\eta \qquad (5)$$

where u_L is a linear part derived from the first integration of expression (4).

COMMENTS

a. The present theory is more accurate than the other theory, when we take a direct integration of shallow water equation.

b. The sinkage, how the experiment, is function of :

depth/length rate
depth Froude number
breadth/length rate
breadth function

c. The theoretical and experiments results of slender body are very close.

d. The aerodynamics and gasdynamics theory is applicable in ship hydrodynamics shallow water problem, how the Feldman & Lea.

e. The difference of results are computational approximation and consideration of ideal fluid.

MODEL'S CHARACTERISTICS

Number of Model	166	165	158
Lenght (m) L	1.500	1.500	3.048
Breadth (m) B	0.100	0.125	0.435
Draught (m) T	0.100	0.100	0.189
B/L	0.067	0.083	0.143
T/L	0.067	0.067	0.062
Displacement (kg)	17.750	18.200	130.30
Wetted Surface (m^2)	0.436	0.488	1.633

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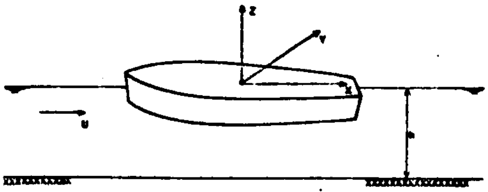
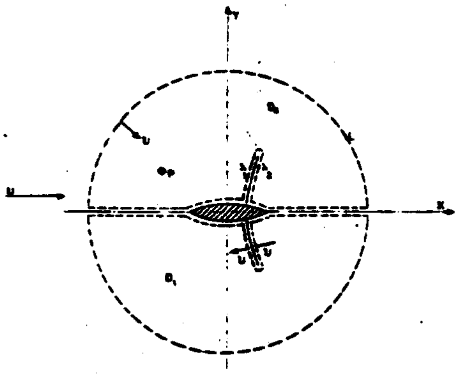


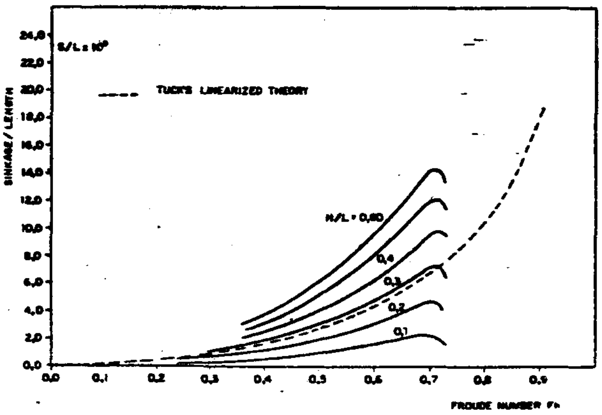
COORDINATED SYSTEMS

FIG. 1

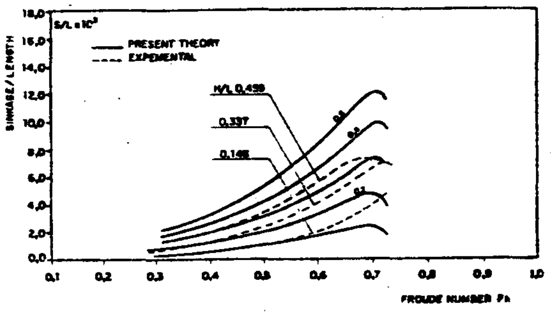


INTEGRATION FIELDS FOR GREEN'S THEOREM

FIG. 2

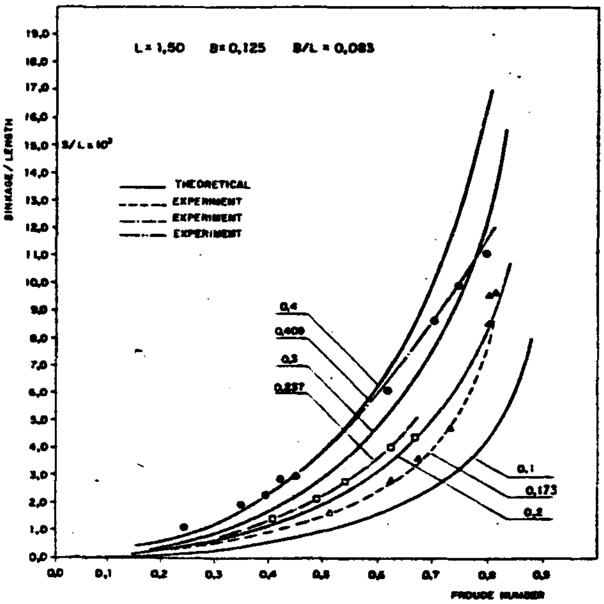


MODEL 166
COMPARISION OF TUCK'S THEORY AND PRESET THEORY
FIG. 3

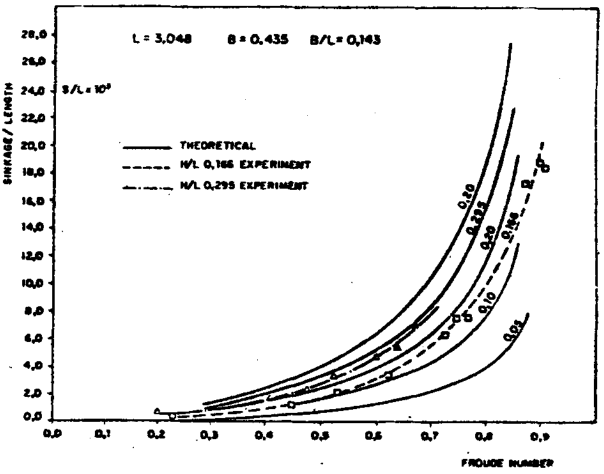


MODEL 166
- EXPERIMENTAL AND THEORETICAL RESULTS COMPARISON -

FIG. 4



MODEL 165
- THEORETICAL AND EXPERIMENTS RESULTS -
FIG. 5



MODEL 158
- THEORETICAL AND EXPERIMENTS RESULTS -
FIG. 6

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STUDY ON PREDICTION OF TRAILING VORTICES OF SHIP

The summaries concerning flow near ship stern (2.4) and trailing vorticity (2.5) are quite interesting.The trailing vortices have a serious influence on the flow near stern, nevertheless , the true aspect disappeared for lack of the data. I would like to explain recent experiences on this problem.

Experimental studies on trailing vortices of ships have been systematically performed by Tanaka and others of the Ship Research Institute (SRI). A factor that has a significant influence on wake distributions of full stern ships seems to be their trailing vortices , however, so far no definitive study has been made of the relationship between distributions of wake and of vorticity.

In order to find a controlling factor of strength of the trailing vortices, the authors intend to analyze the data of vorticity distributions on a propeller-disc-plane, which are steadily accumulated in SRI. An example of vorticity distribution is shown in Fig.1 comparing with its wake distribution. A current result is shown in Fig.2 in which the strength of the trailing vortices is presented as a function of bottom-area-coefficient, $\frac{A_B}{L^2} = C_W(Z=0)\cdot\frac{B}{L}$ (A_B ; bottom-area, $C_W(Z=0) = \frac{A_B}{L\,B}$, water plane coefficient at bottom of ship, L and B ; length and breadth of ship respectively).

The strength of trailing vortices may be surely represented by the circulation coefficients, $\frac{\Gamma}{UL}$ using measured circulation (Γ) on a propeller-disc-plane at velocity, U . It is experimentally confirmed that the circulation coefficient hardly changes by alternating 1) length of model, 2) full and ballast load conditions (but not extremely shallow draft), 3) Froude number and 4)towing and self-propelling conditions.

Contrary to expectations, a result of the analysis showed that fullness of an afterbody of ships or run angle does not seem to be adequate controlling factor of the strength of trailing vortices. Consequently, the author found that the bottom-area-coefficient made definite relation to the circulation coefficient, as in Fig. 2.

It is well known that wake distributions of full stern ship are partly concentrated so that its wake contour diagrams make a couple of "eye" as in Fig.1. Fig.2 also shows that there are two categories in wake distributions with "eyes" and without "eye" (having normal wake contours) and their trailing vortices have different characteristics.

Untill extending theoretical studies will be finished, the bottom-area-coefficient, by itself, is not a complete criterion of the trailing vortices. According to the present analysis, it can be imagined that accumulated vorticity in the boundary layer of a bottom of hull plays important role for generating the trailing vortices.

In this study, vorticity distributions were measured by the rotor-type vortexmeter developed by Tanaka and others, which were minutely explained in Ref. 1.

REFERENCE

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on the Structure of Ship Vortices Generated by Full Sterns, 12th Symposium on Naval Hydrodynamics.

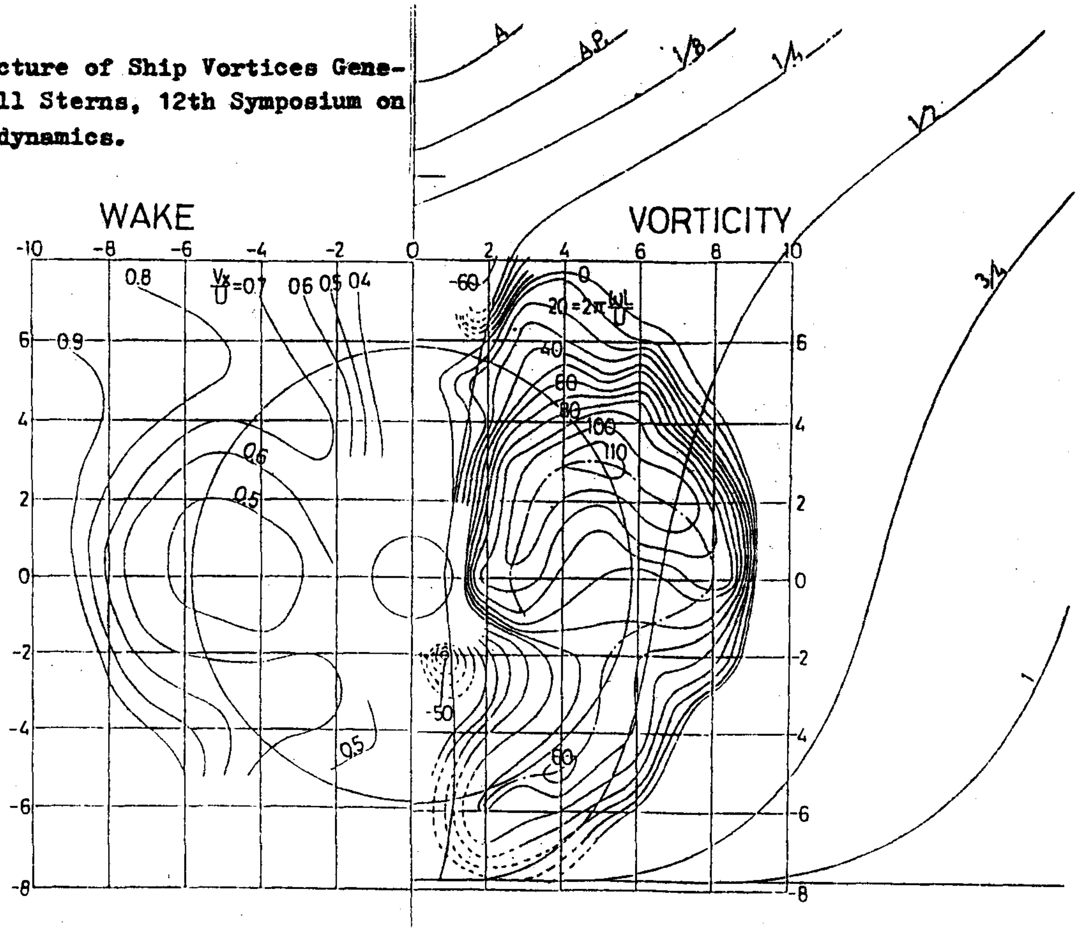

Fig.1 Wake and Volticity Distributions (Model F)
ω : Vorticity (sec^{-1})

Table 1 Measuring Conditions
and Particulars of Model Ships

Model Ship	Measur. Cond.		L	L/B	B/d	C_p
	Load. Cond.	Froud. No.	(meter)			
A	F	0.28	5	7	2.4	0.601
B	F	0.20	8.2	6	3.75	0.711
C	65%F	0.18	7	6	2.76	0.799
D_1/D_2	65%F	0.18	7/4	6	2.76	0.810
E	F	0.21	8.4	5.7	2.9	0.801
F	65%F	0.18	7	6	2.76	0.828

(F, Full Loaded Cond,)

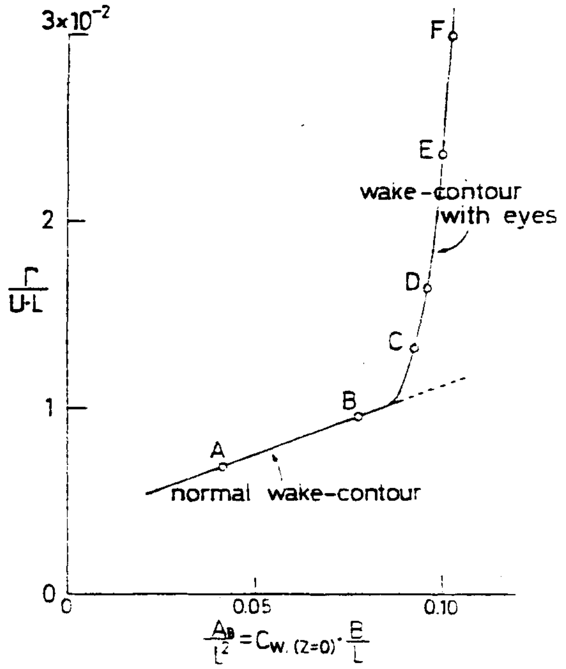

Fig.2 Relation between circulation (Γ) of Trailing Vortices and Bottom Area (A_B) of Models.

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A NEW SLENDER SHIP FORMULATION FOR STEADY FORWARD MOTION

The usual method of computation of the flow around the hull depends on the approximation that the surface of water is undeformable like a rigid wall. However it is known by the flow visualization that streamlines over the hull surface differ considerably from those of the double model and the inclusion of the effect of free surface evaluation is unavoidable for the determination of flow field around the hull which is necessary for the boundary layer calculation, unless the Froude number is extremely low.

No reliable method has been established so far, in respect of the accurate computation of the flow field around practical hulls when the free surface elevation is taken into account. A possibility is expected in the employment of the Neumann-Kelvin approximation which assumes the linearized free surface condition but deals with the body boundary condition in its exact form. However the process of solution of this method is by no means simple, because of the complication of the kernel which appears in the integral equation to be solved, and existing computers available in ordinary towing tanks and research laboratories are short of capacity for the purpose of computation with sufficiently high accuracy for practical feasibility. Therefore we should have much advantage in practical applications, if any other method which is simpler than the Neumann-Kelvin approximation would be available.

The method, which is introduced here, is an approximation derived from an application of the slender body theory. The slender body formulation for a ship in steady forward motion was first presented by Vossers. Then Tuck rearranged it by the use of matched asymptotic expansions. However numerical results for wave resistance by this theory have been very disappointing. Serious discrepancies between theoretical computations and tank test results even condemn the slender body approximation as almost useless.

The approximation we are considering here is not similar to the above-mentioned theory. It is basically equivalent to an approximation for the kernel function of the Neumann-Kelvin problem by means of the slender body assumption. The boundary value problem will be simplified to a considerable extent by use of this approximation.

Consider a uniform flow of velocity U in the direction of positive x taken along the longitudinal axis of the ship, and take the axis of z vertically downwards. In order to find out the asymptotic expression of the velocity potential for a slender ship, the lateral length in y and z directions is measured by a different scale from that of the longitudinal length in x direction, in such a way that we employ distorted coordinates $x^* = x$, $y^* = y/\varepsilon$, $z^* = z/\varepsilon$, assuming a small fraction $\varepsilon \ll 1$. Expanding the Kelvin source with respect to ε and discarding terms of the order of ε^2, we obtain an approximate expression for the velocity potential near the hull as follows.

$$\Phi = \Phi_1 + \Phi_2 \tag{1}$$

with

$$\Phi_1 = \frac{1}{4\pi}\int_{C(x)}\left(\frac{\partial\Phi_1}{\partial\nu} - \Phi_1\frac{\partial}{\partial\nu}\right)\ln\frac{(y-y')^2+(z-z')^2}{(y-y')^2+(z+z')^2}\,ds(y',z') \tag{2}$$

$$\begin{aligned}\Phi_2 = {}& \frac{1}{4\pi}\int dx'\Big[\pi K_0 H_1(K_0|x-x'|) + \Big\{\pi K_0 Y_1(K_0|x-x'|) + \frac{1}{|x-x'|}\Big\} \times \\ & \times \{1+2\,\mathrm{sgn}(x-x')\} - 2K_0\Big]\int_{C(x')} V_n\,ds(y',z') + \\ & + \frac{2\sqrt{K_0}}{\pi}\int^{x} dx'\int_{b(x')}^{\infty} V_z(x',y')\,E(x-x',y-y',z)\,dy'\end{aligned} \tag{3}$$

where C(x) is the contour of the transverse section of the hull at x, ν is its outward normal in the transverse plane, b(x) is the half breadth of the section, $K_0 = g/U^2$, and V_n and V_z are defined by

$$V_n = \partial\Phi_1/\partial\nu \quad (4), \qquad V_z = \partial\Phi_1/\partial z_{z=0} \quad (5)$$

The function E(x,y,z) is defined as

$$E(x,y,z) = \int_0^{\infty} e^{-u^2 z}\cos(u^2 y)\sin(u\sqrt{K_0}\,x)\,du \tag{6}$$

and is expressed by the complex Fresnel integral.

The boundary condition on the hull surface is expressed as

$$V_n = -Un_x - \frac{\partial\Phi_2}{\partial\nu} \tag{7}$$

Where n_x is the direction cosine of the outward normal of hull surface to the x axis. If V_n is assumed to be known, the potential is determined from eq.(4) by means of the conformal mapping of the section onto a unit circle in a complex plane. Since V_z is determined by V_n, eq. (7) provides an integral equation for V_n. An advantage of this approximation is that the solution of the integral equation does not necessitate the complex matrix inversion, and the boundary value problem becomes of the parabolic type instead of the elliptic type of the Neumann-Kelvin problem. The marching process can be effectively applied and numerical solution becomes much less laborious. The calculation of the flow field, such as velocities and the pressure distribution, is easily obtained from the differentiation of the velocity potential.

The wave resistance is determined from the momentum analysis of the far field expression of the velocity potential. The assumption of the slender body simplifies the expression derived from Havelock's formula. The approximate formula for the slender ship becomes then

$$\begin{aligned}R = {}& \frac{2}{\pi}\rho K_0^2\int_0^{\infty}\left|\int dx\int_{b(x)}^{\infty} V_z(x,y)\exp(iK_0 x\sqrt{v} + iK_0 y v)\,dy\right|^2 dv + \\ & + \frac{1}{\pi}\rho\int dx\int_{C(x)} V_n\,ds\int dx'\int_{C(x')} V_n\,ds\Big[\frac{1}{(x-x')^2} - \\ & - \frac{\pi}{2}K_0^2 Y_0\{K_0(x-x')\} + \frac{\pi K_0}{2(x-x')^2}Y_1\{K_0(x-x')\}\Big]\end{aligned} \tag{8}$$

The first term on the right hand side gives the wave resistance due to diverging waves and the second term gives the wave resistance due to transverse waves.

It is expected that the approximation presented here will provide a practically feasible method of computation of the flow around the hull, as well as the prediction of wave resistance.

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ON LINE INTEGRAL TERMS

The topic of line integral contribution to wave flow and wave resistance has been on the agenda of this Committee ever since it turned its attention to questions of wave resistance some twenty years ago. It is the discusser's belief that some of the intensive debates in our community could have been smoothened if a concise terminology had been elaborated at an early stage. Therefore, if even in the present report reference is made to this controversial issue, such statements should be made free from any ambiguity and safe against misinterpretation. This is my motivation for the following comments.

(i) Contribution to the flow field.

Under 1.2.1 (Computational methods) we read that " a line integral contribution along the intersection of the hull and the undisturbed free surface is automatically included in the Neumann-Kelvin formulation and in the low-speed theory." As far as the Neumann-Kelvin problem is concerned, a source line integral must be taken care of explicitly in order to achieve regularity of the flow nerated by a surface distribution over the hull and this obviously can not be achieved by whatever line integral term if we start with a normal doublet surface distribution*). As far as I am aware it was only Tsutsumi's approach which clearly incorporated a regularizing line integral term.

The next sentence reads: " A line integral is also included in higher-order theory even when the ship hull boundary condition is linearized". The discusser believes to have demonstrated once and for all at least at the 1976 Tokyo seminar that the consistent second-order potential may be generated from surface source distributions only, i.e. without any line integral term. And more recently, in appendix C of the paper quoted by Eggers and Gamst, he showed that the first-order thin-ship potential has the proper limit of normal velocity even under a sidewise approach within the undisturbed free surface. Hence a line integral " correction " to Michell's potential must disturb the regularity of the flow in the water line area, quite contrary to the situation encountered with the N.-K. problem. This is why the discusser feels embarrassed with regard to frequent lack of discrimination between the Neumann-Kelvin and the Michell approach.

(ii) Contribution to resistance.

Under 6) of workshop findings, with special application to transom stern ships, a "hydrostatic pressure drag" is referred to, defined as $\iint \rho g z \, dS - \int \rho g \zeta^2/2 \, dy$, where the integration is over the non-wetted part of the transom up to the undisturbed free surface $z=0$, (the effect of trim and sinkage may be included) and where ζ stands for the wave elevation. This is obviously a meaningful complement to any resistance calculation performed through integration of dynamic pressure (obtained by whatever method) over the <u>wetted part</u> of the hull, in particular for speeds larger than that for which incipience of transom emersion is observed and where this component divided by U^2 attains its maximum value.

It should be observed, however, that under the usual linearisation of the free surface condition and the consequent lirearisation of wave height it is the line integral term $\rho g \zeta^2/2dy$ (with orientation such that the contribution of the stern is positive) which must be subtracted from a normal pressure integral over the hull surface up to z=0 in order to take account of the wave profile for evaluating pressure resistance, whereas addition of this term yields the (far-field) wave pattern resistance, which is equivalent to the conventional integrals over a weighted amplitude (Kochin function) squared. The non-coincidence of these two expressions is a consequence of the inconsistency committed in linearizing the free surface condition, but not the hull boundary condition. The magnitude of the difference term, i.e. twice the line integral introduced above, indicates how far the use of such simplification is permissible.**)

*) On the irregularities of the wave-flow due to source panels and how to compensate them by adding Kelvin-source line elements. Contribution to the continued workshop Izu Shuzenji, 10-12. Oct. 1981.

**) A method for assessing numerical solutions to the Neumann-Kelvin problem. Contribution to the Izu-Shuzenji depth study meeting May 16-18 1980, published in an appendix, p. 526 ff of the Washington workshop proceedings.

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WAVE-RESISTANCE STUDIES APPLIED TO HULL FORM DESIGN PROBLEMS

In the Resistance Committee Report mainly discussed are the fundamental studies and the prediction methods of ship wave resistance, ship boundary layer and ship viscous resistance. Besides such fundamental studies, effort to improve hull forms and to find means to reduce ship resistance components has been also devoted.

In the Committee Report, however , the studies related to the application to hull form design problems are not reviewed. The present discussers think that the activity of Towing Tank in this area is also important. For reference a list of papers published in Japan after 15th ITTC is prepared and some comments are added.

(1) TSUTSUMI, T., An Application of Wave Resistance Theory to Hull Form Design, Journal of the Society of Naval Architects of Japan, Vol. 144, Dec. 1978.

(2) LIN, Y.J. et al., A Hull Form Improvement by Guilloton's Method, Journal of the Kansai Society of Naval Architects, Japan, No.172, March 1979.

(3) MIYATA, H. et al., On the Optimization of Aft-Part of Fine Hull Forms (First Report) , Journal of the Kansai Society of Naval Architects, Japan, No.177, June 1980.

(4) MATSUI, M. et al., A Method for Optimization of Ship Hull Forms based on Wave-Pattern Analysis Data, Journal of the Society of Naval Architects of Japan, Vol. 147, June 1980.

(5) TAKEKUMA, K., Hydrodynamic Design and Development of High Speed Cellular Container Ships in MHI, Mitsubishi Technical Review, Oct. 1980.

(6) MIYATA, H. et al., Resistance Reduction by Stern End Bulb (First Report), Journal of the Society of Naval Architects of Japan, Vol. 148, Dec. 1980.

(7) SAKAO, M. and SHIMOYAMA, N., On the Stern Waves of Transom-Stern Ships, Journal of the Kansai Society of Naval Architects, Japan, No.179, Dec. 1980.

(8) LIN, Y.J., et al.,On the Optimization of Aft-Part of Fine Hull Forms (Second Report), Journal of the Kansai Society

of Naval Architects, Japan, No.179, Dec. 1980.

(9) LIN, Y.J.et al., On the Optimization of Aft-Part of Fine Hull Forms (Third Report), Journal of the Kansai Society of Naval Architects, Japan, No.181, June 1981.

(10) MIYATA, H.et al., Resistance Reduction by Stern End Bulb (2nd. Report), Journal of the Society of Naval Architects of Japan, Vol.149, June 1981.

Papers by Tsutsumi (1) and Matsui et al. (4) deal with the application of wave-pattern analysis to hull form improvement. A series of paper (3), (8) and (9) by Miyata et al. and Lin et al. show the results of efforts on reduction of wave resistance of aft-body and on improvement of self-propulsion factors.

A series of study by Miyata et al.(6)and (10) make us aware of the importance of study on ship stern waves. The volume of stern-end-bulb is less than 1% of ship total displacement volume and it is located in ship viscous wake piercing the free-surface. Based on model experiments Miyata et al. explain that the stern-end-bulb is effective in reducing linear stern waves and weakening free-surface shock waves at the stern. About 5% of power saving has been confirmed by speed trials of 100 m class passenger with stern-end-bulb.

Because of the complexity of flow around ship stern, much effort has been devoted hitherto mainly in reducing bow waves. However, the studies by Miyata et al., Lin et al., a study of submerged stern bulb by Takekuma (5), and a study by Sakao and Shimoyama on stern wave of transom stern ships (7) indicate the importance of the study of stern waves and their reduction.

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ON THEORETICAL PREDICTION OF STERN FLOWS

I note with great interest with regard to the progress made with respect to flow near ship sterns. Mr. Zhou Liandi of CSSRC (1980) made calculations similar to Muraoka (1980) for the axisymmetric body tested by Huang. He applied a transformation so that points at infinity may be mapped onto a closed contour. This enabled him to solve the outer potential flow as well as the pressure variations and curvature effects, but saved much time in computation. He was able to carry out the computations up to a point about 1.04L behind the tail, and the agreement of computed results with that of Huang's experimental data was good. I regret , however, that I could not give a more detailed discussion right at the moment, since I received the Conference Proceeding only yesterday , and Zhou's work is not at hand. I hope that the Resistance Committee and the Conference will permit me to submit a supplementary written discussion of Zhou's contribution immediately after the closure of the conference.

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The Committee is to be congratulated on its excellent report which I enjoyed reading. I have a few comments:

1. Committee's cooperative experimental program is a very good idea, so MARIC supports it. We guarantee that we'll

finish the work in 1983.

2. We support Committee's recommendation that studies on bow phenomena should be continued. MARIC will do some work for it.

3. We appeal that some attention should be paid by the Committee to the research of appendage resistance of multi-screw ships because this is ship designers' headache problem. It is accepted that appendages yield no wave-making, but at shallow draft or higher Froude number it is not the case. MARIC is analysing this problem by wave pattern measurement now, and the 1st part of it is shown in (1). MARIC asks other ITTC members to do something about appendage resistance.

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1. Wang Huai, Du Shao-Qiu and Li Ying-Huan, "Analysing Appendage Resistance by Wave Pattern Measurement". Report No.K5110-2, the Ship Laboratory, MARIC, 1980.

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ANALYSING APPENDAGE RESISTANCE BY WAVE PATTERN MEASUREMENT

Abstract

This paper is the second part of the report on 'The Effects of Appendages on Ship Resistance and Propulsion'. It introduces the test results of appendage resistance through wave pattern measurement and orthodox towing test for a research ship model. Wave pattern measurement indicates that for a ship of medium draft the wave resistance of appendages is small. Due to interaction between hull and appendages, the wave pattern resistance of appendages (ΔC_{Wp}) shows humps and hollows with varying Froude number. The waviness of ΔC_{Wp} curve is in general accord with ΔC_W derived from towing test.

Nomenclature

The nomenclature used in the text follows the standard symbols of ITTC. Only a few special terms are defined as follows:

ΔC_r	Residual resistance coefficient of appendage,
ΔC_W	Wave resistance coefficient of appendage,
ΔC_{Wp}	Wave pattern resistance coefficient of appendage,
F	Sine amplitude function of free wave,
G	Cosine amplitude function of free wave,
FG	Amplitude spectrum of free wave.

Introduction

Appendages of multi-screw ships have an adverse effect on ship resistance, especially when designed improperly, so research on appendages is important to ship design.

Appendage resistance can be split into wave-making resistance, viscous resistance and that due to interaction between hull and appendages, etc. The viscous components have been studied in MARIC's low speed wind tunnel, and the results are presented as the first part of the report on 'The Effects of Appendages on Ship Resistance and Propulsion (1). Here, application of wave analysis method is attempted to the study of wave resistance of appendages. Generally speaking, it is accepted that deep-submerged appendages yield no wave-making. But when they are fitted on the hull of medium draft, will they exert any influence on the wave resistance of the hull ?

A model for a T.S. ocean research ship was tested in CSSRC's towing tank, including orthodox towing test and wave pattern measurement. The model length is 3.4 m, with a scale ratio of 1:30. The appendages fitted include: bossings, struts, bilge keels and a rudder (see fig 1, bilge keels not shown). The range of test speed is 0.6-2.1 m/s (corresponding to F_N =0.1 - 0.364), and that of Reynolds number is $2\times10^6 - 6.8\times10^6$. Wave profiles are measured for speeds $\geq$ 1.1m/s. In assessing form factor K , Hughes's method is adopted for the calculation of flat-plate frictional resistance

Subdivision of appendage resistance

According to Froude's hypothesis, the resistance of a naked hull can be separated into two components: frictional(which can be calculated by flat-plate frictional resistance formula) and residual. Alternatively, by the (1+K) method, hull resistance R can be subdivided into viscous resistance R_V and wave resistance R_W ; or more precisely

$$R = R_V + R_W = (1+K)\,R_f + R_W$$

However, such subdivision is not strict, because no interaction between the components is taken account of.

Similarly, appendage resistance ΔW may also be splitted into components. For example, W.C. Kiang (2) proposed that ΔW be subdivided into: equivalent flat-plate frictional resistance with curvature correction, pressure resistance , wave resistance and resistance for interaction between hull and appendages. Having studied the viscous part in wind tunnel, the authors attempt to assess the wave-making part through wave pattern measurement. The wave pattern resistance of appendages may be taken as the difference between the resistances of hull with and without appendages; or, in non-dimensional form

$$\Delta C_{WP} = C_{WPA} - C_{WP0} =$$
$$= R_{WPA}\Big/\tfrac{1}{2}\rho V^2 S_A - R_{WP0}\Big/\tfrac{1}{2}\rho V^2 S_0$$

where subscript A denotes hull with appendages, and subscript 0 denotes naked hull. In fact, ΔC_{WP} as measured includes also the wave-making interaction between hull and appendages.

To compare ΔC_{WP} with towing test results, residual resistance coefficient for appendages

$$\Delta C_r = C_{rA} - C_{r0} =$$
$$= R_{rA}\Big/\tfrac{1}{2}\rho V^2 S_A - R_{r0}\Big/\tfrac{1}{2}\rho V^2 S_0 =$$
$$= (R_A - R_{fA})\Big/\tfrac{1}{2}\rho V^2 S_A -$$
$$- (R_0 - R_{f0})\Big/\tfrac{1}{2}\rho V^2 S_0$$

and wave resistance coefficient for appendages

$$\Delta C_W = C_{WA} - C_{W0} =$$
$$= R_{WA}\Big/\tfrac{1}{2}\rho V^2 S_A - R_{W0}\Big/\tfrac{1}{2}\rho V^2 S_0 =$$
$$= [R_A - R_{fA}(1+K_A)]\Big/\tfrac{1}{2}\rho V^2 S_A -$$
$$- [R_0 - R_{f0}(1+K_0)]\Big/\tfrac{1}{2}\rho V^2 S_0$$

have to be calculated, where K_A and K_0 are the form factors for hull with appendages and naked hull respectively. It is admitted that splitting the resistance of hull with appendages into wave and form resistances by the (1+K) method does not sound reasonable. But it may be justified somewhat, since the sole intention is merely to compare the two analogous components obtained from different test methods.

Apparently, hull with appendages has a larger wetted surface, S_A , which leads to smaller coefficients not comparable to those for naked hull. As a remedy, the non-dimensional coefficients are rewritten as following, with S_A substituted by the square of model length:

Wave pattern resistance coefficient for appendages

$$\Delta C_{WPL} = \Delta R_{WP} / \tfrac{1}{2} \rho V^2 L^2 = (R_{WPA} - R_{WPO}) / \tfrac{1}{2} \rho V^2 L^2 =$$
$$= R_{WPA} / \tfrac{1}{2} \rho V^2 L^2 - R_{WPO} / \tfrac{1}{2} \rho V^2 L^2 = C_{WPLA} - C_{WPLO}$$

Wave resistance coefficient for appendages

$$\Delta C_{WL} = \Delta R_W / \tfrac{1}{2} \rho V^2 L^2 =$$
$$= (R_{WA} - R_{WO}) / \tfrac{1}{2} \rho V^2 L^2 =$$
$$= R_{WA} / \tfrac{1}{2} \rho V^2 L^2 - R_{WO} / \tfrac{1}{2} \rho V^2 L^2 =$$
$$= C_{WLA} - C_{WLO}$$

Residual resistance coefficient for appendages

$$\Delta C_{rL} = \Delta R_r / \tfrac{1}{2} \rho V^2 L^2 =$$
$$= (R_{rA} - R_{rO}) / \tfrac{1}{2} \rho V^2 L^2 =$$
$$= R_{rA} / \tfrac{1}{2} \rho V^2 L^2 -$$
$$- R_{rO} / \tfrac{1}{2} \rho V^2 L^2 = C_{rLA} - C_{rLO}$$

Test results and analysis

The wave pattern resistance coefficients C_{WPL} for hull with and without appendages obtained through wave pattern measurement (after Sharma's single-longitudinal-cut method) are shown in Fig.2, together with the wave resistance coefficients C_{WL} obtained through towing test. The form factors K for hull with and without appendages are calculated to be 0.364 and 0.28 respectively. From Fig.2 it is easy to deduce the wave and wave pattern resistance coefficients for appendages, which are given in Fig. 3, together with the residual resistance coefficient ΔC_{rL} for appendages.

From Fig.3 it can be seen that:

(1) Both ΔC_{rL} and ΔC_{WL} (through towing test) are greater than ΔC_{WPL}, and have humps and hollows with changing Froude number,

(2) ΔC_{WPL} (through wave pattern measurement) has positive and negative values, indicating the existence of wave-making interaction between hull and appendages,

(3) Though the accuracy of wave pattern measurement is not so high as towing test, the resistance curves obtained through different test methods are much alike in shape and tendency. It may be concluded that the humps and hollows in the resistance curves are mainly due to the effects of wave-making and interference between hull and appendages,

(4) The great difference between the values of ΔC_W and ΔC_{WP} may be due to wave breaking, the interaction between resistance components etc.. However, splitting the towing resistance of hull with appendages into its components by the (1+K) method is also questionable. These have to be investigated later.

From Fig.2, it may be seen that when $F_N < 0.33$ there is little difference between the wave pattern resistance for hull with and without appendages. To clarify this, wave profiles and wave amplitude functions for $F_N = 0.24$, 0.33 and 0.364 are given in Fig.4-7. For $F_N = 0.364$, there exist some differences both in amplitude and phase (Fig.4). As to $F_N = 0.24$ and 0.33, the wave profiles nearly coincide with each other. Wave amplitude functions F, G and amplitude spectra FG show similar tendency (Fig.5-7).

Conclusion

(1) Wave pattern measurement indicates that for a ship of medium draft such as tested the wave resistance of appendages is small,

(2) Due to interaction between hull and appendages, the wave pattern resistance of appendages (ΔC_{WP}) shows humps

and hollows with varying Froude number,

(3) The waviness of ΔC_{WD} curve is in general accord with that derived from towing test.

Acknowledgement

The authors wish to express their sincere thanks to the staff of CSSRC for carrying out the tank experiment.

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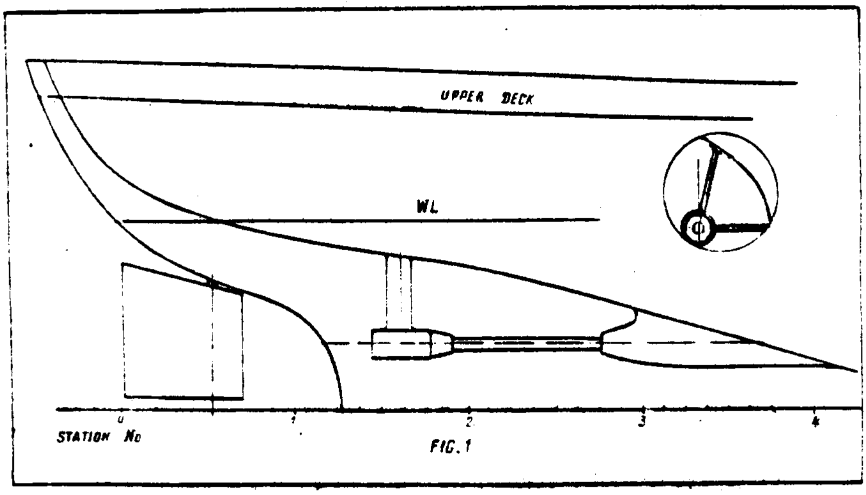


FIG. 1

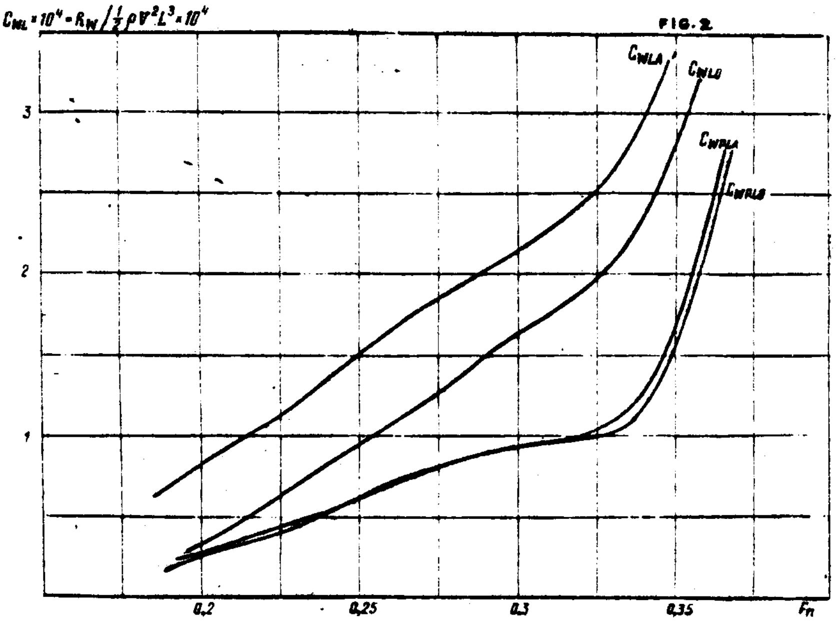
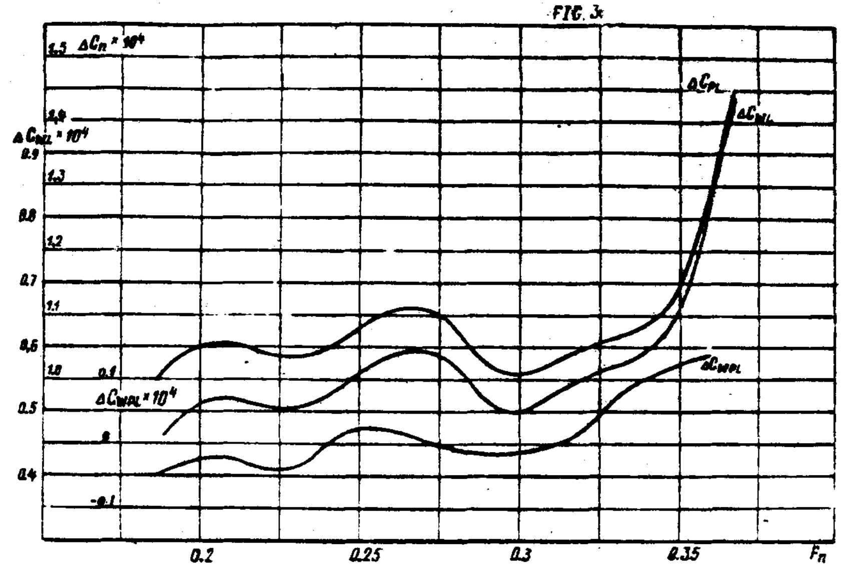


FIG. 2

FIG. 3x



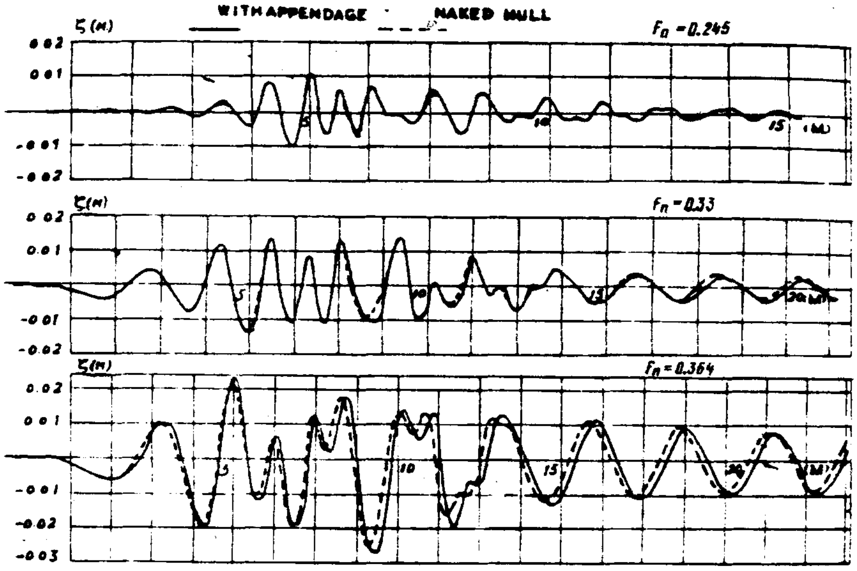


FIG. 4

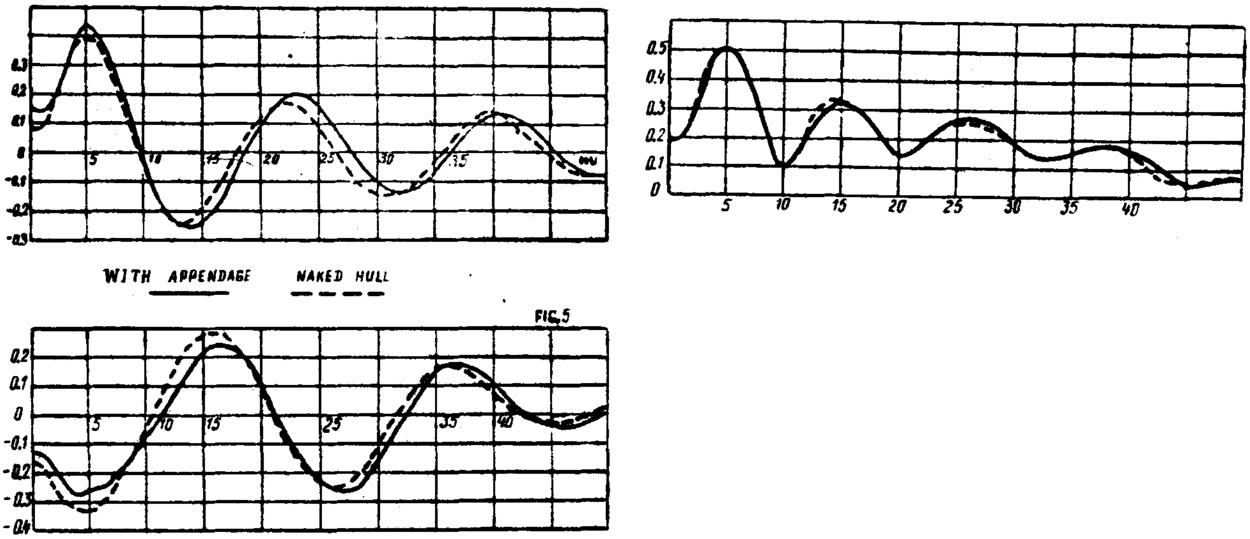


FIG.5

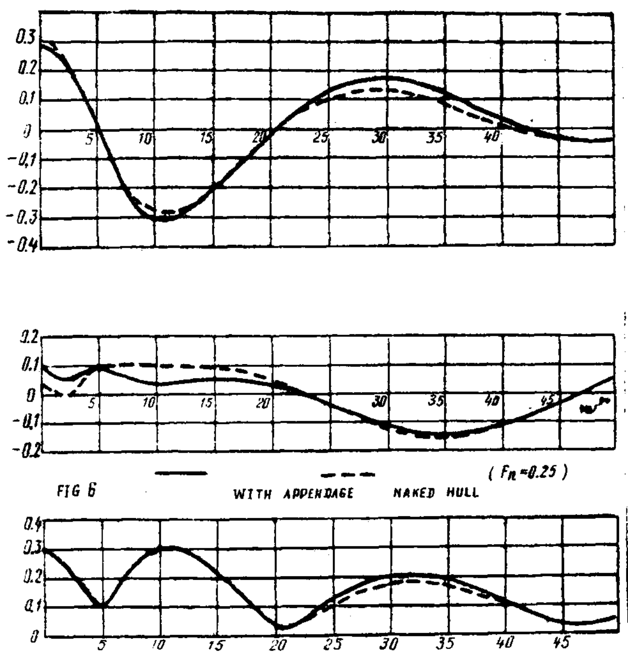


FIG 6

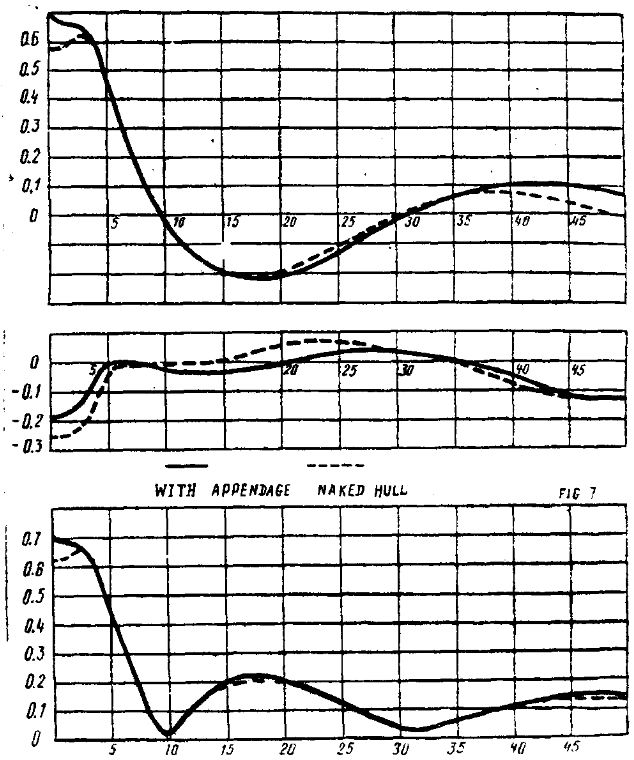


FIG 7

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A NOTE ON THE RANKINE SOURCE METHOD FOR FREE SURFACE FLOW PROBLEM: RADIATION CONDITION AND INFLUENCE OF TRUNCATION OF SOURCE DISTRIBUTION

Introduction

The method of Rankine source distribution is emerging as a powerful tool for the solution of complicated free surface problems. But it has been uncertain whether the radiation condition could be satisfied by distributing the simple sources on the free surface only.

This method was applied to two-dimensional free surface flow problems by Dawson [1] and Mori & Nishimoto [2]. They assumed the radiation condition be satisfied without proof by observing the sinusoidally varying wave profiles, which had been obtained by using a finite difference operator of specific order to satisfy the free surface condition.

Another effort was made by Gadd [3] to satisfy the radiation condition, who distributed the Kelvin sources along a longitudinal axis in the centerplane and Rankine sources on the free surface near the hull and on the hull surface. But as stated in the Report of the 16th ITTC Resistance Committee, more rigorous investigations of the numerical radiation conditions are necessary.

In recent work [4] , the present discussors showed that the Rankine source method could be applied successfully to the free-surface flow problems. In Reference [4] , they demonstrated that a remarkable accuracy could be maintained even with the distribution of lowest-order concentrated singularities of delta function nature. In their subsequent work [5] , the discussors made a general proof that even with the distribution of Rankine sources on the free surface the radiating waves could be generated. They also derived a formula to give bounds of the relative errors in the induced velocity computation due to the truncation of the extent of Rankine source distribution on the free surface.

It is the aim of this discussion to introduce the works of the present discussors on the Rankine source method and the associated problems of numerical radiation condition to the English readers.

Formation of the Radiating Waves by Rankine Source Distribution

Consider a linearized free surface boundary condition

$$\phi_{xx} + \kappa\phi_y = 0 \quad on \quad y = 0 \tag{1}$$

where k is the wave number. From equation (1), the velocity potential can be deduced to be sinusoidal in x, i.e.,

$$\phi \sim \cos(\kappa x + \alpha) \tag{2}$$

If we distribute sources on the free surface, the strength of the sources satisfying equations (1) and (2) should also be sinusoidal, i.e.,

$$\sigma(x) = \sigma_0 \cos(\kappa x + \theta) \tag{3}$$

In fact, in Reference [4] , it has been observed that the source strength be always sinusoidal in the downstream of body. In Reference [4], the two-point differentiation formula was used to calculate the variation of velocity along the axis (unlike the higher order of References [1] and [2]), and the free surface sources were repeated twice with the wave length λ .

Without losing the generality, the phase angle θ in (3) may be dropped, and the following analysis can be extended to the finite depth case with a properly defined wave number k and images of free surface sources with respect to the bottom.

Let us consider the Rankine source distribution as shown in Fig.1 whose strengths are varying sinusoidally. The sources extending from $-\infty$ to $+\infty$ could be placed either on the free surface or above the free surface. The latter cases will be used in the analysis.

The x-component of the induced velocity at a field point P(x,y) may be expressed as

$$u(x,y) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \sigma_0 \cos\kappa\xi \, \frac{x-\xi}{(x-\xi)^2+(y-\Delta y)^2}\, d\xi \tag{4}$$

With some manipulation and aid of integral tables, equation (4) can be reduced to (Refer to Reference [5] .)

$$u(x,y) = \left(\frac{\sigma_0}{2} e^{-\kappa\Delta y}\right) e^{\kappa y} \sin\kappa x \tag{5}$$

Similarly for the vertical induced velocity,

$$v(x,y) = \left(-\frac{\sigma_0}{2} e^{-\kappa\Delta y}\right) e^{\kappa y} \cos\kappa x \tag{6}$$

Then the velocity potential is obtained from equations (5) and (6),

$$\phi(x,y) = \left(\frac{-\sigma_0}{2\kappa} e^{-\kappa\Delta y}\right) e^{\kappa y} \cos\kappa x \tag{7}$$

This is the velocity potential obtained by the distribution of Rankine source from $x=-\infty$ to $x=+\infty$ on $y=\Delta y$. It is obvious from equation (7) that the sinusoidal distribution of Rankine sources could satisfy the radiation condition. But it is in practice impossible to distribute the sources in the infinite extent, hence it is important to know the influence of the truncation of source distribution on the computation of the induced velocities. A formula for the error analysis is derived in the next section.

Truncation Error Analysis

Let us assume the sources are distributed from $x = -\infty$ to $x = x_r$, and consider the error in induced velocity computations due to this truncation.

The x-component of the induced velocity at P(x,y)

$$u(x,y) = \frac{1}{2\pi}\int_{-\infty}^{x_r} \sigma_0 \cos(\kappa\xi+\theta)\frac{x-\xi}{(x-\xi)^2+(y-\Delta y)^2}\,d\xi \qquad (8)$$

Equation (8) can be deduced as (Refer to Reference [5] .),

$$\begin{aligned} u(x,y) = {} & \frac{\sigma_0}{4\pi}\cos\theta\left\{e^{\kappa(y-\Delta y)}\mathrm{Re}E_1(r_1)+e^{\kappa(\Delta y-y)}\mathrm{Re}E_1(r_2)\right\} + \\ & + \frac{\sigma_0}{2}\sin\theta\, e^{-\kappa(\Delta y-y)} + \\ & + \frac{\sigma_0}{4\pi}\sin\theta\left\{e^{\kappa(y-\Delta y)}I_mE_1(r_1)+e^{\kappa(\Delta y-y)}I_mE_1(r_2)\right\} \end{aligned} \qquad (9)$$

where E_1 is the exponential integral defined as

$$E_1(z) = \int_z^{\infty}\frac{e^{-t}}{t}\,dt\ , \quad |\arg z| < \pi$$

and

$$r_1 = -\kappa(\Delta y-y) - i\kappa(x_r-x)$$

$$r_2 = \kappa(\Delta y-y) - i\kappa(x_r-x)$$

Hence, the error in u(x,y) due to truncation is

$$\begin{aligned} \varepsilon_u \equiv {} & u|_{x_r=x_r} - u|_{x_r=\infty} = \\ = {} & \frac{\sigma_0}{4\pi}\left\{e^{\kappa(y-\Delta y)}\left[\mathrm{Re}E_1(r_1)\cos\theta + I_mE_1(r_1)\sin\theta\right] + \right. \\ & \left. + e^{\kappa(\Delta y-y)}\left[\mathrm{Re}E_1(r_2)\cos\theta + I_mE_1(r_2)\sin\theta\right]\right\} \end{aligned} \qquad (10)$$

Similarly, the error in v(x,y) may be obtained as

$$\begin{aligned} \varepsilon_v = {} & v|_{x_r=x_r} - v|_{x_r=\infty} = \\ = {} & \frac{\sigma_0}{4\pi}\left\{e^{\kappa(y-\Delta y)}\left[-I_mE_1(r_1)\cos\theta + \mathrm{Re}E_1(r_1)\sin\theta\right] + \right. \\ & + e^{\kappa(\Delta y-y)}\left[I_mE_1(r_2)\cos\theta - \mathrm{Re}E_1(r_2)\sin\theta\right] \end{aligned} \qquad (11)$$

Here, let us define the truncation error, ε , as follows

$$\varepsilon = \frac{\sqrt{\varepsilon_u^2+\varepsilon_v^2}}{\sqrt{\left(u|_{x_r=\infty,\,y=0}\right)^2+\left(v|_{x_r=\infty,\,y=0}\right)^2}} \qquad (12)$$

After proper substitution and manipulation, the error can be expressed as

$$\begin{aligned} \varepsilon = {} & \frac{e^{\kappa\Delta y}}{2\pi}\left\{e^{2\kappa(y-\Delta y)}|E_1(r_1)|^2 + e^{2\kappa(\Delta y-y)}|E_1(r_2)|^2 - \right. \\ & \left. + 2|E_1(r_1)|\,|E_1(r_2)|\cos(2\theta+\theta')\right\}^{1/2} \end{aligned} \qquad (13)$$

where $\theta' = -\tan^{-1}\dfrac{\mathrm{Re}E_1(r_1)I_mE_1(r_2)+\mathrm{Re}E_1(r_2)I_mE_1(r_1)}{\mathrm{Re}E_1(r_1)\mathrm{Re}E_1(r_2)-I_mE_1(r_1)I_mE_1(r_2)}$

By inspection, it is obvious ε becomes maximum when $2\theta+\theta' = \pi$, minimum when $2\theta+\theta' = 0$, hence the following inequalities are obtained

$$\begin{aligned} & \frac{e^{\kappa\Delta y}}{2\pi}\left|e^{\kappa(y-\Delta y)}|E_1(r_1)| - e^{\kappa(\Delta y-y)}|E_1(r_2)|\right| \\ & \leq \varepsilon \leq \\ & \frac{e^{\kappa\Delta y}}{2\pi}\left\{e^{\kappa(y-\Delta y)}|E_1(r_1)| + e^{\kappa(\Delta y-y)}|E_1(r_2)|\right\} \end{aligned} \qquad (14)$$

Figure 2 shows the typical case of error bound in the induced velocity computation with variation of the field-point position away from the truncation boundary. It can be seen that the maximum error is 76% when the field-point is placed at the truncation boundary (i.e. $x - x_r = 0$). It should, however, be noted that the maximum error be only 3.4% when the field-point is two wave lengths upstream of the truncation point in Reference[4] . It is clear, the error is between near zero and 3.4% depending on the phase angle of truncation θ defined in (13).

Conclusion

(1) It has been shown that the Rankine source distribution can be used to generate the radiating waves.

(2) The formula for the error analysis can be used effectively in determining the position of the truncation boundary.

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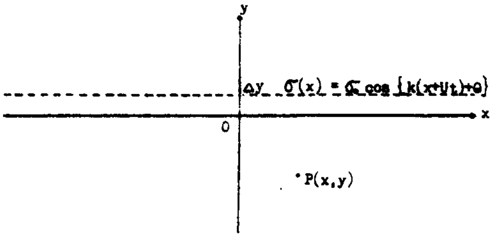

Fig. 1 Sinusoidal Rankine Source Distribution in Case of Infinite Depth

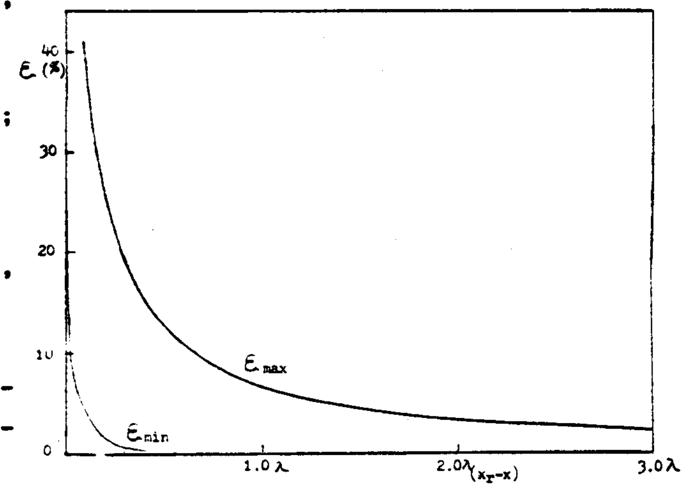

Fig. 2 The Upper and Lower Bounds of the Errors ε in the Induced Velocity Computation ($\Delta y = \lambda/20$, $y = 0$)

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A SIMPLE METHOD TO ESTIMATE THE VISCOUS RESISTANCE OF SHIPS BY TOTAL HEAD-LOSS MEASUREMENTS

Several methods to estimate the viscous resistance of ships by wake traverse measurements are checked by using available wake-survey data of a body of revolution and Series 60, $C_B=0.6$ and a new simple method is proposed within the reasonable accuracy of measurements. Let's distinguish eight formulae suggested in the past as follows:

D^{BT}	Tulin/1/
D^{J}	Jones/2/
D^{LW1}	Landweber and Wu /3/ eq.(20)
D^{LW2}	Landweber and Wu /3/, eq.(21)
D^{TL}	Tzou and Landweber/4/
D^{B}	Baba/5/
D^{M}	Maruo/6/
D^{L}	Landweber/7/, eq.(89)

Baba keebs only the total head-loss term, but the others differ in their treatments of the fictitious velocity. They suggest one-half ship-length behind the stern for the wake-survey, where effects of higher order terms and the measuring accuracy are compromized.

Here if we assume that the fictitious velocity u_1 is equal to the free-stream velocity U, then we can show that

$$D^B > D^J > D^{LW1} = D^{LW2} = D^{BT} = D^M = D^{TL} = D^L$$

Since the total head-loss mainly contributes to the viscous resistance, Baba's form is very simple and convenient. Both the total head-loss and the velocity (or static pressure) should be measured when another formula is adopted. This requires much more works and complex devices. Therefore a way to correct the velocity-quadrature term from measured total head-losses is suggested here. For that the velocity is obtained from the total head by assuming the static pressure is fully recovered to be p_e. That is

$$\rho g H = p_0 + \frac{1}{2} \rho u^2 \qquad (1)$$

Since $H=H_e$ and $u=U$ at the edge of the wake, they are consistent assumptions. Then the velocity is given by

$$u = \sqrt{U^2 - 2g(H_0 - H)} \qquad (2)$$

where H_0 is the total head in the free-stream. If we substitute eq.(2) into Landweber and Wu's first formula, then the viscous resistance D^K is given by

$$D^K = \gamma \int_W \left[(H_0 - H) - \frac{1}{2g} \left\{ U - \sqrt{U^2 - 2g(H_0 - H)} \right\}^2 \right] dS \qquad (3)$$

Measured wake data of a low drag body of revolution ($L=1.219$m, $r_{max}=0.1426$m, $R_L= 1.2\times10^6$), which was tested in the wind tunnel by Patel and Lee/8/ for the research of the thick boundary layer and near wake, are available. Estimated values of the resistance coefficient are represented in Fig.1. They are considerably decreasing in magnitude along down-stream. Blockage effects and higher order terms neglected in the formula can not explain this large deviation. The interesting point to us is the comparison of them at a fixed station.

The order of magnitude of estimated resistances is as follows:

$$D^B > D^K > D^{TL} > D^L \doteqdot D^J \doteqdot D^{LW1} \doteqdot D^{LW2} \doteqdot D^{BT} \doteqdot D^M$$

Discrepancies among estimated resistances, except formulas of Baba, Tzou and Landweber and present study, are less than 1% even at the very near wake ($x/L = 1.06$). This shows that the assumption $u_1=U$ is very rearonable for practical purposes. On the other hand, discrepancies of the resistance by D^K from D^{LW2} are still less than 1% at x/L = 1.4 and 2.472. Therefore the present formula is verified to be efficient one if the wake survey is performed at one-half body length behind the ship.

Resistances according to D^B, D^{TL}, D^{LW1} and D^K by using the available wake data of Series 60, C_B=0.6 model, which was tested in the towing tank by Tzou and Landweber /4/, are also compared in Table 1. In the first column are shown the estimated resistance from the original work of Tzou and Landweber. Recalculated values are represented in the second column, which shows differences from the original ones. Wake data at two depths (z=0.025, 0.075ft) are not available in the reference /4/. That seems to be a main reason of such deviation. Therefore recalculated values are used as a reference for the numerical consistency.

Estimated values of the viscous resistance by D^B is overpredicted by about 5%. D^{LW1} which adopting the assumption u_1= U shows the same values as D^{TL} within 0.5% deviations. The present formula D^K also gives reasonable values (less than 1% error except at F_r=0.332).

Such results coinside with Kayo's /9/ conclusion that any significant differences between formula are within the experimental accuracy. But simple integration of the total head loss will considerably overpredict the resistance. A new simple formula suggested in this discussion is verified to give reasonable estimations of the resistance by measuring the total head only. Therefore it will be a time-saving and efficient one.

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Table 1. Comparison of resistance coefficients(Series 60, 0.6)

Fr	D^{TL***}	D^{TL}	D^B	D^{LW1}	D^K
0.166	3.64*	3.79	3.99(5.1)**	3.80(0.3)	3.81(0.5)
0.193	3.44	3.75	3.90(3.8)	3.74(-0.3)	3.75(0.0)
0.221	3.31	3.85	4.01(4.0)	3.87(0.5)	3.86(0.3)
0.249	3.21	3.35	3.50(4.3)	3.36(0.3)	3.37(0.6)
0.276	3.43	3.53	3.68(4.1)	3.53(0.0)	3.53(0.0)
0.304	3.53	3.91	4.05(3.5)	3.91(0.0)	3.89(-0.5)
0.332	3.41	3.27	3.43(4.7)	3.26(-0.3)	3.31(1.2)

* Resistance coefficients x 10^{-3}

** Relative error from Tzou and Landweber' method(%)

*** Reffered from /4/

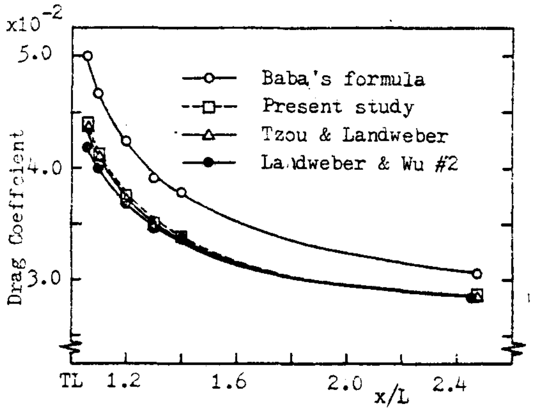

Fig.1 Resistance coefficients of a low-drag body of revolution

J.V. WEHAUSEN - University of California, Berkeley, California, USA

In Appendix 2 of the Committee Report a cooperative experimental program is proposed for four hull forms. I urge that the experimental program include tests with the hulls fixed in their zero-speed equilibrium positions. This may seem to be unrealistic, but in fact takes account of the fact that many theoretical calculations are initially carried out for this case. If good agreement with appropriate experiments is obtained, one may then devise computational methods that include the effects of sinkage and trim.

T.A. LOUKAKIS - National Technical University, Athens, Greece

Before my comments to the Committee Report, I would like to mention that in future resistance experiments, to be used for the validation of prediction theories, the models can be run even-keeled by pre-trimming them in the static condition. The initial draft plus the measured parallel sinkage can then be used for the analytical predictions. This should be a cheaper method than restraining (especially) heavy models.

I would like now to notice that, in my opinion, both the report of the Committee and the up-to-now discussion of it give me the impression that I am attending a "Numerical Ship Hydrodynamics Symposium" and not a Towing Tank Conference.

If this trend is justified by practical considerations, meaning that more and more numerical work will be done in our Organizations, I would like to suggest that:
a) the numerical solution of the viscous resistance problem is done using not the double model inviscid potential but rather a potential, which takes account of the free surface. In this way the predictions will correspond better to the real life problem.

b) During the numerical calculations for the viscous resistance, some of the problems in the stern region might be alleviated if the propeller effect is included, even in some simple form as e.g. momentum sources.

B.R. PARKIN - Applied Research Laboratory, the Pennsylvania State University, State College, Pennsylvania, USA

This discussion amplifies the material of the Committee Report relating to potential flow methods for submerged bodies. For axisymmetric flows there appear to be three approaches which lead to a solution of the inverse or design problem in which one prescribes the pressure on the body surface and then calculates the shape of the body which will provide this pressure distribution. These three approaches are reported in the following four references.

1. BRISTOW, D.R., "A Solution to the Inverse Problem for Incompressible, Axisymmetric Potential Flow," AIAA Paper 74-520, June 1974.
2. ZEDAN, M.F. and DALTON, C., "Incompressible Irrotational Axisymmetric Flow About a Body of Revolution: The Inverse Problem," J. of Hydronautics, Vol. 12, January 1978, pp. 41-46.

3. ZEDAN, M.F. and DALTON, C., "Potential Flow Around Axisymmetric Bodies: Direct and Inverse Problems," AIAA Journal, Vol. 16, March 1978, 242-250.
4. FERNANDEZ, J., "A Higher Order Surface Singularity Method for the Axisymmetric Inverse Problem," The Pennsylvania State University, Applied Research Laboratory, Post Office Box 30, State College, PA 16801, Technical Memorandum File No.TM 79-125, 1979.

Reference (1) is based upon the iterated use of the Douglas-Neumann direct solution. References (2) and (3) use sources or sinks along the axis of the solid and Reference (4) uses source or sink rings as fundamental building blocks for the solution.

In addition to these solutions, the related mixed boundary value problem for axisymmetric bodies has been studied by Bulgarian and Soviet hydrodynamicists. Two citations to this literature are

5. VOSAMOV, K. and HAIMOV, A.J., "Axisymmetric Potential Flow About a Multiply-Connected Body in a Duct," Proc. of the Sixth Conference on Fluid Machinery, Scientific Society of Mechanical Engineers, Section of the Technical Sciences, Hungarian Academy of Sciences, Budapest, 1979.

A related work involving vorticity is

6. VOSAMOV, K. and HAIMOV, A.J., "Axisymmetric Shear Flow in Ducts," Hydro-Turbo 81, Bulgarian Ship Hydrodynamics Center, Varna 9003, Bulgaria.

In these solutions, vortex rings are used as fundamental solutions.

REPLY OF THE RESISTANCE COMMITTEE

The members of the Resistance Committee thank all discussers for their contributions which have enhanced the value of the Committee's Report. Most discussions provide new material but some contain comments and suggestions concerning the report itself. In the following, replies are given in the same order as the discussions were presented.

Dr. Shpakoff discussed two problems. With regard to the problem of the added resistance caused by real ship roughness it is necessary to know the influence of roughness on the boundary-layer velocity field and the relationship between this influence and the geometrical and statistical characteristics of the roughness. In spite of previous investigations a satisfactory formulation of this relationship is not yet available. Therefore investigators often use data from experiments with regular, artificial roughness even though its influence upon the boundary-layer characteristics is different. The information about new results which were obtained at the Krylov Institute is interesting and we are looking forward to publication in full detail. It is important to compare the results of the rough-disk experiments with data obtained in experiments with pipes and flat plates.

The problem of shallow water is of great practical value but knowledge of shallow-water effects on wave and viscous resistance is still insufficient. There are difficulties with experimental and theoretical investigations in shallow water especially when the ship speed is near its critical value. Therefore, in accordance with Dr. Shpakoff's remark, it would be useful for future Resistance

Committees to evaluate investigations of ship flow and resistance in shallow water.

The quantification of longitudinal vorticity in the wake is an important practical problem and *Dr.Tanaka* shows an interesting correlation between the circulation in the wake and the so-called "bottom area coefficient" (Fig.2). Such a correlation between a flow property and a purely geometrical property of the hull is surprising. However, since the longitudinal vorticity in the wake results from the migration of boundary-layer fluid on the bottom of the hull to the side, and over the stern, the bottom geometry may be an important parameter. We look forward to further development of these ideas especially to study other hull shapes and possible scale effects on the observed correlation.

The Committee welcomes *Prof. Maruo's* new slender body theory. It is a refreshing departure from the old slender body theories, which were based on the representation of the hull by a line of singularities and proved to be of limited value for the purpose of calculating wave resistance. The new theory now presented amounts to the use of surface singularities and uses elementary solutions of a two-dimensional problem as building blocks for the construction of a solution to the actual three-dimensional problem. It appears to be closely related to the recent "unified" slender body theory of Newman, Mays and Sclavounos. It would be useful if Professor Maruo would illuminate this connection and also a possible relation to the recent work of Noblesse which is also called a new slender body theory by the author. The final proof of the pudding is in the eating, of course. So we look forward to a numerical evaluation of Professor Maruo's multiple integrals for wave resistance, preferably for one or more of the hulls recommended by the Committee for its Cooperative Experimental Research Program and already used as test cases for the 1979 Wave Resistance Workshop.

Prof. Eggers legitimately points out the ambiguous use of the term "line integral" in the Committee Report as well as in many recent papers on ship wave theory. His plea for semantic precision is well taken; however, it also applies to various other terms such as thin ship theory, slender body theory, higher order effects etc. Evidently, a more precise and logical terminology would be of great help. As to the "line integral" itself, one should distinguish between the line integrals of convenience, which are mathematically equivalent to certain surface integrals and may be optionally used in consistent higher order thin ship theory as a matter of expediency, and line integrals of necessity required for regularizing the flow near the edge of the singular surface in the inconsistent, so-called Neumann-Kelvin approach to the problem. Professor Eggers' statements are substantially correct and constitute a useful elucidation of the remarks in the Committee Report. However, the entire theory of wave resistance is still in an active state of flux; so it would be premature to conclude that the intricate question of the usefulness of "line integrals" had already been settled.

The list of recent Japanese publications presented by *Drs. Tamura and Baba* dealing with the application of wave resistance theory to hull design is a welcome addition to the report. The absence of such material results from the Committee's decision to focus attention on methods of computation of the wave-making and viscous resistance of specified hulls, as highlighted by the two workshops planned in cooperation with the Committee, rather than the inverse problem of hull design. This decision arises from the space limitations imposed on the report and in view of some coverage of the applications of theory to design given in the Committee's report to the 15th ITTC. It is quite obvious that the design problem is still an important topic which should be considered in future Resistance Committee reports.

Prof. Gu has informed the Committee of the application at CSSRC of a calculation method similar to that of Muraoka to the flow past an axisymmetric body. We hope that the referenced paper will be made available soon.

The Committee appreciates very much MARIC's announcement of its interest to take part in the Committee's cooperative experimental program and also its plan to do studies on bow flow phenomena.

The wave pattern measurements carried out by *Messrs.Wang, Du and Li* with a model of a multiple-screw vessel are noted with interest. The results show that the appendage drag is not only a function of the Reynolds-number but also of the Froude-number, at least for small drafts. The next Resistance Committee should consider the possibility of evaluating research on appendage drag.

The contribution of *Messrs.Yang, Kang and Lee* deals with the application of Rankine sources to satisfy the boundary conditions on a free surface. In order to estimate the error which arises when the source distribution is truncated, the velocity field of a given sinusoidal source distribution has been calculated for a two-dimensional problem. The authors claim that the error will not exceed 3.4% if the field point is two wave lengths upstream of the truncation point. In this way, however, the effect of the truncation in the real problem is only taken into account partly. The truncation of the singularity surface before the unknown source strengths have been determined, will affect the source strengths upstream of the truncation point and introduce an error of unknown magnitude not estimated by the authors.

Dr.Kang's contribution is a comparative study of various alternative formulas for estimating the wake momentum resistance, carried out at KIMM. A simplified new formula is also proposed.

As is pointed out, many methods for determining the viscous resistance from a wake survey have appeared since the early work of Prandtl, who suggested that the resistance could be simply obtained by integrating the total head loss across the asymptotic wake. This original suggestion was later refined by Betz, Jones and others, who added extra terms to Prandtl's formula involving static pressure, to enable momentum surveys much closer to the body. Baba, however, some ten years ago reverted to Prandtl's method for the sake of simplicity.

In the present proposal an extra term of the Betz type is retained but calculated on the assumption that the pressure is constant in the wake and equal to that in the free stream. As in Prandtl's method, the only quantity which needs to be measured then is the total head. Support for this suggestion is given by comparisons with some of the more exact methods for two test cases.

It is the opinion of the Committee that the extra effort of also measuring the static pressure in addition to the total head is not necessarily very substantial and this would of course speak in favour of the more exact methods. However, the demonstrated correspondence in performance between these and the present proposal is quite striking and the Committee feels that if such similarity could be given further evidence the method may well be recommended as a convenient tool. It should be remarked that comparisons should be made for bodies in the presence of the free surface, since the waves may prevent the static pressure from reverting to the free stream value for a long distance behind the body.

The suggestion by *Prof. Wehausen* that experiments under the Committee's Cooperative Experimental Program be conducted with the model fixed is endorsed and is in fact included as one of three conditions to be investigated by participants.

Prof. Loukakis raises several questions related to our report:

1. It is suggested that instead of recommending a fixed model in the resistance tests of the cooperative experiments the model should be pretrimmed in such a way that the even keel condition is obtained at the Froude number of interest. The Committee agrees that this might be a method worth trying, since the disadvantage of the transmission of carriage vibrations to the model might then be alleviated. For very big models this disadvantage is a serious one.
2. Professor Loukakis also suggests that a potential flow considering the free surface should be used instead of the double model solution when computing the boundary layer. This suggestion is reasonable, but it probably requires better methods with respect to the free surface boundary condition than what are available today. Larsson & Chang (1979) used the Neumann Kelvin solution for calculating the boundary layer, but since the upper streamlines did not coincide with the computed wave profile (which was close to the measured one) the results were worse than those based on the double model potential.
3. Professor Loukakis raises an important question when he asks why stern flows are not studied with the propeller in operation. The Committee believes that the present emphasis on base sterns in most experimental and theoretical investigations may be attributed to several factors, e.g.
    1. The stern boundary layer is complicated even before it comes under the influence of the propeller.
    2. Although propeller-induced suction may prevent or alleviate separation at the bottom of the stern, the separation near the top of the propeller disc (and at the free surface for shallow drafts) is accentuated.

3. As discussed in the Report of the Performance Committee (pp. 168-171), the propeller may induce strong asymmetry and unsteadiness of the stern flow.

Therefore, studies without a propeller are useful in the understanding of certain basic flow features essential to the development of analytical models. Needless to say, the eventual goal of the models is to represent the real flow with propellers.

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