

SESSION ON RESISTANCE AND FLOW

Chairman: Mr. M. E. Davies

Resistance and Flow Committee Memberships: Y. Himeno (Chairman) – A.J. Musker (Secretary) – V. Bulgarelli – R.E. Henderson – J.Kux – Y.Z.Liu – E. Müller – S. Ogiwara – Y. Yovev.

Discussion of the Report and the Draft Recommendations of the Resistance and Flow Committee (Cf. Proceedings, Volume 1, pp.55 –107).

I. DISCUSSIONS

RF-1

C.W.B. GRIGSON

Marine Consulting, Kristiansand, Norway

ON THE SIGNIFICANCE OF ΔU_r FOR HULLS

The Report of the Resistance and Flow Committee concludes that the shape of the roughness function does not matter, particularly if the height of roughness is small. However there is much evidence that even for lowdrag surfaces, ΔC depends very much on the shape of Δu_r .

To investigate the significance of the shape of Δu_r , it is essential to solve the boundary layer at full-scale. This has been done for many examples of test surfaces representing hulls, both newly painted and after some time in service. Δu_r must be expressed analytically: there is no theory which can predict Δu_r for a practical random surface, so that curves must be drawn through the data so as to give, approximately, the smallest root – mean – square scatter. This scatter should be acceptable, and is usually between 0.1 and 0.2 in rms value of non-dimensional velocity (NDV).

To demonstrate the effects of the shape of Δu_+ , results are shown for five surfaces, having the particulars given in the Table.

Details of Surfaces

Fig.	Test surface	Source	Test Label	Rig	h(BSRA inst.)
1	new coating	Nakato 1	P2	Pipe	0.08 mm
2	"	Couch 2	FSPH	T.Tank	0.11
3	"	Nakato 3	P3	Pipe	0.14
4	hull replica	Musker 3	R156	Pipe	0.16
5	"	Musker 4	R253	Pipe	0.25

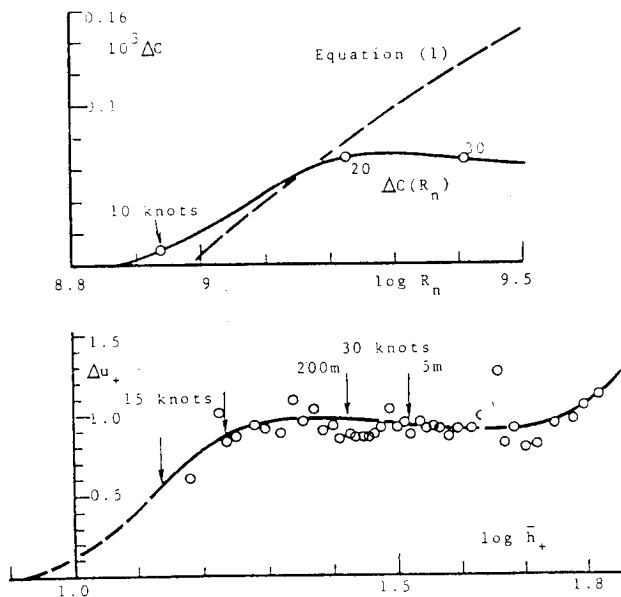


Fig. 1. Coating P2 of Nakato et al, [1]. h, by BSRA instrument, is 0.08mm.

Each figure shows the measurements and the best curve of Δu_+ fitting the data, a curve which is exactly reproduced by logarithmic spline. In the uppermost graph the corresponding curve of $\Delta C(R_n)$ is calculated for a planar boundary layer of length 200m at speeds between 6 and 30 knots. The boundary surface is

considered to be identical with each test specimen. At a given speed, the part of the function Δu_+ involved is quite small and is indicated by arrows which delimit the operating values of $\log h_+$ as the streamwise coordinate varies from 5m to 200m. The graphs also show the equation

$$10^3 \Delta C = 44 \left[\left(\frac{L}{h} \right)^{-\frac{1}{3}} - 10 R_n^{-\frac{1}{3}} \right] + .125 \quad (1)$$

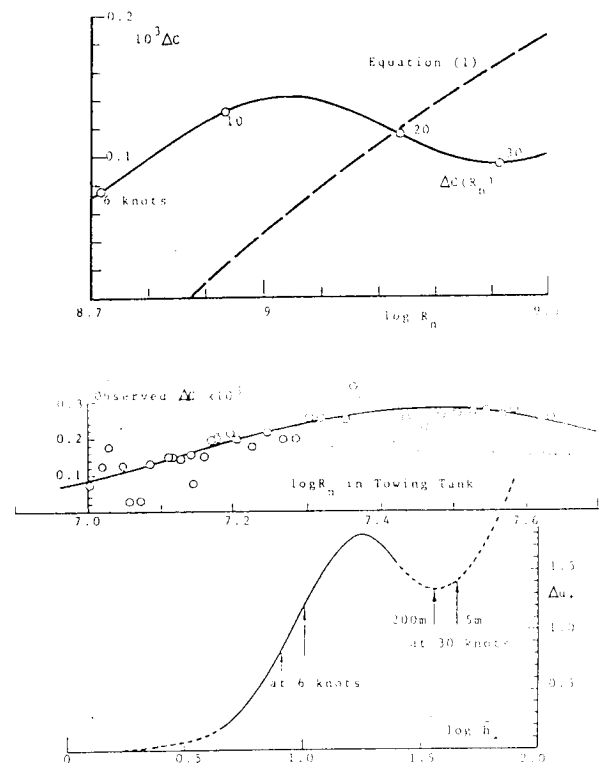


Fig. 2. Flame - sprayed hot plastic antifoul, from Couch, [2] Δu_+ must have the shape shown in order to reproduce the curve of ΔC observed in the towing tank. To do so, the roughness function must be quite exact.

The values of roughness height in the table must be approximate, because the surface profiles are random functions and too little of the waveform is available for the confidence limits on h to be precise, i.e. the sample lengths of waveform from the test surfaces are always too small. This does not matter, however, since

as the Committee point out, the values of h are not required for the calculation of $\Delta C(R_n)$ when Δu_+ has been measured.

(iii) Formula (1) bears little resemblance to the true curve of ΔC . Indeed it predicts that R253 is the worst surface, yet in fact it is one of the best.

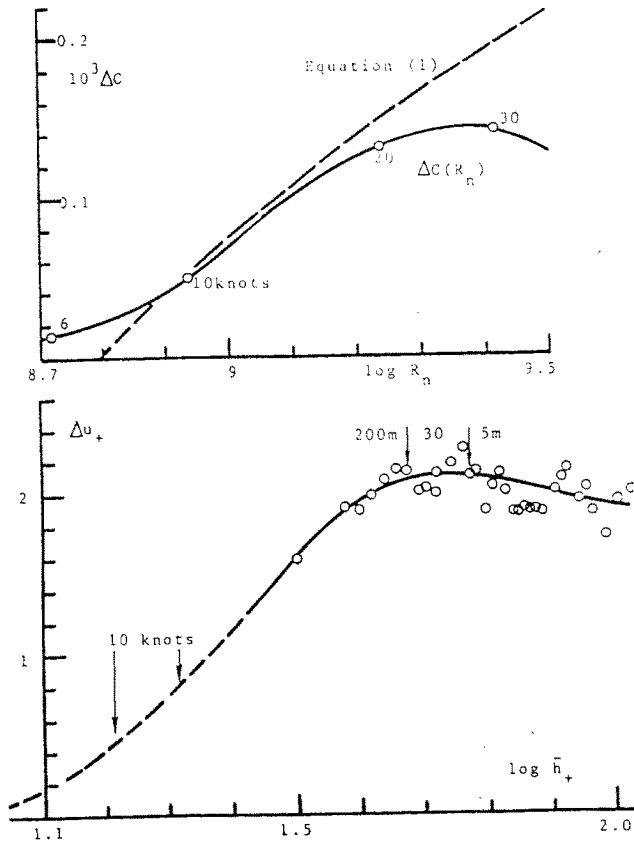


Fig. 3. Coating P3 of Nakato et al, [1]. $h=0.14\text{mm}$.

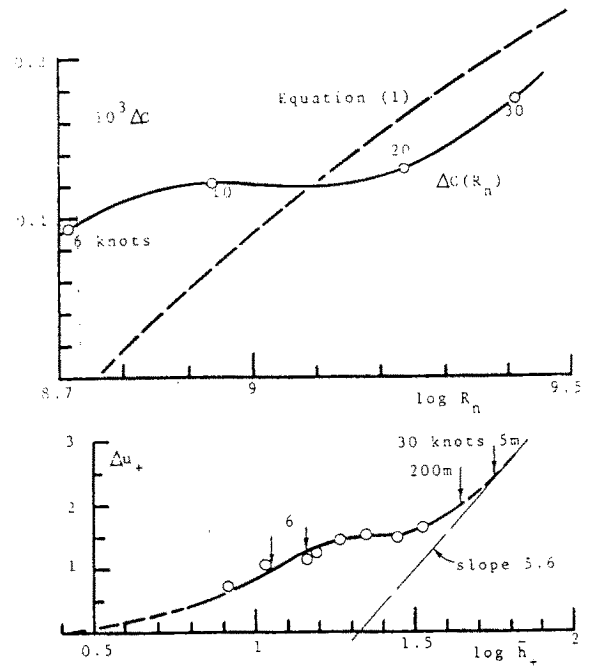


Fig. 4. Replica R156 of Musker and Das, [3]. $h=0.16\text{mm}$.

One may observe in each figure that:

- (i) The shape of Δu_+ strongly affects the shape of the full-scale function of ΔC .
- (ii) The operating region of Δu_+ is quite small. For example on surface P2 at 30 knots, the value of Δu_+ is nearly constant at about 1 NDV all along the boundary layer, except for the initial 5m. The operating values of Δu_+ ought in general to be checked by solving the boundary layer.

Space allows few examples. The author has some thirty more painted surfaces modelling hulls for which Δu_+ is available with adequate accuracy. For all of these, statements (i), (ii) and (iii) are true. The author would gladly communicate these results to the R and F Committee if they would like to consider them.

The evidence of [5] has been considerably extended and all of it supports the conclusions of that paper.

R.L. TOWNSIN

Newcastle University, Newcastle – United Kingdom.

INTERNATIONAL WORKSHOP ON MARINE
ROUGHNESS AND DRAG. RINA, LONDON,
MARCH 29, 1990

RECOMMENDATIONS

Each of the papers contains its own recommendations but the following list was compiled at the end of the Workshop:

- 1) ITTC should continue to encourage more model-to-ship correlation studies and a more scientific approach to speed and power trials.
- 2) ITTC should consider recommending that in all newbuilding purchase contracts there should be clauses requiring hull and propeller roughness assessments. Assessments should be made by standardised procedures using stylus instruments and/or a surface replication technique. Importantly the assessment should include a standard report of a visual inspection of the surface noting the extent and severity of any surface defects including overspray, drips, runs and sagging.
- 3) New types of meteorological instrument should be investigated for their suitability to measure hull roughness. It was noted that current alternatives to the stylus instrument are only appropriate to the Laboratory and that whilst the stylus instrument had all the

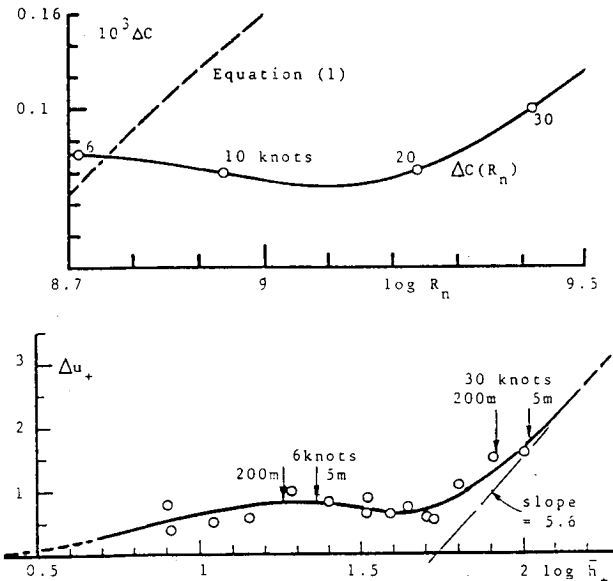


Fig. 5. Replica R253 from [4]. This is Lewkowicz and Musker's replica with the lowest added-drag. But $h=0.25\text{mm}$.

References

1. Nakato et al: "Resistance Increase due to Surface Roughness", 15 th Symp. on Naval Hydrodynamics, Hamburg, 1984, pp 45-59.
2. Couch: "Friction plane resistance tests of Antifouling paints", DTMB Report No. 789,1951.
3. Musker and Das: private communication to author, 1982.
4. Musker and Lewkowicz: "Effect of Hull Roughness on Turbulent Boundary Layers", Paper 11, Int. Symp. on Ship Viscous Resistance, SSPA, Gothenburg,1978.
5. Grigson: "Full-scale viscous drag of actual ship surfaces and effect of quality of roughness on power", J. Ship Research, 31, 1987, pp 189-206.

qualities required for use in the field, the stylus ball diameter could be reduced to include more high frequency components but there would be a curing-paint penetration problem.

4) Whenever a rig was set up to measure roughness functions standard sample surfaces should be tested to prove the rig.

5) More replicas of hull painted surfaces and propeller surfaces are required for laboratory testing.

6) Standards for published results of surface statistics, their measurement and their storage should be formulated and adhered to.

7) The differential effects of roughness located in different positions over the hull should be studied further.

8) There is a requirement for more fundamental studies of the physical properties of slimes on marine surfaces, especially their effect on drag.

9) Future large scale experiments aimed at creating data banks of surface topography and roughness functions, should include a wide range of associated turbulence parameters with a view to validating future computational methods for predicting flows around ship hulls.

10) A higher standard and specification of new propeller surface roughness is required and could be met.

11) It is recommended that the RINA sets up similar sponsored Workshops on other specialist topics.

RF-3

T.T. HUANG

**David Taylor Research Center, Bethesda, Maryland
(U.S.A.)**

ROUGHNESS

The shapes of roughnesses are important even for small roughness heights. It is known that the 3M - NASA Langley two-dimensional grooves ($10 < u_r/h/v < 100$) do reduce drag rather than increase drag.

RF-4

D. KOSTOV, S. KYULEVCHIEV

**Bulgarian Ship Hydrodynamics Centre, Varna,
Bulgaria**

SEMI-EMPIRICAL METHODS FOR RESISTANCE ESTIMATION IN HULL FORM DESIGN

1. INTRODUCTION

In the report of the Resistance and Flow Committee of the 19th ITCC, when discussing the application of computational fluid dynamics (CFD) to towing tank problems, a regret is expressed that "many research

establishments adopt a somewhat unstructured approach to CFD in that ad hoc predictive tools are under development which themselves form only a part of what should be a 'CFD system'. This may be true, but the present authors' opinion is that the R & F Committee report, especially in the part dealing with the applications of CFD to tankery problems, suffers a similar shortcoming. The CFD is considered in the Report as a primary importance issue, and the hull form design as one of its applications. Following this approach the report treats inherent problems of CFD, which are rather subject of the validation panel. The opposite is the natural situation the hull form design is the primary activity and CFD is a tool for it.

In this sense it is more important to apply system approach to the hull form design, and CFD should conform to the features of the design.

2. CDF IN HULL FORM DESIGN

The hull form design practice is still far from the ideal implied in the R & FC Report: direct application of sophisticated theoretical methods (such as Rankine source methods for wave resistance problems, Navier-Stokes solvers, ect). And this is due neither only to the still unsatisfactory performance of these methods, nor to their computer time and storage requirements, but is determined by the objective nature of the design process. The ship design passes different stages, characterized with increasing completeness and particularization of hull form data. Thus for instance, following the concept of the BMT's system BRITDES [1], three stages can be specified:

- 1) Concept design
- 2) Preliminary design
- 3) Advanced design

Stage 1 deals with the identification of the principal design variables. Concerning the hydrodynamics, only purely empirical methods are used at this stage systematic series model test results or prototype hull forms.

Stage 3 is aimed at the final and complete hull form definition. As for the CDF tools applicable at this stage, these are exactly the methods discussed in the R & F Committee's report.

The preliminary hull form definition is performed at stage 2. Larger amount and more specific hull form data is already available at this stage than at stage 1. The corresponding hydrodynamical analysis methods should be able to utilise this extra information. Semiempirical prediction methods are suitable for this purpose, filling the gap between purely empirical and purely theoretical methods for hydrodynamic performance prediction. These methods are based on appropriate theories and are tuned up with the use of relevant experimental data. This gives them sufficient accuracy for the design practice at low computer time consumption.

Resistance prediction methods of this type, developed at the BSHC are described briefly further on.

3. RESISTANCE OF FINE MERCHANT SHIPS

The data sample has been divided in two groups:

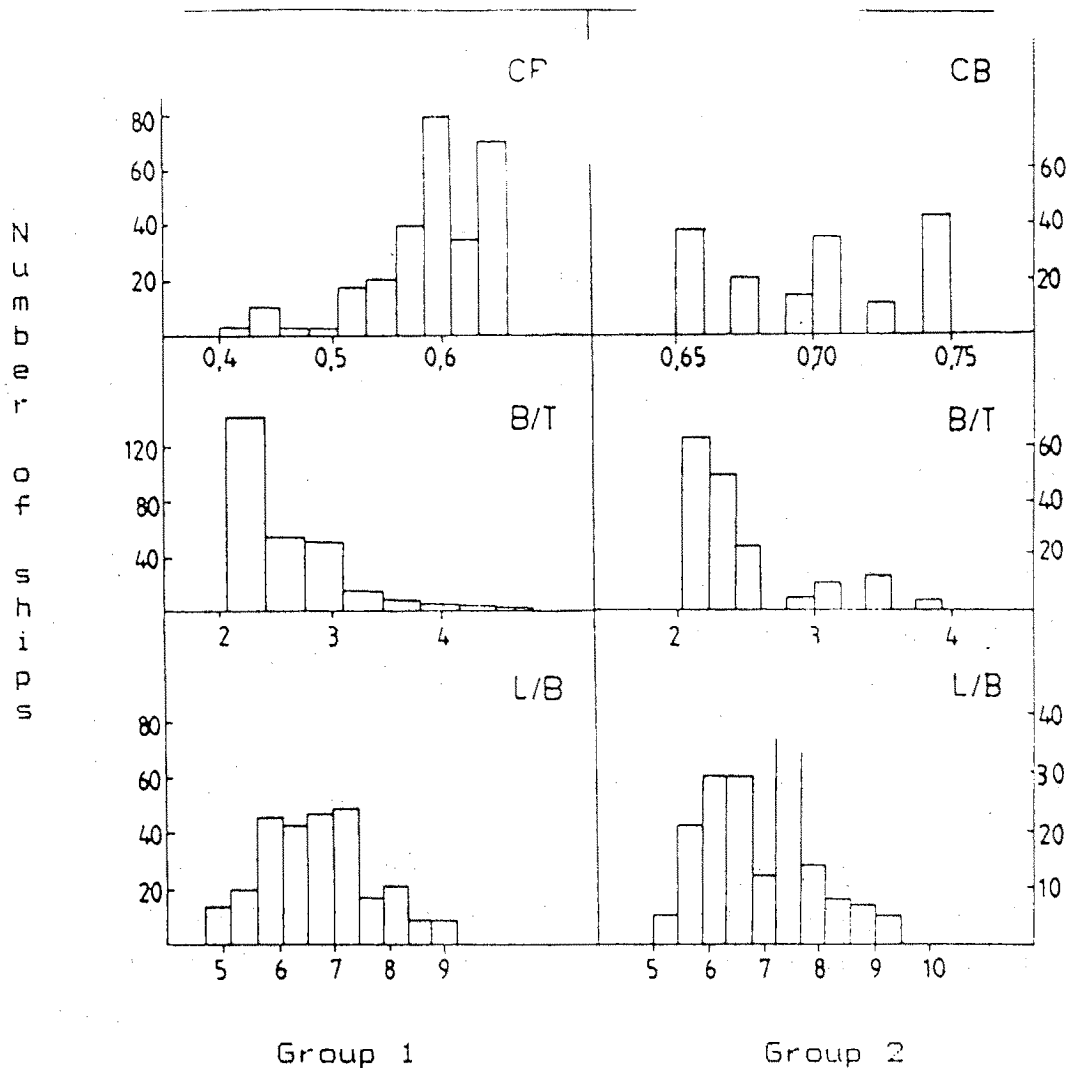
A regression model of residual resistance has been developed, with its structure derived from the linear thin-ship theory. Following and further developing the approach of Tagano [2], with certain simplifying assumptions the Michell's wave resistance integral has been transformed to obtain the following regression formula [3]:

$$C_R \approx CP^{cc} (L/B)^{cl} (L/T)^{ct} \sum \sum q_{ij} f_i f_j$$

	Group 1	Group 2
Block coefficient	$CB \leq 0.65$	$0.65 \leq CB \leq 0.75$
Fn-range	0.2 - 0.3	0.17 - 0.25
Number of hull	275	168

Here f_i are some typical sectional area curve ordinates and the coefficients CC , CL , CT and q_{ij} are determined by non-linear regression analysis - one set of coefficients for each F_n .

Fig. 1 shows histograms of same main particulars for the two groups.



The bow bulb, being a major means for resistance reduction, has been treated separately. Bow bulb efficiency has been defined as a correction factor to the bulbless hull resistance. Empirical formulae have been derived by statistical analysis of experimental data, representing the bulb efficiency as a function of three bulb parameters: protruding length, cross section and height coefficient [3].

The regression model described above is used as an objective function evaluator in a sectional area curve optimization procedure [4].

4. RESISTANCE OF FULL SHIPS

High-block-coefficient ships operate at relatively low speeds. According to the present-day concept about the low-speed resistance, it can be presented as:

$$CT_m = (1+k).CF + pFn^6$$

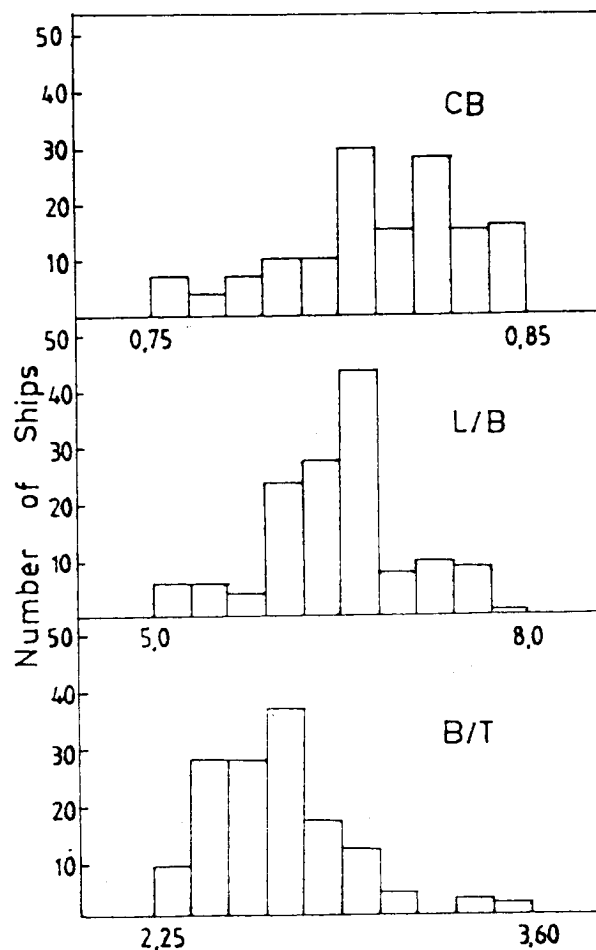
The assumption has been made that Eq.(2) holds for the whole F_n -range and it has been fitted to the experimental curves $CT_m(F_n)$ of all processed hulls by linear least-squares method [5]. Relationships have been searched for than between $(1+K)$ and p , and geometrical parameters of the hull forms. The selection of the parameters, influencing most significantly the dependent variables has been performed by correlation analysis.

Two sets of regression formulae have been derived:

- "Simple" formulae, including only principal dimensions and LCB, i.e. parameters treated at the Concept Design stage.

- "Complete" formulae, including also local hull form parameters, such as angles of entrance and run of main waterline and sectional area curve, bow bulb parameters, etc.

A sample of 140 hulls has been processed in this way. Histograms of some main particulars of the hulls in this sample are shown in Fig.2



5. CONCLUSIONS

The semi-empirical hydrodynamics prediction methods will preserve their importance for the optimum hull form design in spite of and simultaneously with the development of the more sophisticated methods referred to as 'CDF' in the R & F Committee Report. This is connected with the very nature of the ship desing process.

The methods, described above, have shown satisfactory performance as resistance prediction tools in various parametric studies and optimisation problems solved at the BSHC.

RF-5

REFERENCES

1. "A Description of BMT Software for Shipbuilding Application", BMT Ltd., 1985.
2. Tagano H., "Prediction of the Wave Resistance of Ships by Statistical Analysis", MTB No. 90, 1974
3. Kyulevcheliev S., "Estimation and Minimization of Wave Resistance in the Computer-Aided Hydrodynamic Hull Form Design", Ph.D. Thesis, 1990 (in Bulgarian)
4. Kyulevcheliev S., "Optimitization of Ship's Prismatic Curve for Resistance", PRADS'89, Varna, 1989.
5. Kostov D., S. Kyulevcheliev, Shen Hongcui, Jiang Quinwei, Guo Shenghan, Fen Youzhang, "Statistical Analysis of Full Ships Resistance", CADMO 91 (to be published).

H.C. RAVEN

Maritime Research Institute Netherlands, The Netherlands

A COMMENT ON THE EVALUATION OF WAVE RESISTANCE IN RANKINE SOURCE METHODS

Section 2.3.1.3. on Rankine source methods for wave-resistance calculations points out that the accuracy of the pressure integration over the hull depends on the panel density, and suggests that using the far-field momentum between the resistance found from pressure integration over the hull and that from the far-field momentum flux is attributed to numerical damping in the free-surface treatment.

However, these two resistance expressions may simply not be expected to give the same result. Only for special formulations of the free-surface boundary conditions the result should agree theoretically as has been pointed out by Eggers [1]; but e.g. for Dawson's condition there is a leading-order difference between them.

Furthermore it may be useful to stress that the panel-size dependence of the pressure integral is not primarily determined by integration errors but by the inaccuracy in the satisfaction of the boundary conditions. A resistance expression using integration over the free surface, based on Lagally's law, has equal inaccuracy and displays exactly the same convergence behaviour upon panel refinement, as

shown in [2]. A similar dependence can be expected for expressions based on the far-field momentum flux.

Finally it is important to realise that the far-field momentum flux is more severely affected by the truncation of the free surface source distribution, to the extent of yielding a zero resistance if the control plane is at the edge of the free surface domain [3].

It may be useful to add these points, in order to prevent any misunderstandings on the origin of inaccuracies in the calculated resistance.

[1]. Eggers, K., "On the Dispersion Relation and Exponential Variation of Wave Components Satisfying the Slow-Ship Differential Equation on the Undisturbed Free Surface", Schiffstechnik Bd. 28, 1981, pp. 223-252

[2]. Raven, H.C., "Variations on a Theme by Dawson", 17 th SNH, The Hague, Netherlands, 1988.

[3]. Raven, H.C., "Adequacy of Free Surface Conditions for the Wave Resistance Problem, 18 th SNH, Ann Arbor, Michigan, 1990.

RF-6

V. FERDINANDE

State University of Ghent, Belgium

CONTRIBUTION TO THE REPORT OF THE RESISTANCE AND FLOW COMMITTEE

Evidently, the Committee paid due attention to the studies of flow around the ship in shallow and restricted water. However, the studies considered are almost limited to the case of a solid impenetrable sea bottom, and to bottom keel clearances not lower than 20 per cent ($h/T \geq 1.2$). Of course, trim and sinkage effects exclude in practice navigation at lower keel clearances, because of grounding hazards. Yet, ship owners and harbour authorities are interested in a safe approach of vessels in channels to harbours at very low bottom keel clearance. This seems to be quite feasible in some areas where the sea, or estuary bottom conditions are characterized by the presence of a mud layer on the bottom. Hence, the study of the hydrodynamic phenomena occurring in such conditions has become a must. However, scientific investigation, of mud layers, of the fluid flows above and in them, and of the interaction, appears to be a delicate task [1], and an engineering approach looks rather risky, because inevitably based on some hypotheses to render the study treatable, [2]. Nevertheless, investigations are going on. It seems to be quite reasonable to simulate the real situation by representing it by a two-layer fluid problem with a well-defined interface, the lower fluid layer of a certain density and certain thickness representing the mud layer [3]. Efforts are done to evaluate the influence of the mud layer on ship

resistance, squat and trim, powering performance and manoeuvrability characteristics, at usual low speeds, [4].

But in the first place, the flow phenomena around the ship, sailing above a fluid layer of density ρ higher than 1000 Kg/m^3 , with certain thickness d above the hard bottom, with low and even negative bottom keel clearance, with respect to the fluid interface, and eventually restricted channel width, should be well understood. I mean the flow in the water layer of depth h , as well as in the simulated mud layer of thickness d , and the behaviour of the fluid interface. I think this committee in the future would find more material in proceedings of harbour congresses, reports of harbour authorities and publications in civil engineering journals.

Although wave propagation in the interface of two fluid layers of different density is a subject well understood since long. I am convinced that much has to be learned yet concerning the behaviour of that interface in the circumstances of a ship sailing above, or through it.

This is not a paper, but please let me communicate some facts.

Full-scale investigations on a suction hopper dredger under sail at small keel clearance revealed the appearance of a well defined undulation pattern in the interface water-mud. During towing tank experiments on two ship models, a similar pattern could be created in the interface of the water and liquid of higher density, viz. a mixture of trichlorethane-petroleum (TCE/P). A schematic general picture of the

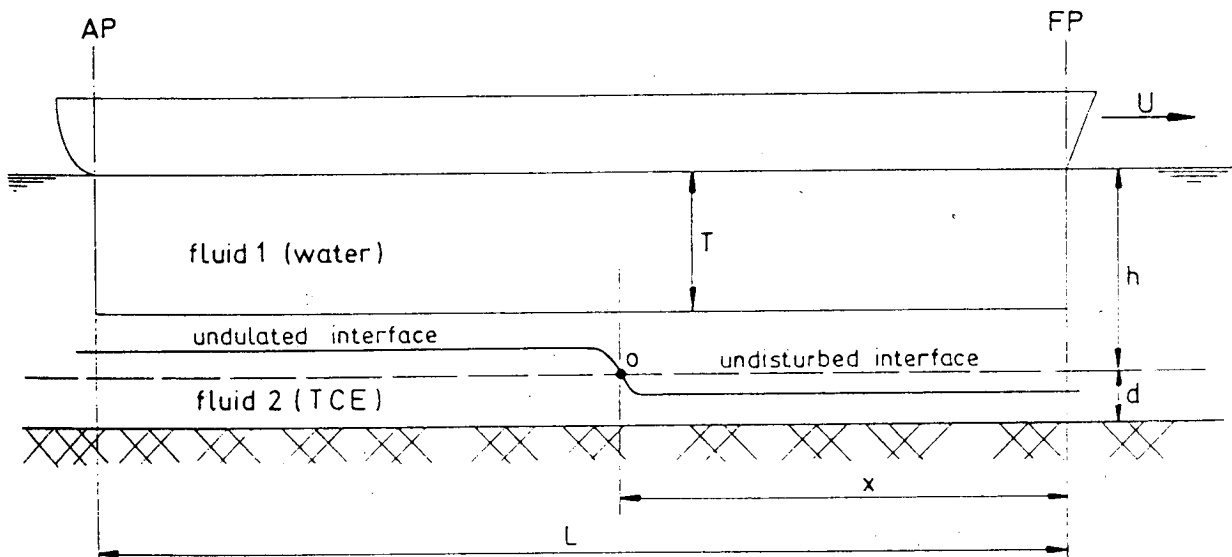


Fig. 1

longitudinal profile of the undulated interface is given in Fig. 1, to show the special feature of the intersection O of the disturbed interface with the original line at rest. This upward zero-crossing, as it could be called, when going from FP to AP, is characterized by the ratio x/L . This picture is merely schematic. The profile of the "sunken" interface between O and FP is not evenly horizontal, nor is the "risen" interface aft of O, which moreover shows some minor undulations when O is not too near AP. Visual observations let us state that the crests of these undulations alongside the ship are perpendicular to the longitudinal axis, extending to the tank walls. We intentionally use the term "undulation" instead of "internal wave" of the interface, because phenomenon corresponds by no means with the known behaviour of internal waves, but rather with a "hydraulic jump".

The results of the experiments under various conditions show clear trends:

- O moves aft with increasing ship speed U ,
- At the same U , O shifts backwards with decreasing density ρ_2 of the sublayer,
- At the same U and ρ_2 , O shifts backwards with decreasing thickness d of the sublayer.

References

[1] Chiang C. Mei and Ko-Fei Liu, "A Bingham-Plastic model for a muddy seabed under long waves", *Journal of Geophysical Research*, Vol.92, No. C13, Dec.15, 1987.

[2] R. Sellmeyer, G. Van Oortmerssen, "The effect of mud on tanker manoeuvres", The Royal Institute of Naval Architects, 1983.

[3] M. Vantorre, J. Coen, "On sinkage and trim of vessels navigating above a mud layer, 9th International Harbour Congress, Antwerp, 1988.

[4] F. Wens, P. De Wolf, M. Vantorre, C. De Meyer, "A hydro-Meteo System for monitoring shipping traffic in narrow channels in relation with the problem of the nautical bottom in muddy areas", 27th International Navigation Congress, Osaka, May 1990.

RF-7

W. B. VAN BERLEKOM

SSPA Maritime Consulting AB, Gothenbourg, Sweden.

CONCLUSIONS AND RECOMMENDATIONS

1. In the conclusion of the Committee Report I find statement 3 (under item 3.1.1.) somewhat premature and I would like to refer to the workshop on CFD methods last week at SSPA. The findings of this workshop were rather that today there are many methods but none can fully support the above mentioned statement 3.

2. This leads to the recommendations on page 107 and I support these but I would also like to draw the attention to the problem in validation of CFD-codes. There is an apparent danger in that the CFD-codes are made to match available experimental data. This means that efforts must be spent on the general applicability of the proposed CFD-codes.

Thus I propose that to the recommendation No. 2 the following sentence is added. "Efforts to validate the general applicability of CFD. codes are of utmost importance".

RF-8

M. SCHMIECHEN

VWS, Berlin Model Basin, Germany

FLOW IN SHALLOW WATER

The problem of navigation in very shallow water is felt to be a ship control and guidance problem. Harbour authorities look at it as a stochastic process in views of the fact, that they have to look not only at one ship, but at many ships. A probabilistic study according to this point of view has been performed at the Berlin Model Basin for large ships approaching the German harbours. The goal of reaching more risky decisions than with the present system of ship guidance can, in the opinion of the discussor not be reached.

RF-9

Y. KODAMA

Ship Research Institute, Japan

COMMENTS ON THE REPORT

In the editorial policy of an ASME journal, it is stated that results of flow computations cannot be accepted as valid, unless they are obtained using more than one grid. This statement shows that CFD (Computational Fluid Dynamics) results can vary depending on the grid used. Dependence of computed results on grids come from two sources. One is grid resolution. This factor has the primary importance, but its check is rather straightforward. One only has to double the number of grid points and re-computer. The other is grid quality, which is related with skewness, irregularity, smoothness, and so on. This factor is difficult to check, because one generally does not have a grid-generation system which is flexible enough to generate grids of various qualities. Still, this factor should be checked whenever possible, for the validation of CFD results.

II. REPLIES BY THE RESISTANCE AND FLOW COMMITTEE

The Resistance and Flow Committee is grateful to all the delegates who participated in the discussions of our report. The replies to the written discussions are grouped according to subject.

Reply to Dr. GRIGSON

The Committee has attempted to focus attention on the very difficult problem of relating the geometry of a solid surface to its associated hydrodynamic roughness function. The fact that the shapes of $\Delta C(R_n)$ are governed by the shapes of the roughness functions is not in doubt; the important question to raise is whether or not, from a practical rather than an academic standpoint, it matters. The Committee has claimed that "From the point of view of engineering accuracy it probably does not matter whether the hump is there or not since curves can be constructed which fit sufficiently accurately given the inevitable amount of scatter inherent in such data". The real issue therefore concerns the precision and roughness Reynolds number range that can be achieved when measuring the roughness function, since Dr Grigson's evidence can only be accepted if it can be demonstrated that the curve fits are reliable. It is the Committee's view that the so-called hump is evident only in Nakato's data for the surface P3 and that, for the other four surfaces of Nakato, Couch and Musker, a monotonic or Colebrook type of function is just as plausible.

The Committee has reported Medhurst's criticisms of Grigson's conclusions but is unable to form a definite opinion until the matter has received more open

debate. The Committee cannot comment on the validity of Equation 1 since this is a full scale correlation formula proposed by the Powering Performance Committee and is strictly outside the terms of reference of the present Committee. The Committee makes the observation, however, that Grigson's work sheds no new light on possible alternatives to be used as a quick but approximate full scale formula.

Reply to Dr. TOWNSIN

The Resistance and Flow Committee was represented in the RINA International Workshop on Marine Roughness and Drag and played an active part in formulating the final recommendations. We therefore endorse all the points raised by Dr Townsin, particularly in relation to the need for more reliable data for roughness functions associated with ship hulls. Such data will help to resolve the problems raised in the previous discussion.

The Committee recognises that environmental issues may lead to renewed interest in the roughness problem from the point of view of the efficient use of energy and also the ecology of coastal waters. In this context there is clearly a need for basic fluid dynamics research into the effects of slime.

From the point of view of long term computational fluid dynamics research it must not be overlooked that real hulls are rough and that therefore the current trend to dispense with wall functions in favour of resolving flows right down to the wall is probably

going to be short lived. Real hull surfaces are fractal surfaces and cannot be modelled by conventional boundary conditions. Hence wall functions, and therefore roughness functions, will be needed in addition to reliable turbulence data in the near wall region.

Reply to Dr. HUANG

Whilst the surface cited does have drag properties (but only if it is precisely aligned) it is not all typical of the naturally occurring roughness which the Committee was addressing. We therefore regard this as a especial case which cannot reasonably be included in any practical data set to be used for identifying possible correlations between geometry and friction.

Reply to Dr. KOSTOV et al

The Resistance and Flow Committee rightly regards CFD as one of its primary activities and hull form design as an area of application of CFD methods. Our objective here was to identify the problems associated with bringing the two disciplines together and by implication it is clear that, at least for Reynolds Averaged Navier Stokes Methods, formidable obstacles need to be negotiated before this can happen. In this sense the Committee felt the need for a systems approach to be applied to CFD in isolation, to facilitate the processes of grid generation, diagnostic, and flow interpretation. With such a properly engineered system, rather than an ad hoc collection of codes, it should be possible to make rapid progress in the area of validation generally and code and geometry verification specifically. Only when the latter problems

have been properly resolved and guidelines established can sophisticated CFD methods be reliably incorporated into a ship design system. The Committee does not accept that the inherent problems of CFD ought to have been addressed exclusively by the validation panel – the fact that similar broad conclusions regarding validation have been drawn should be regarded as encouraging.

It was not the Committee's intention to suggest that the direct application of sophisticated theoretical methods was everyday occurrence. The Committee was addressing the question of the present and future role of CFD in ship design as perceived by the CFD Community.

Although our report does not pay direct attention to the problem of hull form design, we do recognise that the semi empirical approach whereby linearised wave resistance theory is combined with statistical analysis of towing tank data, will play an important role at the preliminary design stage.

The Resistance and Flow and Powering Performance Committees had an opportunity to discuss the problem of form factor on the occasion of the ISRP held at Shanghai last year. At this joint meeting, we reviewed the existing methods to predict form factor, namely the polynomial function which is proposed in the discussions, the method using geosim models and the application of computational methods. We did not arrive at any clear conclusion. When applying the polynomial function method, however, the need for careful measurement of the resistance in the low speed range was recognised, paying attention to the effects

of turbulence stimulation, size of model and tank environment.

Reply to Mr. RAVEN

When wave resistance is computed it is important to clarify whether the calculation has been performed using the far field flux or the surface pressure integral approach. In the latter case, the accuracy certainly depends on the number of the panels used to compute the pressure; the integral of the pressure cannot be improved by increasing the panel density. We agree that in the case of the far field momentum flux method, we should take account of the effects of panel density and truncation of the free surface in the far field – both of which are likely to affect the accuracy in treating boundary conditions.

Reply to Prof. FERDINANDE

This contribution discusses a special problem of shallow water, namely the treatment of the border between two media – mud and water. The pressure distribution and also the flow under the hull depend not only on the ship dimensions but also on the ratio h/T and on the density, thickness, and physical properties of the mud. This greatly increases the complexity of the problem and suggests that more research is required in this important area.

Reply to Dr. van BERLEKOM

The committee agrees that agreement between CFD predictions and experiment in the stern region is far from satisfactory. The phrase 'with reasonable accuracy'

is a rather subjective one. However, the latest RANS methods do represent a considerable improvement over the older boundary layer integral methods and in qualitative terms do describe many important features of the flow in this complex region.

There is certainly a danger of CFD practitioners adjusting the various parameters at their disposal to fit the experimental data. Access to the same code by many teams is one possible solution to the problem, however. It is difficult to see how in practice this could be achieved. A major difficulty might present itself in the form of commercial software licence arrangements or intellectual property rights. The committee believes that the way ahead is firstly to cooperate more closely through international workshops and conferences such as the recent one at SSPA, and secondly to pay more attention to code verification studies.

Reply to Prof. SCHMIECHEN

The committee has been addressing only the resistance characteristics in shallow water and the associated effect of backflow. The practical problems of navigation ought to be addressed by the Manoeuvring Committee.

The committee agrees that the design of a CFD validation experiment needs very careful planning, with especial emphasis being placed on the problems of uncertainty analysis and choice of variables. We are confident that these issues will be the subject of debate for the next committee.

Reply to Dr. KODAMA

The Resistance and Flow Committee appreciates Dr. Kodama's comment on the importance of the check of grid quality in CFD validation. It is necessary to evaluate all sources of numerical errors like truncation errors, iteration errors, etc., by changing grid arrangement or by using other checking methods. Errors due to mathematical modelling would also be an important item for CFD code validation. However, the most urgent problem at the present time would be to establish a methodology of how to make the CFD validation, including numerical error prediction.

III. COMMITTEE REPORT ERRATA

The following corrections need to be drawn to the attention of the Community:

1. Page 67, fig. 1: $m = AM/AT = 0.0$
should read $m = AM/AT = 0.051$
2. Page 61 left up 9 lines: (1987) → (1988)
3. Page 79, table 2: Multi-block RANS
should read: RANS
4. Page 95 left up 8 lines: add Tanaka H. to Author
5. Page 102 right 6th ref. delete all (same as 8th)
8th ref. delete one of Stern F.