

SESSION ON FLOW AROUND THE HULL
RESISTANCE

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Discussion of the Report and the draft Recommendations of the RESISTANCE COMMITTEE

I. DISCUSSIONS

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First of all, I must express my gratitude to all members of the Resistance Committee for their efforts exerted to preparation of this excellent report within rather limited time. However, I would like to add a few comments on the Recommendations (pp. 52):

- The report reads in item 1) that "Further studies of possible interactions between viscous and wave effects". In my opinion this item is rather advanced course and must be mentioned at the final stage of the report. The problem of "Flow around Hull" can

be treated with the highest efficiency by separating into two problems i.e. first: "The flow around the Bow"; second: "Flow around the Stern". For the first problem we can exclude completely the viscous effects and thus the overall bow wave patterns can indicate the local non-linear free surface effects more clearly. In this regard I would like to ask the Committee to refer to the paper given in Ref. /1/.

- Needs of complete wave pattern for comparison between theory and experiment should be emphasized more and more. Only by this approach the outward (or forward) shift of bow wave patterns can be clarified in connection with local non-

linear free surface effects.

In my opinion, full understanding of the very complicated wave-making interference, which takes place among elementary free waves originated at bow through stern, will be most important for further improvement of hull geometry with least resistance.

- Finally, I would like to mention the importance of roughness effects on viscous resistance of full-scale ships. In this connection anti-fouling devices will be most important.

REFERENCES

1. Inui, T. and H. Kajitani: "A Study on Local Non-Linear Free Surface Effects in Ship Waves and Wave Resistance". Schiffstechnik, No. 118, Vol. 4 (November 1977).

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In the report of Resistance Committee, the recent development toward further improvement of existing theories of wave resistance is widely reviewed. Here let me introduce another possibility of better expressions for waves and wave resistance of full hull forms by means of a kind of coordinate straining technique. The method of coordinate straining by Guilloton's transformation has shown some success towards better agreement between theoretical prediction and measurement in wave resistance and ship wave profiles. However this method is a kind of thin ship perturbation, so that its application is confined in the case of fine form ships. On the other hand, there is a low speed theory which aims better prediction of wave resistance of full hull forms at low Froude numbers.

Though results by Baba and Hara and those by Maruo and Suzuki show some improvement in the agreement between computed and

measured wave resistance of Wigley model, difference is not yet negligible at speeds of practical importance. At sufficiently low speed, the flow field around a ship hull is nearly similar to the flow as if the free surface were a rigid plane or the flow around a double model fixed in a uniform stream. The deviation from it gives the free surface elevation which causes the wave-like disturbance. Therefore the resultant fluid motion is regarded as the sum of the double model flow and an additional motion due to the free surface deformation. At low Froude numbers, the latter is regarded as a small perturbation from the base flow, i.e. the double model flow. Let the fluid velocities be non-dimensionalized by the uniform velocity U of the oncoming stream and expressed as the sum of the base flow velocities u_0, v_0, w_0 and perturbation velocities u', v', w' . Assuming the perturbation velocities small, one can linearize the non-linear boundary condition at the free surface with respect to u', v', w' . Because of Bernoulli's theorem, the free surface elevation is given by

$$Z_w/\ell = \frac{1}{2}F_n^2(1 - u^2 - v^2 - w^2) \quad (1)$$

where ℓ is the ship's length taken as the characteristic length and F_n is the Froude number. Therefore the perturbation velocities have wave-like terms of wave length which is proportional to F_n^2 , so that their spatial derivatives change the order of magnitude by F_n^{-2} as indicated by Ogilvie (1968). If u', v', w' are $O(F_n^2)$ as assumed above, their derivatives $\partial u'/\partial x$ etc. are of the order of unity. Now let us write down the boundary condition at the free surface as follows.

$$\frac{1}{2}\left(u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial z}\right)(u^2 + v^2 + w^2) + F_n^2 w = 0 \quad (2)$$

Here the cartesian coordinates x, y, z have been non-dimensionalized by the characteristic length ℓ . Replacing the velocities by $u_0 + u', v_0 + v',$ and $w_0 + w',$

assuming $u', v',$ and w' are $O(F_n^{-2})$ and their derivatives are $O(1)$, and retaining the lowest order terms with respect to F_n^{-2} , the following equation is valid on the plane $z = 0$.

$$u_0^2 u'_x + u_0 v_0 (u'_y + v'_x) + v_0^2 v'_y + F_n^{-2} w' = \Psi(x, y) \quad (3)$$

with $\Psi(x, y) =$

$$\frac{1}{2} \left[\frac{\partial}{\partial x} \{u_0(1 - u_0^2 - v_0^2)\} + \frac{\partial}{\partial y} \{v_0(1 - u_0^2 - v_0^2)\} \right] \quad (4)$$

Now let us look for a method of finding out the velocity potential ϕ , whose gradients are perturbation velocities u', v', w' , which is regular in the lower half space and satisfy the boundary condition (3) on the plane $z = 0$ when the base flow velocities are known. First we define the velocity potential ϕ and the stream function Ψ of the double model flow in the plane $z = 0$, by the following relations.

$$u_0)_{z=0} = \phi_x = \frac{1}{h} \Psi_y, \quad v_0)_{z=0} = \phi_y = -\frac{1}{h} \Psi_x \quad (5)$$

where h is a solution of the partial differential equation

$$\frac{\partial}{\partial x}(u_0 h) + \frac{\partial}{\partial y}(v_0 h) = 0 \quad \text{on } z = 0 \quad (6)$$

Now employ ϕ, Ψ as independent variables in place of x, y , and transform the equation

$$u_0^2 \phi_{xx} + 2u_0 v_0 \phi_{xy} + v_0^2 \phi_{yy} + F_n^{-2} \phi_z = \Psi(x, y) \quad (7)$$

Since ϕ_ϕ and ϕ_ψ are of higher order by F_n^{-2} in comparison with $\phi_{\phi\phi}$ and may be omitted, the transformed equation is

$$q_0^4 \phi_{\phi\phi} + F_n^{-2} \phi_z = \Psi(x, y) \quad (8)$$

where $q_0 = \sqrt{u_0^2 + v_0^2}$

Next we transform the coordinates to ξ, η, ζ , by the following relations

$$\phi = F_n^2 \int \xi q_0^3 d\xi, \quad \psi = F_n^2 \int \eta q_0^3 d\eta, \quad z = F_n^2 q_0^2 \zeta \quad (9)$$

where $q_0(\xi, \eta) = q_0(x, y)$

The lower limit of the integral depends on the position of the coordinate origin.

We have the relation

$$\begin{aligned} \phi_\xi &= \phi_\phi \phi_\xi + \phi_\psi \Psi_\xi + \phi_z \zeta_\xi \\ &= F_n^2 [q_0^3 \phi_\phi + \phi_\psi \int^\eta (q_0^3 h)_\xi d\eta + \phi_z q_0^2] \end{aligned} \quad (10)$$

Now we assume that q_0 and h are very slowly varying functions of x and y . If $\partial(q_0^3 h)/\partial\phi$ is $O(1)$, the transformation (9) indicates that $\partial(q_0^3 h)/\partial\xi$ is $O(F_n^2)$. Therefore second and third terms on the right hand side of (10) may be omitted if $\eta = O(1)$. Differentiating again with respect to ξ and omitting higher order terms, we obtain

$$\phi_{\xi\xi} = F_n^2 q_0^6 \phi_{\phi\phi} \quad (11)$$

By the similar argument,

$$\phi_\zeta = F_n^2 q_0^2 \phi_z \quad (12)$$

Multiplying $F_n^2 q_0^2$ on both sides of (8) and putting

$$\hat{\Psi}(\xi, \eta) = \Psi(x, y) \quad (13)$$

we obtain

$$\phi_{\xi\xi} + \phi_\zeta = (F_n^2 q_0^2)^2 \hat{\Psi}(\xi, \eta) \quad (14)$$

The same assumption can apply to the transformation of the Laplace equation.

The result is

$$\phi_{\xi\xi} + \phi_{\eta\eta} + \phi_{\zeta\zeta} = 0 \quad (15)$$

Thus the Laplace equation again and the boundary value problem is to seek a solution of the Laplace equation in the transformed space which satisfies the well-known linearized free surface condition with applied surface pressure, eq. (14). If we define the fundamental solution $G(\xi, \eta, \zeta; \xi', \eta')$ which satisfies the boundary condition at $\zeta = 0$

$$G_{\xi\xi} + G_\zeta = \delta(\xi - \xi', \eta - \eta') \quad (16)$$

and the radiation conditions at infinity, the solution we are looking for is given by $\phi =$

$$F_n^4 \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \hat{q}_0^2(\xi', \eta') \hat{\Psi}(\xi', \eta') G(\xi, \eta, \zeta; \xi', \eta') d\xi' d\eta' \quad (17)$$

The free surface at infinite downstream is given by

$$\begin{aligned} \frac{Z_w}{l} &= \frac{1}{\pi} \int_{-\pi/2}^{\pi/2} [P \cos(F_n^{-2} p \sec^2 \theta) + \\ &+ Q \sin(F_n^{-2} p \sec^2 \theta)] \sec^3 \theta d\theta \end{aligned}$$

where $p = x \cos \theta + y \sin \theta$

$$\begin{aligned} P &= F_n^4 \int_{-\infty}^{\infty} \hat{q}_0^2(\xi', \eta') \hat{\Psi}(\xi', \eta') \cos(\xi' \sec \theta + \\ &+ \eta' \sec \theta \tan \theta) d\xi' d\eta' \end{aligned} \quad (19)$$

and the wave resistance is

$$R = \frac{\rho U^2 g^2}{2\pi} \int_{-\pi/2}^{\pi/2} (P^2 + Q^2) \sec^3 \theta \, d\theta \quad (20)$$

For numerical purposes, one can employ another form of transformation. Take the length s along the streamline of the double model flow on the plane $z = 0$ and the length t along the equipotential line of the same. Then there are relations $d\phi = q_0 ds$, $d\psi = hq_0 dt$, so that the transformation (9) becomes $\xi = \int^s(x,y) (F_n q_0)^{-2} ds$,

$$\eta = \int^t(x,y) (F_n q_0)^{-2} dt, \quad \zeta = (F_n q_0)^{-2} z \quad (21)$$

These relations mean that the coordinates ξ, η are obtained by stretching the original space by the scale ratio $(F_n q_0)^{-2}$ along streamlines and equipotential lines. Since the wave number of elementary waves propagating in the stream velocity q_0 is proportional to $(F_n q_0)^{-2}$, the coordinates are strained according to the local wave length, that is in accordance with the physical nature of short waves propagating on non-uniform base flow.

The above formulation takes account of the distortion of ship waves due to the local non-uniformity of base flow velocities around the hull, which has been pointed out by Inui and Kajitani, and is expected to present a better prediction of wave resistance of non-thin practical hull forms.

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This discussion concerns the interaction between viscous and wave effects.

1. One of the most important findings in research on ship resistance, which have been made since the 14th ITTC, is the evident interaction between the wave pattern and wake traverse resistance. It has been also considered in the report of the Committee. It should be noted, however, that this phenomenon is obviously the primary cause to

the scale effect in wave pattern resistance, which has been reported by Yokoo and Tanaka /1/. According to their measurements made by longitudinal cut method, larger model has bigger wave pattern resistance. Differences are in some cases considerable. Similar results have been obtained in our Laboratory by P. Hervalá /2/. He made his measurements with matrix method and with 4 m and 8 m models of a two-propeller ferry ship.

2. Scale effect in wave pattern resistance calls for wave pattern measurements in ship scale. One attempt has been made in Ship Hydrodynamics Laboratory of Helsinki University of Technology to measure ship wave profiles from abroad a ship using stereophotography. This method seems, however, unsatisfactory /2/. Analysis field is limited because the cameras are near to water surface.
3. This interaction between viscous and wave resistance is basically a conversion of energy forms, the energy of wave motion is converted to the energy of viscous wake. Therefore if both wave pattern and wake traverse measurements are made for purpose of determining the total energy loss and resistance, the control surface should be the same in both measurements. From the known methods of wave pattern measurement only transverse cut method can then be used.

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1. Yokoo, K. and H. Tanaka: "Application of Wave Analysis to Tank Experiments". Int. Sem. on Wave Resistance, Tokyo 1976.
2. Hervalá, P.: Studies in Measurements of Wave Pattern in Model and Ship Scale and in Calculation of Wave Pattern Resistance. Helsinki University of

Technology, Ship Hydrodynamics Laboratory. Memorandum M-74. 1978.

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Viscous pressure at the stern of a tanker model is calculated by using the finite difference method for 3-dim. partially-parabolic flows. The agreement between calculation and experiment is considerably good. Although further calculation is needed, this method is considered to be a first step to predict viscous pressure resistance.

Introduction

One of the ship's problems left to be solved is to evaluate the viscous pressure resistance. As all first order methods using boundary layer, they fail to predict the viscous flow and pressure at the stern. Spalding (1975) has proposed the higher order method which the pressure variation in a viscous flow can be assumed. His method has recently been applied to a tanker model ($C_b=0.83$) by Abdelmequid et al. (1978). This report introduces the calculated results and discussion.

Calculation

In order to calculate the viscous flow at the stern, we assume the 3-dimensional partially-parabolic flows, where the convective fluxes of flow are transferred only to downstream, the diffusive fluxes are diffused to the normal direction to the main flow and the pressure is the only dominant transmitter of the downstream effects. The governing differential equations are those of continuity and momentum. Two additional differential equations, one for the kinetic energy of turbulence and the other for its dissipation rate, are required for the turbulent mod-

el. All these partial differential equations are transformed to the finite difference equations under the entire flow field of interest. The calculation domain is usually composed of the circular tube and the reflex model is fixed at the center of this tube. Under these circumstances, the equations are solved by the iterative marching integration scheme of Pratap et al. (1975), where the potential flow solution is given at the outer boundary of the tube.

Results and Discussions

Calculation is applied to the tanker model "M2" of which the hull pressure is measured by Namimatsu (1976). Fig. 1 indicates the pressure variations of inviscid and viscous flow at the cross section of 1/2 station. The calculated value of viscous pressure is lower than inviscid one, though the values of inviscid and viscous flow are the same at the outer boundary. At the hull surface, the calculated value of viscous pressure gets close to the experimental one. Fig. 2 shows the comparison of the pressure variations on the hull surface. The calculated value of viscous pressure coincides well with the experimental one.

It introduces in this case that this higher order method is effective in evaluating viscous pressure variations. It is considered that this method provides a first step to evaluate the viscous pressure. Further calculation of this method will be carried out for a better understanding of viscous pressure variations and viscous pressure resistance.

REFERENCES

1. Abdelmequid A.M. et al.: A method of predicting three dimensional turbulent flows around ship's hulls. International Symposium on Ship Viscous Resistance, SSPA, 1978.
2. Namimatsu M.: A measuring method of

hull pressure resistance and its application. J. Soc. Naval Architects of Japan, 139, 1976.

3. Pratap V.S. et al.: Numerical computation of the flow in curved ducts. The Aeronautical Quarterly, 26, 1975.

4. Spalding D.B.: Calculation procedures for 3-D parabolic and partially-parabolic flows. Imperial College of Science and Technology, Dept. of Mech. Eng., HTS/75/5, 1975.

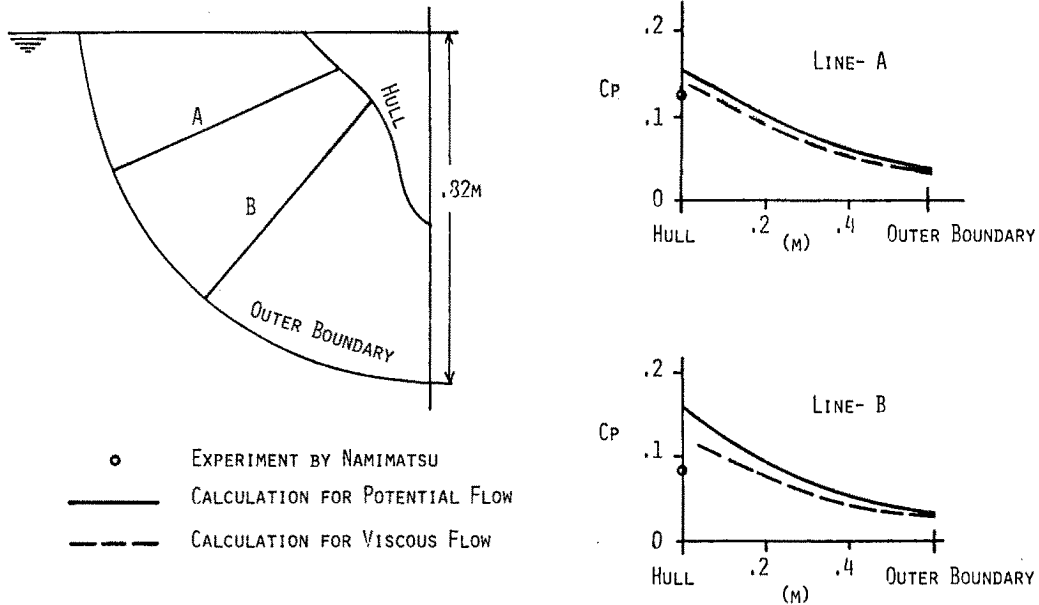


FIG. 1 PRESSURE VARIATIONS ALONG THE LINES A & B AT THE CROSS SECTION OF 1/2 STATION FOR 7M TANKER MODEL 'M2'.

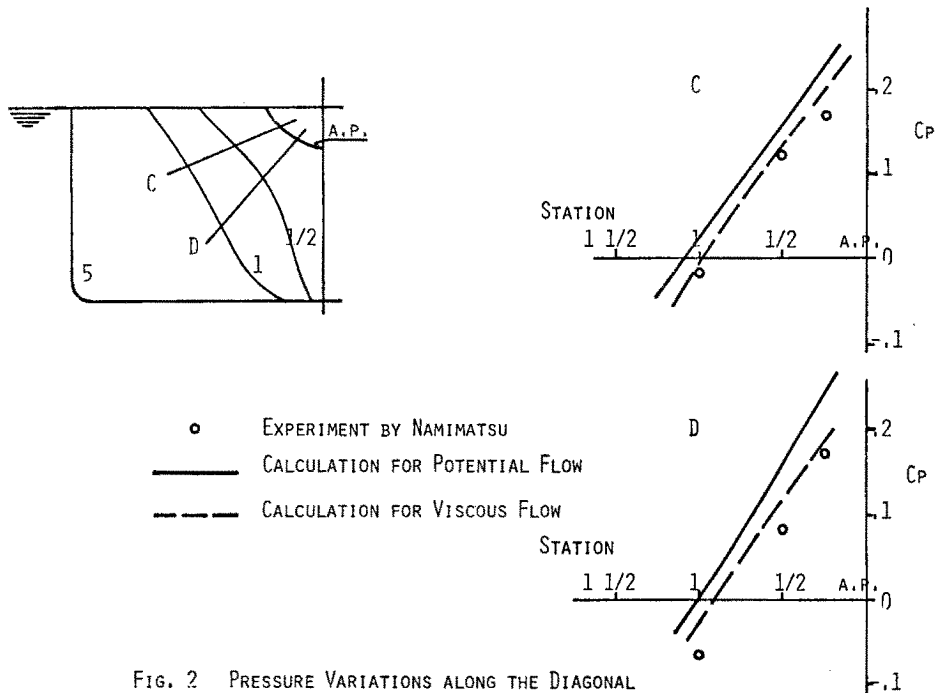


FIG. 2 PRESSURE VARIATIONS ALONG THE DIAGONAL LINES C & D ON THE HULL SURFACE OF 7M TANKER MODEL 'M2'.

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On the occasion of the 18th American Towing Tank Conference in August 1977, the new 380 ft. high-speed towing tank at the U.S. Naval Academy was dedicated. During the dedication ceremony, representatives from towing tanks around the world poured water samples from 31 different facilities into the new tank in the "mixing-of-the-waters" tradition.

Prior to the ceremony, the samples from each facility were themselves sampled in two different sets. One set of subsamples was added to sterile tubes containing glucose and sucrose; the other subsample was reserved for a display in the towing tank laboratory.

Results from examination of the subsamples from 31 different facilities indicate that bacteria capable of synthesizing drag-reducing polymers are present in every towing tank. This reinforces the view of Kenis (Ref. 1) that bacteria capable of producing high molecular weight drag-reducing polymers are ubiquitous in all fresh and ocean waters.

Methods and Results

The subsamples containing glucose and sucrose were made up to 0.5% concentration of each sugar by adding sterile water when the original sample was small (as was the case in several instances). These tubes were held aseptically, at room temperature in the dark, for 90 days. The samples were then examined by standard microbiological techniques for bacterial and fungal growth.

Two culture media were used. Difco nutrient agar, selective for bacteria, and Sabouraud Dextrose agar, (Difco) selective for fungi, were used for plate counts. The results, shown in Table 1, indicate tremendous concentrations of bacteria and

fungi in the sugar-enriched water samples. The data are shown as colonies of bacteria or fungi per ml of water sample.

The friction properties of the samples were then measured on a turbulent-flow rheometer, a device which measures the pressure drop in a small tube at a Reynolds number of 14,000. As shown in Table 1, all samples had reduced drag compared with deionized water, ranging from 1% drag reduction to 65%. Five of the samples had drag reductions of over 40%.

Discussion

It appears that bacteria or fungi capable of synthesizing drag-reducing polymers are present in every towing tank. Since bacteria and fungi can use almost any imaginable organic substrate as a carbon source, it appears necessary to exclude gross forms of contamination from towing tanks for reliable and reproducible results. The results shown here are of course due to a much higher magnitude of contamination than might ever be expected in a towing tank, except possibly where large growths of algae are permitted.

From Table 1 it can be seen that the visual appearance of the test samples had no relation to the observed drag reduction. Some of the samples which were crystal clear at the time of the testing showed the highest drag reduction, while on the other hand, samples showing heavy growth occasionally gave minimal drag reduction. Thus the appearance of towing tank water would not be a reliable guide to water quality.

Further, there was no correlation between bacterial count, fungal count, appearance and drag reduction. Evidently, only certain bacteria or fungi produce the high molecular-weight exocellular polysaccharides believed responsible for the drag-reduction effects. However, these bacteria seem to be ubiquitous in all fresh

and ocean waters.

The results indicate that, if subjected to contamination, towing tanks could have a reduced turbulent-friction level, resulting in noticeable effects on measured ship-model resistance results. Tank cleanliness is thus an important concern.

REFERENCES

1. Kenis, P.R.: Turbulent-Flow Drag Reduction by Polymers from Marine and Fresh Water Bacteria. International Shipbuilding Progress, 16, p. 342, 1969.

TABLE 1

Characteristics of Water Samples from Towing Tanks
(enriched with 0.5% sucrose and glucose)
90 Day Incubation period

TANK	Bacteria colonies/ml	Fungi colonies/ml	Appearance of Samples	Drag Reduction rating *
Akashi Ship Model Basin	610,000	440	no visible growth	++++
University of Osaka	130,000	140	clear	+++
Meguro Model Basin	740,000	6,600	clear	++++
Ship Research Institute	52,000	41,000	grey, stringy growth	+
Shipbuilding Research Center	680,000	8,300	no visible growth	+++
Ishikawajima Harima Heavy Industries Co.Inc.	810,000	460	no visible growth	++++
University of Tokyo	2,500,000	150,000	very slight white growth	++
Nagasaki Technical Institute, Mitsubishi	180,000	150,000	slight turbidity	+++
Iowa Institute of Hydraulic Research	2,200	1,800	heavy red strings	+
Offshore Technology Corp.	74,000	63,000	slight grey strings	++++
Davidson Laboratory	220,000	3,700	very slight white growth	+
Marine Dynamics and Ship Laboratory, Ottawa	270,000	2,400	light white stringy	++++
David Taylor NSRDC	300,000	1,800	very slight white strings	++++
St. Anthony Falls	980,000	7,800	slight white strings	+
University of California	960,000	3,000	no visible growth	++
MIT	640,000	1,800	no visible growth	++++
Canal Experiencia, El Pardo	340,000	150	very slight strings	++
Canal Escuela Ing. Navales, Madrid	300,000	30,000	blackish strings	+
Lake Pontchartrain	650,000	550	light white floating	++
Berlin Model Basin, #1 tank	430,000	26,000	heavy fluffy white growth	++++
University of Michigan	130,000	16,000	slight white stringyness	++++
Mixed water from British Tanks	1,200,000	28	some whitish stringy	++++
Instituto de Pesquisas Technologicas, São Paulo	340,000	300	clear	++++

Webb Institute of Naval Architecture	370,000	450,000	heavy, cloudy greenish grey	++
US Naval Academy 85' tank	550,000	4,000	no visible growth	+
Arctec, Inc. (sea water)	270,000	260,000	whitish growth	+
Hydronautics, Inc.	---	---	no visible growth	++++
First Russian Towing Tank (1891)	10,000	6,000	blackish growth	+
2000 ft. Russian Towing Tank (1950)	240,000	190,000	small blackish growth	+
Russian High Speed Circular Basin(1967)	60,000	5,400	moderate amt. blackish	+
Taiwan University	---	---	slight white stringy	+++

* Drag Reduction Code

+ 1 to 5% drag reduction
 ++ 5 to 10%
 +++ 10 to 20%
 ++++ 20 to 40%
 +++++ 40 to 65%

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Brown or black spots frequently appear on wax ship models held in the storage dock. These have been shown to be caused by aquatic fungi of several types. In addition to giving a poor appearance, these patches are rough to the touch and require scraping to establish a smooth surface before tank testing, making reproducible resistance results difficult. Aquatic organisms which utilize solid hydrocarbons such as waxes and tars are not well known; they are of interest not only from the ship model standpoint but also because of their possible role in controlling oil pollution problems.

Experimental

Aquatic fungi taken from ship models in two British towing tanks have been grown in pure culture and tentatively identified. As explained in Ref. 1, the dark brown or black color of the spots on ship models is due to the fungal spores or

fruiting bodies, which are produced in enormous numbers. Two predominate organisms, "A" from NPL, and "B" from AEW, were selected for further study. These have been tentatively identified as species of the genus Dictyarthrinium. (A number of specialists have been consulted, but no authoritative determination, even to genus, has yet been obtained). Figures 1a and 1b show the appearance of these two species at a magnification of 575X. Fig. 2a and b show the appearance of fully developed colonies of these organisms.

After isolation in pure culture, and growth on both agar and paraffin, effort began to develop a formulation which would prevent these growths from occurring. Selection of a fungicide with both high-temperature stability (to incorporate in the melted wax) and solubility in the wax was a major problem.

The following biocides were investigated:

CANDIDATE BIOCIDES

Biocide	Comments
Mercuric Chloride	Not Soluble
Copper sulfane	Not Soluble
Biocide N-521	Wax Soluble
3,5 dimethyl-tetrahydro-1,3,5,2H-thiadiazine-2-thione (Stauffer Chemicals)	
Stauffer N-948	Not Heat Stable, Irritating, pungent fumes
Methylene Dithiocyanate (Stauffer Chemicals)	-NOT USED-
Stauffer N-1386	Pungent lachrymator
Hexachloro dimethyl Sulfone (Stauffer Chemicals)	-NOT USED-
Zinc Omadine, 1-hydroxy-pyridine-2-thione (Olin Chemicals)	No undesirable odors, Moderately wax soluble

Biocides N-521 and zinc omadine were selected for further study. The two organisms were grown as before on paraffin wax (as controls) and on wax which has been melted and biocide added. The following table shows the results of observations after a 6-week incubation period:

CANDIDATE BIOCIDES EFFECTIVENESS

Biocide	Test Fungus			
	A Control Biocide		B Control Biocide	
Biocide N-521 (Stauffer Chemicals) 1000 ppm	++	+++	+	+++
Zinc Omadine (Oline Chemicals) 500 ppm	+++	0	+++	0

As can be seen from the above, the organisms were able to utilize Biocide N-521 as well as the wax as a carbon source. In fact, growth with this biocide was greater than in the controls. In contrast, zinc omadine was extremely effective in eliminating all fungal growth. Repeated tests verified this result.

Other experiments were conducted to show that zinc omadine remains bound up in the wax and does not leach into the water. Fig. 3a and b show how treated wax samples (squares) remain free of growth

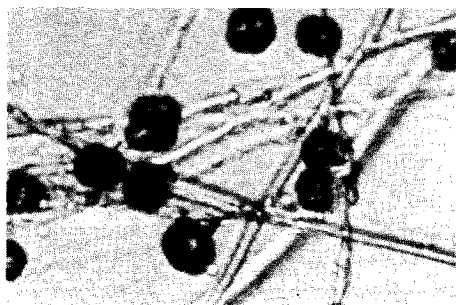
while the untreated paraffin (triangles) growing in the same tube of water are being colonized. In longterm (over 2 years) experiments, fungi did cover the biocide-treated wax surfaces, but on lifting the fungi aside, the wax was white and free of growth; the fungi had used the wax as a support, but had not invaded the surface. Other work has shown that 100 ppm zinc omadine is as effective in suppressing fungal growth as higher concentrations.

Extensive testing by the manufacturer indicates the material is safe for human contact (Ref.2) and in fact omadines are used in cosmetics, shampoos, textiles, cutting oils and coolant systems, vinyl films, and rubber products (Ref.3). However, the material is not suitable for ingestion, and should be handled with caution, both before adding to the wax, and during wax model fabrication, in accordance with manufacturers recommendations.

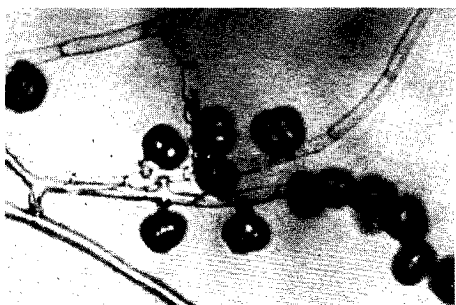
Summary of results

From this study of towing-tank fungi, extending over a period of 5 years, the following results may be summarized:

1. Fungi are the cause of the brown or black spots produced on wax ship models held in the storage dock.
2. The fungi utilize the wax as a source of carbon.
3. These fungi are not well known, and authorities are unable to accurately describe them. Tentatively they are assigned to the genus Dictyarthrinium.
4. Zinc omadine, incorporated in the wax at concentrations of 100 ppm and more, is extremely effective in eliminating these growths.
5. The zinc omadine does not enter the water, but apparently remains locked up in the wax.
6. Fungi may grow over zinc omadine surfaces, but do not attack the wax and



(a)



(b)

Figure 1 - Fungal species isolated from wax ship models (a) NPL (b) AEW. 575X

can be lifted off to reveal a clean surface.

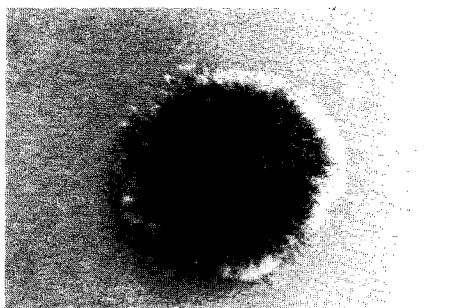
7. Zinc omadine is reasonably safe for human contact, but should be handled with caution.

Recommendation

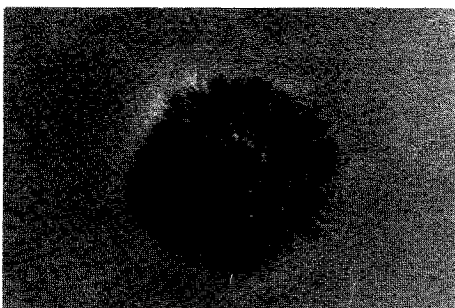
On the basis of the experimental results, it is recommended that 100 ppm zinc omadine be incorporated in wax ship models on a trial basis, in order to eliminate fungal-spot growth

Acknowledgement

This paper is a preliminary report on material intended as a Master's thesis for submission to the faculty of the San Diego State University, Department of Botany.



(a)



(b)

Figure 2 - Appearance of fungal colonies. Approx 3X (a) NPL (b) AEW



(a)



(b)

Figure 3 - Fungal growth on wax treated with zinc omadine (rectangular pieces) grown in same tubewith untreated wax (triangular pieces). Incubation period: 2 weeks. (a) NPL (b) AEW Approx 3X

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G. DYNE - The Swedish State Shipbuilding Experimental Tank, Göteborg, Sweden

Both the Resistance and the Performance Committees report on a certain confusion regarding the influence of Reynolds number on the form factor. This confusion is partly due to a paper I presented at the Norske Veritas symposium in Oslo in 1977. The calculations described in this paper indicated that the form factor of a body of revolution should be larger in full scale than in model scale. When I prepared another paper on the same subject for our symposium on Ship Viscous Resistance in Göteborg last week I discovered, however, that this conclusion was an effect of an error in one of the data programmes used. After having corrected this error I found that the variation of the form factor with Reynolds number was quite small as long as no flow separations occur.

L. LARSSON, The Swedish State Shipbuilding Experimental Tank, Göteborg, Sweden

A notable event related to the subject of this session was the International Symposium on Ship Viscous Resistance, held in Göteborg last week. In order to update the Committee Report I would like to very briefly summarize the most important results of the Symposium.

Transition

In the Report only two-dimensional and axisymmetric transition is treated. This is so, since very little work has been carried out on three-dimensional transition in which the crosswise component of velocity is taken into account in the stability analysis. However, during the Symposium, calculations by Hoekstra showed that it is in fact the cross-flow instability which causes transition, at least for the one case calculated. If a two-dimensional criterion is used the predicted separation occurs considerably further aft.

3-D boundary layer calculation methods

Three new methods for the calculation of the boundary layer on a ship form were presented at the Symposium. There are the ones by Hoekstra, Gadd and Abdelmeguid et al. These methods should be included in Table 2 of the Report.

Hoekstra's method is a differential method based on Patel's work at Iowa. It goes into great detail concerning the initial conditions for the boundary layer calculation. This very important question has never been investigated before.

Gadd's and Abdelmeguid's methods represent in a sense the two extremes of all available calculation methods. Gadd has sought for extreme simplicity. By some congenious approximations many of the difficulties usually encountered are completely avoided. Although the method is simple and cheap, the accuracy compared with most other methods seems to be good. Abdelmeguid et al, on the other hand, have developed a method based on Spalding's wellknown method for internal flows. This is of the differential type making use of a two-equation model for turbulence and it includes several higher order effects as well.

Higher order effects

The very recent development of higher order methods for axisymmetric flow is

reviewed in the report. Further discussions on the two methods by Patel et al. and by Dyne, were held at the Symposium. Not included in the report is, however, the description of three-dimensional methods of this kind. At the Symposium for the first time I think, such methods were discussed. Himeno tried to assess the influence of the higher order terms and he also carried out calculations taking some of them into account. The method by Abdelmequid has already been mentioned.

Surface roughness

Three papers at the Symposium dealt with surface roughness. Karlsson determined the roughness function for four different surface roughnesses, obtained from real ship hulls. Using these functions he was able to draw charts for the increase in resistance (ΔC_f) at different speeds and ship lengths. These charts should be very valuable for preliminary estimations of the effect of roughness.

In the work at Liverpool, presented by Dr. Lewkowicz and Dr. Musker, emphasis is placed on finding suitable geometrical descriptions of the roughness. In Musker's paper a relation based on the standard deviation of the surface profile from the mean line was given. The relation accounted for the departure from the Gaussian distribution of the roughness heights measured. It could be used in many of the already existing methods for turbulent boundary layers.

B.R. PARKIN - Pennsylvania State University, Applied Research Laboratory, State College, U.S.A.

It would be presumptuous of me to make recommendations counter to those already made by the Resistance Committee, because the entire report is the result of careful thought and attention to detail. Instead, I propose to amplify the material in the report about two aspects of

axially symmetric flows. I want to record some recent progress by members of the Garfield Thomas Water Tunnel staff on blockage corrections on large axially symmetrical bodies and upon measured transition from laminar to turbulent flow.

It is safe to say that no wind tunnel or water tunnel test section is ever big enough to satisfy all test requirements. Therefore one is faced from the beginning of considering the blockage by the body and its wake even for axially symmetric flows in a closed test section. Moreover, if one wishes to achieve high Reynolds numbers, he will want to use a large body compared to the test section diameter. In this case, the usual corrections for horizontal buoyancy and wake blockage are not applicable. In order to account for the effects of skin friction on the tunnel walls and the body upon the pressure distribution on the body, we have developed a method of analysis, which uses the Douglas-Neumann program plus a control-volume calculation. The potential-flow calculation provides the measure of the geometric constraints for flow. The balance of stresses, pressures and momentum fluxes in the control-volume calculation provides a correction due to skin friction on the potential-flow pressure distribution. Experiments on an axially symmetrical body of .324 m diameter in a water tunnel of 1.10 m diameter have shown that this straight-forward method of correcting the potential-flow pressure distribution gives excellent agreement with experiment everywhere on the forebody, but not on the tail where severe adverse pressure gradients are found.

In some cases one may wish to compare transition measurements in wind tunnels or water tunnels with comparable results in towing tanks. Not only will blockage effects differ in these facilities, but the free-stream-turbulence levels will also vary. In the report of the Resistance Committee it has been noted that if linear stability theory is used in order to

estimate the transition Reynolds number one must select a value for the amplification ratio. Experience has shown that different values of this parameter may be required for different flows. In the case of the axially symmetric flow discussed above, we have made measurements of the transition point on the body for a range of Reynolds numbers and free-stream turbulence levels. We used a formula due to Dr. L. Mack of the Jet Propulsion Laboratory, California Institute of Technology, in order to select the value of amplification ratio to be used in linear-stability transition calculations. Good agreement was found between calculated and observed transition points.

If item 9 under "Future Tasks of the Efficient Organization of the ITTC" is implemented, the technical reports from the GTWT describing the above investigations will be listed. In the meantime those members of the Conference desiring further information can feel free to write directly to the author of the reports, Dr. G.C. Lauchle, at the above address. Those wishing to become acquainted with Dr. Mack's theory should look in the indices of the A.I.A.A. Journal for 1977 or possibly 1976.

A.M. FERGUSON - University of Glasgow, Scotland, U.K.

It is basic knowledge that when a displacement ship passes through calm water, there are three primary reactions:

1. There is a resistance to motion.
2. A wave system is created.
3. The vessel changes position vertically (i.e.) sink and trim or "squats".

In the discussor's opinion insufficient attention is paid to this third reaction. The amount of change in vertical position and therefore "form" is sensitive to any change in the hull's environment. From experiments conducted at the Glasgow University Laboratory the writer has noted

the changes in sinkage and trim and the associated form effect due to changes in depth of water, blockage, hull roughness and the effects of polymer etc.

Sinkage and trim is simple to measure during model tests and the writer has been successful in conducting a number of full scale squat tests on a variety of ships in open water, so allowing the effect of scale to be studied.

With this knowledge it is requested that the Resistance Committee when collecting model test data from member organizations should include a request for details of the changes in sinkage and trim due to forward speed with the aim of providing a means of increasing our knowledge and understanding of form effect.

K. KAFALI - Technical University of Istanbul, Shipbuilding Research Institute, Istanbul, Turkey.

As it is well known, because of surface tension, for the substance moving into free surface of the water the boundary arises as is shown in (Fig. 1). The rise is approximately 4 m/m. This value is the same for all the geosim series.

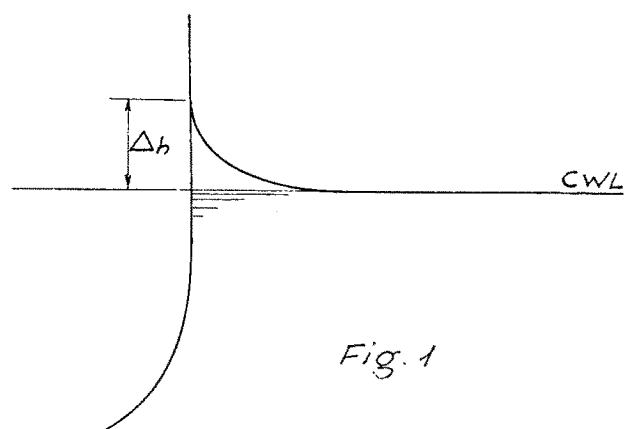


Fig. 1

Since so, it should be taken into consideration that this rise either increases the wetted area or increases the viscous resistance in the model experiments.

If we take the problem as the increase in

wetted area of the model, the additional wetted area will be $\Delta h.G$, here Δh , the height of water at the board of ship or model is agreed to be 4 m/m and the G value is the girth length of the water lines at the particular loading condition. According the above consideration, if necessary corrections are done on total resistance coefficients of geosim series

of two fishing boats the (Fig. 2-3) would be accomplished.

It is clear from these figures that by considering the surface tension effect a smaller form factor value will be obtained. This result is very important especially for the experiment tanks which use small models having larger surface tension effect than the large models.

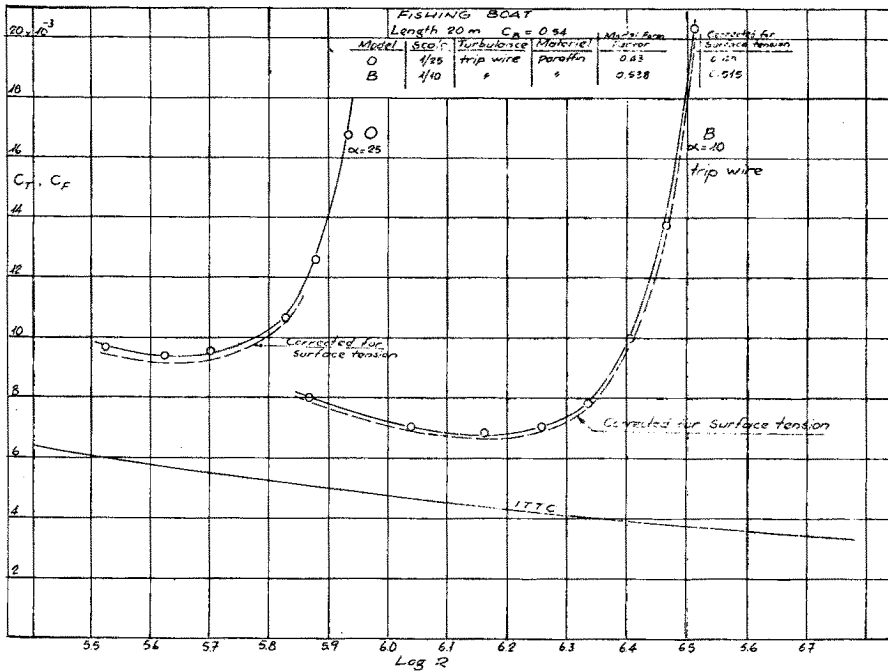


Fig. 2

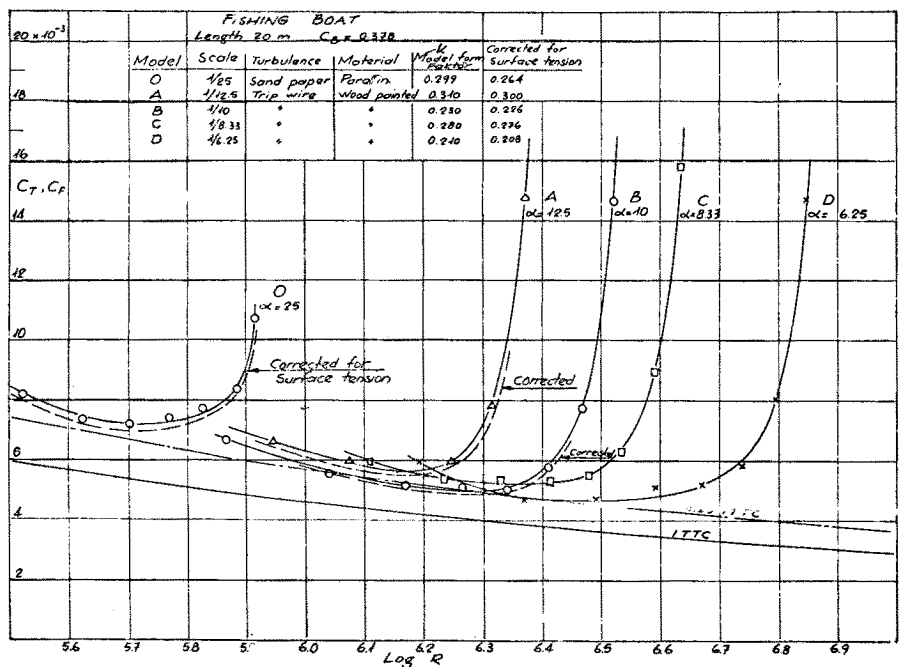


Fig. 3

II. REPLY OF THE RESISTANCE COMMITTEE

Prof. Inui's kind remarks are greatly appreciated. We admit that our first recommendation is a long-term goal, but as mentioned at the beginning of the section, the order of the recommendations does not represent an order of priorities. It may well be fruitful in the study of local non-linear effects to concentrate attention on the forebody. Although flow separations can sometimes occur here, it will usually be the case that the waves generated from this part of the hull will be substantially unaffected by viscous boundary layer effects. We agree that for making comparisons with theoretical predictions it would be valuable to have measurements of the complete free-surface geometry in the bow region, and not just of the radiated far-field waves. Stereophotogrammetry is probably the best way of making very detailed measurements of this kind. The technique, which is more convenient for most tanks, of using fixed electrical probes past which the model moves, cannot give information within one half of the beam from the model track, but if sufficiently closely spaced probes are used, the results may still be useful in quantifying non-linear local wave effects.

We endorse *Prof. Inui's* opinion that the prevention of fouling is very important in minimizing the resistance penalties due to roughness.

We thank him for drawing attention to his joint paper with *Dr. Kajitani*. This is significant in two respects. First it shows (as was also pointed out by *Maruo*) that the original double integral expression underlying *Baba's* evaluation of wave resistance at low Froude numbers does not eliminate the excessive humps and hollows in the resistance curve and that more realistic smooth curves are only obtained if further approximations are made. Second, it achieves in at

least the one case investigated a great improvement in the prediction of wave resistance by taking account, in an admittedly heuristic way, of the distortion due to the hull of the free-wave system. A major step towards putting this procedure on a more rigorous mathematical basis has been provided by *PROF. MARUO's* contribution. It is a welcome feature of this method that Laplace's equation is obeyed, whereas in other coordinate straining methods it is not fully satisfied.

We thank *Prof. Kostilainen* for drawing attention to the effects of scale on wave pattern measurements, as shown by the results of *Yokoo and Tanaka* and of *Hervalá*, and we welcome his courageous attempts to make such measurements at full scale. Full scale measurements have also been made by *Tanaka* in Japan and *Ward* in America, in those cases using wave buoys and analysing the results by longitudinal cut methods. The interpretation of the results was, however, made difficult by the ambient sea waves, which must always present serious problems. Likewise the greater tendency of full scale ship waves to break as compared with the model waves may perhaps lead to discrepancies between full scale and model scale results. *Prof. Kostilainen's* final comment seems to rest on the misconception that the transverse cut method measures momentum flux across a transverse plane, whereas the longitudinal cut method measures the flux across a longitudinal plane. In fact neither sort of measurement gives the momentum flux directly. Rather in both methods the momentum flux is deduced from the measured wave elevations by using an approximate mathematical model of free-wave propagation.

The contribution of *Dr. Muraoka* and *Dr. Markatos* provides a most interesting

addition to the information contained in their first reference paper. Although the method requires further development, it already shows promise of being able to make useful predictions of the effects of viscosity on pressure near a ship's stern.

Dr. Hoyt and *Mr. and Mrs. Kenis* have performed a useful service in showing that most towing tank waters contain microorganisms which are potentially capable of causing serious drag reduction effects. Fortunately, however, nutrient conditions capable of increasing the population density of the organisms to the degree obtained in the experiments described by *Hoyt* and *Kenis* are scarcely ever found in the natural tank surroundings. On the other hand the spots on wax models discussed in their other paper are of common occurrence and the discovery of an effective antidote to this is most welcome.

We are grateful to *Dr. Dyne* for pointing out an error in his earlier calculations of scale effect on the viscous resistance of bodies of revolution. Recent calculations carried out at DTNSRDC are broadly in agreement with his latest findings. It is important in such calculations to calculate the flat plate resistance, used to normalize the results, by the same boundary layer calculation method as is used for the axisymmetric body.

We thank *Dr. Larsson* for summarizing the results of the recent Göteborg Symposium on Ship Viscous Resistance. The papers given there represent a further very useful contribution to this subject.

Dr. Parkin's welcome comments point out the difficulties associated with the calculation of the viscous contribution to blockage. Some of the methods, discussed in the Committee Report, for calculating thick stern boundary layers and wakes for axisymmetric bodies, may be applicable for

the elucidation of this problem, as outlined in Recommendation 13. The Committee agrees that the free stream turbulence level has an important effect on transition in wind and water tunnels, but feels that it does not present a problem in towing tanks.

We agree with *Dr. Ferguson's* suggestion that measurements of sinkage and trim can be useful. The results may help to resolve anomalies which may arise when the same hull form is tested in different facilities. They can also help in the assessment of form factor, since the sinkage is a measure of the average speed increase over the hull, as was pointed out long ago by *Horn*, and any marked change of trim with changing speed may be associated with corresponding changes of form factor, due to the change of the effective geometry of the immersed part of the hull. Such information is particularly important for unconventional forms such as SWATH ships.

Prof. Kafali makes an interesting point in showing that the influence of surface tension on wetted area is not negligible for small models. It is worth noting that the generated waves may also be affected as was shown by *Webster*.

In conclusion the Committee thanks all the discussers whose comments have helped to clarify many of the topics discussed in the Report.