REPORT OF THE POWERING PERFORMANCE COMMITTEE

CONTENTS

I. GENERAL

1. MEMBERSHIP AND MEETINGS

The 18th ITTC appointed the Powering Performance Committee with the following members:

Prof. R. Bhattacharyya
Dr. G. Collatz
Dr. A. Garcia-Gomez
Mr. Y. Guo
Mr. J. Holtrop (Chairman)
Prof. K. Nakatake
Dr. R. L. Townsin
Dr. K. G. Varsamov

At a preliminary meeting following the 18th ITTC in Kobe, those members present elected Dr. Townsin as Secretary to the Committee.

The Committee experienced the sad loss of Dr. Günter Collatz, who passed away on 1989-01-13. The Powering Performance Committee is grateful for all the work Dr. Collatz has done within the scope of the ITTC and greatly miss his co-operation and contributions.

The Powering Performance Committee found Mr. P. Schenzle prepared to take over Dr. Collatz's position and the Executive Committee formally confirmed Mr. Schenzle's membership during 1989.

The following technical committee meetings were held:

1.	El Pardo	January	1988
2.	Varna	October	1988
3.	Shanghai	April	1989
4.	Ede	December	1989

In conjunction with the meeting in Shanghai in April 1989, a joint meeting was held with the ITTC Resistance and Flow Committee. A final meeting with a minimum attendance was held in Newcastle upon Tyne in March 1990 to prepare the final report.

2. RECOMMENDATIONS OF THE 18TH ITTC

Recommendations of the 18th ITTC for the Future Work of the Committee:

2.1 Form Factor

The Committee should prepare practical guidelines for determination of 1 + k from routine tests. In cooperation with the Resistance and Flow Committee, the effects of flow separation and surface tension on the model measurements should be considered carefully and advice given as to how these effects may be minimized.

2.2 Appendage Drag

The Committee should work towards a solution to the problem of scaling model hull appendage drag.

2.3 Effect of Hull Roughness

A revision to the ΔC_F formulation should be considered which can be applied in assessing the effect of hull roughness in both the ship's trial and service conditions.

2.4 Propeller Characteristics

The Committee should examine the relevant studies made on propeller performance studies with particular reference to the applicability of new findings to routine testing and with respect to the physical bases involved.

2.5 ITTC Performance Prediction Method

The Committee should continue to monitor the use of the 1978 ITTC Method and to examine any problems raised. Particular attention should be paid to refining the analysis procedure for twin screw ships.

2.6 Performance of Ships in Restricted Water

The Committee should continue to review the progress made in predicting performance in shallow and restricted waters.

2.7 High Speed Craft

The Committee should cooperate with High-Speed Marine Vehicle Committee to develop a method of power prediction for high speed craft.

II. REVIEW OF RESEARCH INTO POWERING PERFORMANCE OF IMPORTANCE TO THE ITTC.

INTRODUCTION

The ITTC Powering Performance Committee has traditionally been dealing with the problem of the relationship between a certain hull form and the power to be installed. Model experiments to predict this relationship are still believed to be the most accurate means, particularly if the form at hand is not sufficiently related to experience with similar cases tested earlier.

The Powering Performance Committee believes that in many cases the activities of the member institutions of ITTC are determined by the nature of the contracts between ship owners and ship builders. The contractual clauses concerning speed, power and revolution rate are referred to an often unrealistic set of circumstances compared with the performance of the ship in service, because of the perceived need to verify satisfaction of the clauses using speed and power trials. It is believed that under the pressure of these contractual clauses ships can be produced which are not optimal designs with respect to their service performance, to the disadvantage of their operators.

Model test institutions sometimes play an unsatisfactory role as a consequence of the nature of the contract, because the best of their services on offer e.g. hull optimisation, are not being fully used, or even worse, their efforts are focussed on optimising a hull form for conditions which will only be encountered during the speed trials.

Should this combination of legal, commercial and technical issues be considered by ITTC?

The Powering Performance Committee recognizes that work on statistical standards for referencing model test results and the growing possibilities of examining alternative designs by means of CFD, prior to model experiments, are positive contributions to the success of many model experiment programmes, and are to be encouraged.

1. QUESTIONNAIRE ON EXPERIENCE OF THE ITTC-1978 PERFORMANCE PREDICTION METHOD

1.1 General

The Powering Performance Committee has circulated a questionnaire to the ITTC member organizations to monitor the use of the ITTC-1978 Power Prediction Method. In this questionnaire the member organizations were invited to indicate problem areas and their experience, and to suggest specific needs for improvement.

21 member institutions responded to the 81 questionnaires sent out. 4 of these replies were left aside from the evaluation because the respondents were not actively engaged in towing tank experiments in the field of ship propulsion. From the remaining 17 institutions who responded it appeared that 5 use the method in more than 10 per cent of the routine model propulsion tests. 4 institutions do not use the method at all and 8 institutions use the method for a minor part (1-10 per cent) of the tests. From the comments given it appears that those who use the ITTC-1978 method restrict its application mainly to single screw conventional hull forms. Very few institutions attempt to apply the method to twin-screw ships.

At this point the Committee wishes to express its thanks to all those who responded to the questionnaire.

1.2 Summary of responses and comments.

Below a summary is given of points to be improved in the ITTC-1978 method according to the respondents to the questionnaire:

1.2.1 Form factors: How to determine them accurately, effects of shallow water, effects of varying draught, what to do in case of flow separation, how to derive form factors of special vehicles, high speed craft, scale effects on form factors, bulb effects.

1.2.2 Appendages: There is an apparent need for a method to treat the appendages in extrapolation.

1.2.3 $C_P/C_N/C_{NP}$: The range of applicability and the level of these coefficients for deviating ship types and the gathering of accurate full scale trials by the ITTC, should be pursued. Pay more attention to unexplained differences between specific towing tanks.

1.2.4 Frictional resistance: Reconsider the flat plate friction and the formulation of the hull roughness effect.

1.2.5 Reconsider the wake scale effect.

1.2.6 Reconsider scale effects on the propeller open water performance and assess the effects of irregular inflow in open water conditions.

1.2.7 Preference for more flexibility to match the method to practical approaches in use for:

propeller design, testing stock propellers, scale effect corrections expressed in a manner prevailing in Japan (e_i and C_A).

1.2.8 Define a unique tow rope unloading force.

2. THE USE OF FORM FACTORS

2.1 Introduction

Form factors as a modification of William Froude's original approach to the extrapolation of model test results have become gradually accepted in the work of ship model basins. Correlation studies for the ITTC Powering Performance Committee made at various institutions have shown that the scatter of the model-ship correlation factors C_P and C_N were reduced if a form factor was introduced in the extrapolation of the model resistance and propulsion test results. The difference in the spread of the correlation data was small however, and, in practice, the change from the classical Froude method to the form factor methods was difficult. Although the form factor methods have become practical tools in many institutions there is not a universal enthusiasm for their use. At previous ITTC's reasons for reluctance to introduce form factors have been extensively discussed, and it is appropriate to review them here.

2.2 Previous Discussion of Practical Form Factor Problems.

2.2.1 - 15th ITTC: The use of a form factor determined from low speed resistance measurements in the range $0.12 < Fn < 0.20$ was recommended using Prohaska's method with the most suitable exponent for the wave making resistance. Practical problems with partially immersed bulbous bows and effects of wave-breaking resistance were recognised, but real solutions were not offered. Possible Reynolds and Froude number dependency of 1+k were ascertained and discussed but their impact on the use of 1+k in routine experiments was ignored. In the discussion, attention was drawn to effects of surface tension on the form factor through its influence on the wetted surface area, (Kafali). Other contributions doubted the lack of consistency introduced with the form factor, (Nethercote) and the confidence that the new methods employing 1+k are really superior to the older ones in which form effects are only implicitly incorporated, (Moor, Crago).

2.2.2 - 16th ITTC: As in the 15th ITTC several practical problems concerning the determination of 1+k were reviewed, but also here, a general solution of these problems was not given, although several good suggestions were made to preserve consistency and accuracy of 1+k. A pre-fairing of rough data points on Prohaska's basis may show rogue points to be deleted in the further analysis. Hughes' proposal to determine 1+k could be adopted if linearisation in the plotting according to Prohaska is insufficient. The suggestion was made, however, that Hughes' method is equivalent to determining the level of C_{Tm}/C_{Fm} at the point where the model resistance coefficient has the same tangent as the flat plate friction line. Essentially, Hughes determined the form factor from the point where C_{Tm} attains its minimum value, (see e.g. the contribution by Jourdain at the 18th ITTC).

The Performance Committee of the 16th ITTC wrote that a disconcerting variability is shown by 1+k analyses of geosim test results. On the other hand the lack of consistency and accuracy of 1+k is suggested to be of minor importance by pointing out that an error of 10 per cent in k results in a deviation in the predicted shaft power of only 2 per cent at maximum. Some attention was paid to how the use of form factors of appended ship models may contribute to an appropriate scaling of the drag of appendages. A possible Froude number effect, as derived by Hogben, was checked against a constant form factor but this amendment did not result in a more consistent method.

2.2.3 - 17th ITTC: The report of the Performance Committee reviewed again the practical problems frequently encountered in the determination of form factors. Solutions were not offered but reference was made to the experience of the staff in judging test data, the simplicity of the graphical procedure involved and the benefits of the method as a whole, by which more consistent results can be obtained than with procedures without form factors.

In contributions by Harvald and Crago the lack of consistency, accuracy and uniqueness of the form factor was expressed. Apparently, the need for a standard form factor procedure was great, but there was not yet a procedure to cover all the influences which may give rise to discrepancies in the form factors.

2.2.4 - 18th ITTC: Both in the report of the Resistance and Flow Committee and in that of the Powering Performance Committee attention was paid to several aspects of form factors. The possible effects of form factor increase due to surface tension effects, particularly around small models, were discussed. An inspection of reported trends as to Reynolds number influences on the form factor did not reveal a distinct tendency and therefore the approach of a Reynolds number independent 1+k was recommended for routine tank work. A need for a more fundamental approach in the form factor procedure was expressed to resolve the several practical problems involved.

2.3 Practical guidance

In reviewing the use of form factors in routine tank work it becomes clear that despite the merits of reducing the dispersion in the correlation, a new factor of uncertainty is introduced which appears to be a nuisance in many test programmes. Most of the uncertainty arises from the problem of how 1+k can be determined accurately from low speed resistance measurements. Since 1+k may vary considerably from one hull form to another, even when forms of equal principal dimensions and equal global form coefficients are compared, there is not much prospect for using statistical formulations of the form factor because then effects of the individual hull form are ignored. Correlation analyses in the past have shown that individual experimental form factors are to be preferred from an accuracy viewpoint. On the other hand the statistical evidence is not such that statistical formulations of 1+k are to be rejected for ordinary ships in many cases.

Below several cases are considered where a consistent approach in the form factor choice is most important:

2.3.1 Hull form optimisation testing

Since form factors are difficult to determine with accuracy in some cases, there is a danger in a particular case that a wrong conclusion may be drawn about the effect of a given hull modification. Thus there is an argument that in order to avoid the occasional serious error of conclusion resulting from this, it is better, at least in an initial analysis, to use a constant form factor, even though it is realised that the modification, if intended to reduce viscous resistance, is changing the form factor. In the event that the modification is clearly affecting only the wavemaking, then a constant form factor is appropriate of course, even though errors in determining the factor may suggest a difference. If the modification is safely judged to be indifferent as regards the wave making, wave breaking, and other components of Reynolds number independent pressure resistance, the difference in form factor can be determined from test points at higher Froude numbers under the approximation that the wave resistance is equal for both variants:

$$k_1-k_2 = \left(R_{m1}-R_{m2}\right)/\tfrac{1}{2}\rho S V^2 C_{Fm}$$

It is therefore concluded that if hull form changes are studied, the predicted power savings could be judged first on the basis of a constant form factor. Well chosen form factors should eventually be established and introduced to make an accurate prediction of the absolute level.

2.3.2 Optimum Trim and Draught Variation Tests

A similar problem exists when small changes in the draught and trim are studied by model experiments. Strictly speaking, for each condition a new form factor should be established, but also here the uncertainty in the form factor determination may hamper consistency in the results obtained. Moreover the assumption of equal wave resistance is certainly not true here and effects of bulbous bow and immersed transoms may become predominant. The choice of the form factor should be made with great care, taking into consideration that, if the bulbous bow is well immersed and there is no transom effect, 1+k should vary smoothly in relation to the draught or trim.

It is concluded therefore, that for this type of model testing, the form factors can be used only if their mutual relation is well preserved by cross fairing and proper interpretation of typical resistance phenomena such as bulb waves and transom immersion.

2.3.3 Tests in which Flow Apparently Present

First of all it is of utmost importance that the occurrence of flow separation is detected, eg using hot film probes [1] or visual techniques. This is a separate problem, not discussed here, but an assessment of scale effects should be considered because, particularly at low speeds, separation may be more excessive and unfortunately the low speed points are those used to determine the form factor. The issue of whether or not a scale effect on the additional drag induced by separation is present will be a matter for careful consideration from test to test. Definite rules are difficult to give but a few general guidelines can be drawn up:

- Much depends on the interaction between stern flow and the propeller action. If this seems to be present, e.g. if 1+k from the load variation test differs essentially from 1+k from the resistance test, the 1+k derived from a combination of a load variation test at one speed and a propulsion test can be considered for the extrapolation. In an evaluation of form factors Lauro and Miranda [2] have included 1+k values derived from propulsion and load variation tests. They come to the conclusion that it is worthwhile to explore further the benefits of form factor determination from propulsion and load variation tests.
- Twisting of boundary layer flows on relatively slender forms is a common phenomenon, sometimes referred to as a form of separation. Experience with this type of flow and hull form shows that the form factor method is adequate to account for the attendant viscous pressure drag and no special steps need be taken.
- On very bluff forms however the separation-type phenomena are of a somewhat different nature, giving rise to high viscous pressure drag. Part of this so-called separation drag coefficient can be constant with Reynolds number change and hence, whilst the remaining part may be extrapolated by a form factor in the usual way, the effective overall extrapolation should be equivalent to using a form factor less than that determined from low speed tests to avoid an overly optimistic powering prediction. Given this dilemma, a form factor might be used which is derived from full forms which do not suffer from severe separation problems. At least in this way some consistency is preserved. See also discussion by Minsaas of [3].

Some ships have very simple forms, resulting in chines, knuckles, holes, protrusions and mis-aligned appendages. Sometimes skegs are off-set to improve steering performance or course stability in towed operation. In all these cases as with the separation on the full form ship, the form factor to be used in the extrapolation of model test results should be lower than that according to the low speed resistance test. As a first approximation a statistical form factor for a streamlined hull form of the same main dimensions and form coefficients may be used.

2.3.4 High Speed Craft

The presence of deeply immersed transoms when at rest and the multitude of various appendages poses problems which are typical for this class of vessel. Next to the form factor problem is the influence of the Froude number on the area of the wetted surface and the velocity defect under a planing craft. By convention, tests on such craft are extrapolated without a form factor.

Another problem is to obtain a reliable form factor from the low speed tests for a transom type ship, which might be considered a medium speed vessel e.g. a frigate, in a condition where the transom does not clear. A current practice is to do either an additional low speed resistance test with the model sufficiently trimmed by the bow specifically for the form factor determination, or to estimate the additional drag caused by the transom immersion by means of an empirical formula. Some good correlations have been obtained with this approach and confidence is gained when the form factors obtained by both procedures agree. Fortunately, the effect of inaccuracy in 1+k is rather small for this type of ship.

2.3.5 Ships with Streamlined Flow-Oriented Appendages

This is an important issue and a separate section, II.5, later in this Report, is devoted to the problems.

2.3.6 Special Devices

Nowadays much research work is undertaken in the field of energy saving devices, e.g. of various types of duct, fin, stator and rudder. The scale effects on these propulsive elements must certainly be accounted for separately. Apart from the scale effects on the action of the element itself there is the consideration as to whether or not there is influence on the flow along the hull. Some devices are intentionally designed to affect flow. This would require ultimately a form factor adaptation because, essentially, the viscous hull resistance is affected and some greater or smaller part of the power gain is caused by this effect. It is, however, extremely difficult to determine reliable form factors due to the complexity of the device. Most probably, the best form factor estimate can be made by the assumption of equal wave resistance at higher speeds at equal Froude number when comparing load variation test results extrapolated to the zero thrust condition. Since the devices show a great variability each case has to be judged individually.

2.4 Fundamental issues on form factors

A better understanding of the form factor concept can only be achieved when the fundamental problems associated with the form factor are treated in depth as suggested by previous Conferences.

2.4.1 Effect of Reynolds number

Current form factor methods assume that the form factor is independent of the Reynolds number. Significant data from various experimental facilities suggest that this assumption, while very convenient from the practical standpoint, may not be correct since viscous pressure resistance may not be a constant fraction of the frictional resistance over the entire range of Reynolds number covering both the model and full-scale ship.

A systematic effect of the Reynolds number is not detected, however, in much of the available experimental data because surface tension and stern flow separation cause an increase in resistance, which in turn causes an increase in the form factor for the smaller model sizes. Our knowledge in the area of viscous flow and separation and its relation to viscous resistance of an arbitrarily given ship hull form as a function of Reynolds number is still not very satisfactory. Moreover, there is a lack of experimental data at high Reynolds number, thus preventing us from making any conclusions regarding the effect of Reynolds number on the form factor. The general assumption that the form factor is independent of Reynolds number can be used for routine work in predicting full-scale resistance from model test data.

It has also been found that the form factor increases with an increase in model size, which may be attributed to the presence of laminar flow during tests with small models. Since laminar flow may cause too low a value for the form factor, resistance test data at very low speeds should be judiciously scrutinized. For all speeds the effectiveness of the turbulence tripping should be preserved, a matter of interest particularly for testing small ship models.

2.4.2 Effect of Froude number

The effect of the Froude number on the form factor cannot be determined without an extensive model testing programme on geosim models.

At past Conferences the validity of Froude's law has been questioned. After performing wave analyses it was found that considerable differences did exist in the wave pattern resistance.

This fact alone may suggest a speed effect on form factor. However, changes in sinkage, trim and wetted surface may be responsible for the major part of variation of form factor with speed.

If the wave resistance coefficient of two models, 1 and 2, which are different in size, is the same at equal Froude numbers, the form factor at various speeds could be obtained from:

$$1 + k = \frac{(C_{T1}) - (C_{T2})}{(C_{F1}) - (C_{F2})}$$

2.4.3 Effect of surface tension

Professor Maruo and his associates studied surface tension effects on model resistance. Consistent differences were found to be present between the resistance data collected with intact surface tension and those collected with surface tension reduced by applying surfactant. It was observed that bow wave breaking was significantly less prevalent with lower surface tension and as a result the total resistance was decreased. This indicates that the value of the form factor was also reduced. It was also noted that surface tension effects caused a significant increase in resistance for smaller models.

Bogdanov et al (1989) have shown that for ship models larger than 6 metres in length, effects of surface tension may be neglected.

2.4.4 Effects of tank blockage

The tank blockage effects is also a factor to be considered when determining the form factor. A blockage correction must be made before the form factor is determined for a specific model tested in a particular towing tank.

According to Millward, whose results are referred to in Section II 9 of this report, the error made by using the form factor measured in the normal depth of water in a towing tank as the deep water form factor is not more than 0.5 per cent.

3. PROPULSION TESTING

Experience with the ITTC-1978 method or some elements of it has been reported in open literature. In [4] Nawrocki presents the results of a series of geosim tests of a high block ship in comparison to full scale results. The model tests results were analysed by means of the ITTC-1972 and the ITTC-1978 method. The scale factors ranged from 24 to 180 and involved 4 models from 1.56 to 11.9 m in length. The results of the resistance tests showed that good agreement was found between the results of the largest three of the four models if the ITTC-1978 method was used, the results obtained with the smallest model were left aside as being too inaccurate. Propulsion tests were carried out with the two largest ship models. In the tests the unloading force was equal to the scale effect of the resistance. This implied that in the ITTC-1978 method the propeller load was comparatively light and this raises the question of whether the thrust deduction was measured with the required degree of accuracy. Good agreement between the effective wake fractions of the two models was reported. The same holds for the speed power relation in connection with the results of the full scale trials. In the paper it is concluded that the minimum size of a ship model of this form is governed by the flow conditions and the avoidance of laminar flow.

In [5] Mewis shows that the use of the form factor in hull form variation experiments leads to erroneous conclusions as regards the choice of the best hull form. The difficulties encountered in assessing accurate 1+k figures from the experiments hamper a proper comparison being made from a number of tests with a modified form. Mewis' conclusions are well in line with the guidelines for the use of form factors included in this report of the Powering Performance Committee.

In [6] it is pointed out that for the self-propulsion point of the ship the conditions do not match those on full scale. Model propulsion tests ought to be carried out at an arbitarily chosen load between the self-propulsion point of the model and that of the ship. In a following paper, [7] an interesting proposal is made to make the ITTC-1978 method consistent as regards the possible effect of the propeller load on the effective wake fraction and the thrust deduction. Moreover, it is proposed to replace the simple assumption that the viscous component of the effective wake fraction is proportional to the viscous resistance coefficient, by a more rational one. Cen and Lin introduce as a wake scale rule:

$$w_s = w_d + (w_m - w_d)(H_s C_{vs}/H_m C_{vm})^n (1+\sqrt{1+C_{Thm}}) / (1+\sqrt{1+C_{Ths}})$$

Here H is the boundary layer shape parameter defined as, $H = 1/(1-4.14\sqrt{C_v})$ and n is an empirical coefficient depending on the propeller arrangement. For single screw ships the value n=0.6 is proposed. The authors claim improved correlation and a practical substitute to define more accurately loading effects in a consistent manner, thus making the loading during the self-propulsion test of an arbitrary nature. It will be of interest to verify the empirical coefficients from some load variation tests and to check statistically the accuracy of the predictions by an analysis of a sufficiently large sample of correlation data.

In [8] Grigson has made a correlation study of model experiments with full scale measurements. In the latter, the speed through the water was measured with the Dutchman's log. Supported by a review of the accuracy, the author gives a re-appraisal of the Dutchman's log for large ships in mid ocean. Grigson concludes that due to uncertainty of the correlation allowances for economical light ballast conditions, full scale trials as presented should be carried out. In the presented study the ITTC-1978 method has been used with some adaptations as regards the form factor, the hull roughness formulation, the propeller roughness effect and the effective wake scaling. The analysis points to a substantial increase of the propulsive efficiency with increasing trim in light ballast.

Another method to measure the performance of a ship underway is the methodology of Abkowitz and Liu. In [9] they apply a system identification technique to the propulsion characteristics of a ship. The procedure involves the acceleration/deceleration of the ship and the instantaneous recording of the propulsion parameters - speed through the water, torque and propeller rotation rate. The heading and rudder angle are measured also.

The testing involves running the ship with a windmilling propeller for a period. The authors thus determine from the zero thrust condition the true resistance of the ship using a calculated correction of the drag of the windmilling propeller. Application of this method aboard the Exxon Philadelphia has produced results which could be compared to some model test data. It appears that the thrust deduction factor t and the effective wake fraction of the actual ship are 0.296 and 0.256, respectively. On model scale these figures are 0.216 and 0.384. This points towards an extremely large scale effect on the hull efficiency. It will be clear that more experience with this method should be gained before an evaluation of its practical use can be made. As in all methods the accuracy depends on the accuracy of the instrumentation and the accuracy by which these instruments, here the standard ship instruments, can be calibrated and validated.

Another novel technique by which the propulsive characteristics can be determined is the procedure of Schmiechen. In [10] a brief outline of the procedure is given with an application on the model scale. The procedure involves the instantaneous measurements of the propulsion parameters in a quasi-steady test. The Powering Performance Committee would like further explanation of this proposal especially concerning its implementation. Nevertheless, the Powering Performance Committee has the opinion that this method should be tried and evaluated in order to see if by this method more accurate predictions and a sound basis for the design of propulsors can be acquired.

In [11] S.I. Yang utilises the propeller load variation test in the optimisation of hull forms. In a similar manner the same author employs the load variation test in the determination of the required propulsive power for a ship in waves, [12]. The wave and wind added resistance is incorporated in the load variation test and the effect of the added drag on the propulsive efficiency is automatically taken into consideration.

Goranov et al, [13] found that in measuring the propulsive performance characteristics over a range of static trims, the propeller load variation test was useful. In this test programme, the variation of the form factor as determined from the load variation test was also determined. Results of a similar programme to determine effects of trim are reported in [14].

In a working paper [15], summarised in [16], Grigson has demonstrated that the traditional concept of analysis of the self-propulsion experiment is insufficiently accurate when dealing with results of model tests on full forms. By analysing the propeller load variation tests Grigson observes that the characteristics of the propeller open water test cannot be matched to the propeller characteristics as measured in the behind condition by assuming a constant effective wake fraction. In other words, the wake fraction is highly dependent on the propeller loading.

As in a previous paper, Grigson addresses the problem of the proper value of the unloading force to be applied in the model propulsion test. By dimensional analysis of the kinematic similarity of the flow around the propeller, a condition is advocated which implies equal J and almost equal K_t as well. This concept leads to simple scaling rules for the propeller rotation rate, the towing force and the thrust. It involves, however, propulsion testing with a propeller which is underloaded from both the viewpoint of the conventional self-propulsion point of ship and from the viewpoint of the propeller hull interaction.

As to the interaction of propellers and rudders, results of a systematic experimental study were published by Stierman, [17]. For several rudder configurations (t/c=0.12 and 0.18 and three propeller rudder clearances) the effects of the rudder on the propeller thrust and torque coefficients were measured in combination with the longitudinal rudder force. The full range of practical pitch ratios and propeller loadings were covered in the experiments. The polynomial representation of the results facilitate their use in parametric studies. An important future prospect for model ship correlation is to derive a more accurate formulation of the effective wake fraction because, by means of the presented formulae, the rudder effects on the classical propulsion factors, w, t and η_r can easily be determined.

4. CORRELATION STUDY BY MEANS OF THE ITTC-1978 POWER PREDICTION METHOD

4.1 Introduction

A statistical model-ship correlation study has been made using the ITTC-1978 method. In this study attention was paid to:

- The scaling of the appendage drag by means of the form factor concept and the Beta factor method.
- Testing the level and scatter in the power prediction if an alternative formulation for the effect of the hull roughness is introduced.
- The introduction of a correlation allowance.
- An examination of the effect of the introduction of a Froude number influence on the form factor.

A sample of 217 ship trial measurement points and the corresponding model resistance and propulsion tests were analysed and reported in 1983 and 1985 [18, 19, 20]. The trial data and model test results were taken from the files of MARIN and included all kinds of new single and twin-screw ships. The trials were run in the period 1970-1989. The sample incorporated the greater part of a sample analysed in 1983 and 1985 Reports [18,19,20].

The sample covered 144 data points of single-screw ships and 73 data points of twin-screw ships. As in the correlation study carried out in the period 1983-1985 the scale effect on the appendage drag was accounted for in most cases by applying the form factor to the resistance test results with all appendages fitted. In the report of the Powering Performance Committee of the 17th ITTC it was shown that this procedure leads more or less to the same average level of the power correlation coefficient C_P for twin-screw and single-screw ships. Also some calculations were made with the Beta factor method to account for the scale effect on the appendage drag.

In the analysis the power correlation coefficient C_P, the rotation rate correlation at speed identify C_N and the rotation rate correlation coefficient at power identity C_{NP} were calculated. These coefficients are the ratios between the values measured at full scale and the values predicted from the model experiment.

In the table below the results of the previous and the present correlation analyses are shown in per cent:

Comparison of the statistical results shows good consistency. The difference between the average levels of the propulsive power predicted for single and twin screw ships (which was 3.6 per cent in the 1983 sample) reduced to 2.5 per cent. The small changes in standard deviations and average values are considered the result of natural variation rather than a reflection of a long term trend. The large overlap in the two samples, the short period involved and the limited sample size prevent any of these trends being ascertained from the present data.

4.2 Scale Effect on Appendage Drag

The first specific item dealt with was the scale effect on the appendage drag. A commonly applied method is the Beta factor method. In this method the appendage drag measured on model scale is reduced by multiplication with a factor Beta prior to scaling the resistance of the appended hull. In this study the full Beta range from 0 to 1 was examined.

		Single Screw		Twin Screw		All ships	
		old	new	old	new	old	new
Sample size		135	144	55	73	190	217
C_P	Stand. dev.	6.9	7.0	7.9	8.7	7.4	7.7
	Average	101.9	101.0	98.3	98.5	100.8	100.2
C_N	Stand. dev.	2.7	2.5	3.5	3.7	3.1	3.1
	Average	100.5	100.3	99.2	98.6	100.1	99.7
C_{NP}	Stand. dev.	2.0	1.9	2.1	2.2	2.1	2.1
	Average	99.9	100.0	99.9	99.2	99.9	99.7

The resistance of the hull was extrapolated by means of the form factor derived for the bare hull. The results are shown in Fig. 4.1 where C_P and the standard deviation of C_P are plotted as a function of Beta.

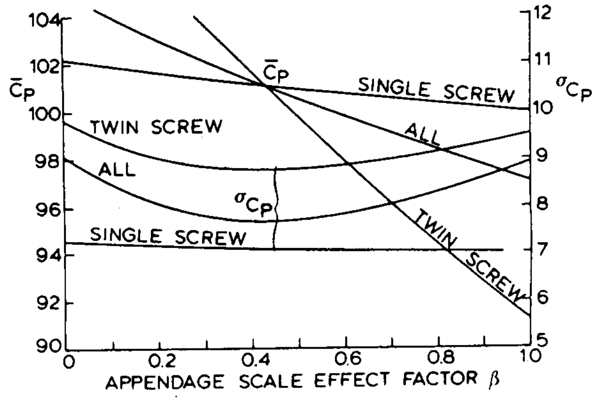

Figure 4.1

Apparently, for Beta equal to 0.44 the average C_P coefficient of single and twin screw ships agree for this particular sample. This corresponds almost perfectly to the Beta value where the standard deviation of the sub-sample of twin-screw ships attains its minimum. The next test was to see if a more accurate prediction could be made on average by using

Beta=C_{Fs}/C_{Fm}

in comparison with the best possible empirically chosen constant Beta value:

		Single Screw		Twin Screw		All ships	
		Average	St.dev.	Average	St.dev.	Average	St.dev.
Beta=optimum (here 0.4)	C_P	101.3	7.1	101.7	8.8	101.4	7.7
	C_N	100.4	2.5	99.2	3.6	100.0	3.0
	C_{NP}	100.0	1.9	98.7	2.3	99.6	2.1
Beta=C_{Fs}/C_{Fm}	C_P	101.0	7.1	98.5	8.8	100.2	7.8
	C_N	100.3	2.5	98.6	3.7	99.7	3.1
	C_{NP}	100.0	1.9	99.2	2.2	99.7	2.1

The figures shown in the above table indicate similar values using Beta as C_{Fs}/C_{Fm} and using the optimum constant value.

As discussed in Section II.5 of this Report, the scale effect on the drag of streamlined, flow oriented appendages can be accounted for by applying the form factor in the analysis of test results of appended ship models. The effect of the increase of the form factor, expressed as $\Delta k.F$ was analysed by varying the factor F. Here Δk is the increase of the form factor due to fitting appendages as derived from the model test. The factor F was varied between 0 (no scale effect on the appendage drag at all) to 1.5. For F=1 the scale effect on the appendage drag is accounted for by the form factor method in the usual way and the results in the aforementioned table pertain to that condition. The viscous scale effect on the resistance was based here on the wetted surface of the hull only. In Fig. 4.2 the level of C_P and the standard deviation of C_P is shown as a function of the multiplication factor F.

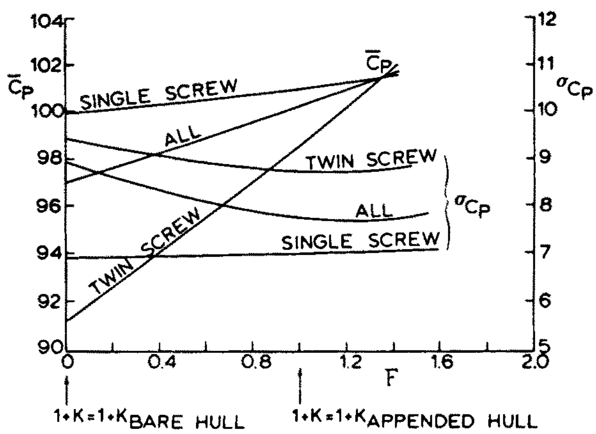

Figure 4.2

If no scale effect is considered on the appendage drag (F=0) the average C_P of the twin-screw ships is about 8 per cent too low. At F=1 the difference between the average C_P values of single and twin-screw ships is reduced to 2.5 per cent. At F=1.35 the average C_P of single and twin screw ships agree. Also plotted are the standard deviations of the power correlation coefficient C_P. Because the appendages do not play an important role in single-screw ships the standard deviation of C_P hardly varies by varying F. For twin-screw ships this is different and apparently a minimum standard deviation of C_P is achieved at F=1.15. Similarly, the minimum standard deviation of all the power correlation coefficients is attained at F=1.25.

The reasonable correspondence between these F-values suggests that the scale effect on the appendage drag when accounted for by the form factor procedure can be successfully applied if the increase Δk for fitting the appendages is multiplied by a factor F with values in the range 1.15-1.35. In the following correlation calculations an F-value of 1.2 was used, thus adding 20 per cent to the experimentally determined increase of the form factor due to fitting appendages. The corresponding statistical parameters are:

	Single Screw		Twin Screw		All ships	
	Average	St.dev.	Average	St.dev.	Average	St.dev.
C_P	101.2	7.0	100.1	8.8	101.0	7.6
C_N	100.3	2.5	98.9	3.6	99.6	3.0
C_{NP}	100.0	1.9	98.9	2.2	99.7	2.1

4.3 Change in Roughness Formulation

The analyses with the ITTC-1978 method presented so far used the original Bowden-Davison formula. Because this formulation is now known to be not an accurate hull roughness penalty predictor correlation analyses were made with the formula of Bowden-Davison replaced by the formula of Townsin et al, [21,51].

This formula reads:

$$10^3 \Delta C_F = 44 \left[(AHR/L)^{1/3} - 10\, R_n^{-1/3} \right] + 0.125$$

Unfortunately, the available sample of ship trial data does not include roughness measurements and so an average hull roughness (AHR) of 150 μm was adopted, thus conforming to the standard figure used in the original ITTC-1978 method. The use of an average value of AHR for the whole sample would be permissible only if the hull roughness is not correlated to the main dimensions of the ship or any other relevant parameter in model-ship extrapolation. The conclusions rely therefore on this implicit assumption. Because of the absence of roughness data in the correlation study it was considered useless to examine similar alternative formulations for the hull roughness effects as reviewed in e.g. the report of the 17th ITTC Powering Performance Committee. The statistical check therefore serves mainly two goals:

- A check of the average level of the power predicted by a physically more justified roughness penalty predictor.
- A check of the standard deviation of the model-ship correlation coefficient as a result of the introduction of a Reynolds number influence in the hull roughness effect.

As regards the second point it is noted that it is not only the formula of Townsin et al which includes an influence of Reynolds number: all alternative formulations express an increasing ΔC_F with increasing Reynolds number, whereas the Bowden-Davison formula supposes ΔC_F independent of R_n.

Below are the average values and the standard deviations of the correlation coefficients of all the ships in the sample in per cent:

	Average	St.dev.
C_P	109.2	10.5
C_N	101.4	3.5
C_{NP}	98.6	2.1

These figures show that by inserting the formula of Townsin et al both the average level and the accuracy of the power prediction is affected significantly. Apparently, the level of the power predicted reduces by about 8 per cent due to the lower levels of the ΔC_F values found from Townsin's formula.

The increase of the scatter in the power correlation coefficient C_P suggests that the Reynolds number effect in the roughness penalty prediction formula of Townsin et al is opposite to some trend in the data. It was ascertained earlier that some trends with regard to speed and/or length were hidden in the power correlation coefficient C_P if the data are analysed by the original ITTC-1978 method, [3] see earlier.

4.4 A correlation allowance additional to roughness effects.

Apparently, the correlation data requires that an additional model-ship correlation allowance is used in combination with the roughness allowance to preserve consistency and accuracy in the extrapolation of model test results.

A statistical analysis was used to test whether the speed influence in the model-ship correlation is depending on Froude number or on Reynolds number. In addition an attempt was made to formulate a correlation allowance with the best possible combination of speed and length.

For the ITTC-1978 method with the appendage drag scaled by the form factor, including an increase of the change in 1+k by 20 per cent, and Townsin's formula substituted for that of Bowden-Davison an analysis was made by investigating:

$C_A=C_A(1) + \text{Log}\ (R_n) \times A$ ....(4.1)

$C_A=C_A(2) + F_n \times B$ ....(4.2)

$C_A=C_A(3) \times V^C \times L^D$ ....(4.3)

(V in m/sec, L in m)

The coefficients A, B, C and D were determined such that the standard deviations of the power correlation coefficient C_P attained their minimum value. The coefficients $C_A(1)$, $C_A(2)$ and $C_A(3)$ are chosen such that the average C_P corresponds to the value found in the original ITTC-1978 method. The correlation allowance C_A was determined from the correlation sample with both single and twin screw ships.

These data show that a Reynolds number correction as in formula (4.1) is more effective than a Froude number based correlation allowance to reduce the standard deviation of the C_P coefficient. Even better is the third formula insofar as it reduces the standard deviation of C_P almost to the level obtained with the original formula of Bowden-Davison.

		Average	St.dev.	Optimum Coeff.
C_A depending on R_n	C_P	101.0	8.3	$C_A(1) = 0.00568$
	C_N	99.8	3.1	$A = -0.0006$
	C_{NP}	99.7	2.1	
C_A depending on F_n	C_P	101.0	9.9	$C_A(2) = -0.00024$
	C_N	99.6	3.3	$B = 0.002$
	C_{NP}	99.8	2.2	
C_A depending on L and V	C_P	101.0	7.7	$C_A(3) = 3$
	C_N	100.0	3.0	$C = -1.4$
	C_{NP}	99.8	2.1	$D = -1.3$

In the ITTC-1978 method the substitution of a theoretically supported hull roughness penalty predictor is only successful if accompanied by the introduction of a model-ship correlation allowance of an empirical nature. From the data base studied the following correlation allowance was established as the most accurate of the three for use in addition to the hull roughness penalty prediction formula of Townsin et al:

$C_A = 3V^{-1.4} L^{-1.3}$ (V in m/sec, L in m)

The choice of the form of eqns. 4.1-4.3 has a certain arbitrariness and subsequent calculations have shown that expressing C_A as a function of R_n raised to a power is also effective.

4.5 Froude number influence on form factor

The next study was to examine how the level and the spread in the C_P figure changed if a certain Froude number influence on the form factor 1+k was assumed. To this end the following Froude number effect on the form factor, as derived by Holtrop from a random sample of 399 model resistance tests, [22], was introduced in the extrapolation of the tests:

F_n	Y	F_n	Y
0.100	0.9300	0.35	0.5625
0.125	0.9395	0.40	0.3800
0.150	0.9513	0.45	0.2844
0.200	0.9500	0.50	0.2200
0.250	0.8744	0.60	0.1000
0.300	0.7500	>0.8	0.0000

$1+k = 1+Y\ k(0)$

Here 1+k(0) is the form factor of the bare hull as determined from low speed resistance measurements by Prohaska's procedure.

	C_P Aver.	C_P St.dev.	C_N Aver.	C_N St.dev.	C_{NP} Aver.	C_{NP} St.dev.
ITTC-1978 Bowden-Davison						
No Froude effect on 1+k	101.0	7.6	99.6	3.0	99.7	2.1
With Froude effect on 1+k	100.1	7.5	99.4	3.0	99.8	2.0
ITTC-1978 Townsin et al and derived correlation allowance						
No Froude effect on 1+k	101.0	7.7	100.0	2.9	99.5	2.2
With Froude effect on 1+k	99.8	7.6	99.7	2.9	99.7	2.1

Apparently, the introduction of a Froude number influence on the form factor reduces the standard deviation of the power correlation coefficient by about 0.1. Because this Froude number effect on 1+k was derived from model experiments only and independently from full scale data the reduction found in the spread of C_p, though of minor magnitude, is considered important for further analysis and its significance should be checked statistically. It is noted that for ships with appendages the Froude number effect on the form factor was extended only to that part which reflected the hull shape form effect.

4.6 Conclusions

From this correlation study using the ITTC-1978 method it appears that the scale effect on the appendage drag can be well accounted for by either the Beta method or the form factor method with equal accuracy in the prediction. The analysed data sample suggest either a Beta value of 0.4 or an increase of the form factor for the appendages increased by 20 per cent. The differences in accuracy with the usual values for Beta and the more common form factor approach are however quite small.

The Bowden-Davison formula can be replaced by the formula of Townsin et al, but then an additional correlation allowance has to be added to achieve the same level and certainty in the power prediction. A suitable correlation allowance was derived from the analysed sample.

The correlation data suggest that a minor improvement of the accuracy could possibly be obtained by the introduction of a certain Froude number influence on the form factor. The effects are however quite small and further research in this area is needed before such a Froude number influence can be adopted.

5. SCALE EFFECT ON APPENDAGE DRAG

Since the time of Froude it is recognised that scale effects are present on the drag of appendages fitted to ship models. Since then it is customary to scale only 50 per cent or 60 per cent of the measured model appendage drag in order to account for scale effect. The fraction of the appendage drag being included in the extrapolation to full scale is usually referred to as the Beta factor. Beside this procedure there are other methods with comparable or even better accuracy. In addition, the case should be considered where the characteristics of the scale effect on the appendage drag is less obvious e.g. when appendages are blunt or not well aligned to the local flow. Also the matter of accurate measurements of the appendage drag on model scale should be addressed.

In the case of well-streamlined, flow-oriented appendages fitted to a ship there are four principal ways to predict the full scale resistance:

- Extrapolation of the resistance of the bare hull to which a fraction Beta of the model appendage drag has been added. For Beta a constant value in the range 0.4-0.7 is usually applied. Alternatively, the measured appendage drag can be scaled by some friction formulation depending on the Reynolds number based on an equivalent length of the appendages.
- Addition of the theoretically computed resistance of the appendages to the resistance obtained by extrapolation of the bare hull resistance test results, [23].
- Application of the form factor concept to the results of resistance tests with appended ship models.
- Calculation of the scale effect on the appendage drag by a theoretical method and reduction of the model resistance measured on an appended ship model by this scale effect prior to scaling.

In the Report of the Powering Performance Committee of the 17th ITTC some of the merits and disadvantages of three of these methods are reviewed. A positive point for the first and two last methods is the experimental basis by which the complexity of the flow is represented on the model scale. Moreover, effects of unwanted misalignment are accounted for in a reasonable manner, in particular if the scale effect on the appendage drag is calculated by the last method for well oriented appendages. It is expected that induced drag caused by misalignment is not subject to scale effect and then the procedure of the last method is important. Then only that part of the appendage drag is considered which is related to the frictional drag of the appendage.

A prerequisite for the first and two last methods is that local flow conditions at the appendages should be made representative of those on the full scale ship. This refers particularly to the type of boundary layer on the appendages, the scale effect in the local flow field upstream and a properly represented propeller action, if relevant. This leads to the conclusion that testing appendages on model scale is appropriate only if sufficiently large model sizes can be used. It further emphasises that determination of form factors from low speed test points on appended ship models is hazardous and that testing appendages which are fully embedded in the boundary layer on the hull may lead to doubtful results as regards the drag of these appendages. It further suggests that it is worthwhile to consider turbulence tripping at the leading edges of the appendages. The second method does not require these prerequisites, but then the problem of the accuracy of the calculations and the assumptions about the flow field just upstream of the appendages are limiting factors. Available calculation methods, of which some have been reviewed by the High Speed Marine Vehicle Committee of the 17th ITTC, are known to be inaccurate, particularly for exposed raked shafts. Because, in testing ship models with respect to propulsion, most of the appendages cannot be dispensed with, no further attention is paid to the computational procedures.

As regards the empirical methods, either based on the form factor concept or on a separate scaling of the appendage drag by the Beta method, the distinction should be made whether or not there will be scale effect on the appendage drag. Blunt appendages with separation of flow will behave differently from those which are streamlined and flow oriented. The first type will show an appendage drag depending on the speed squared, whereas the latter are subjected mainly to frictional drag and therefore the resistance of these appendages will depend rather on the speed to the power 1.8 approximately. In [24] an attempt was made to discern between these two types of appendage by plotting the appendage drag coefficient C_{app-m} on the basis of the friction coefficient of the hull C_{Fm}. The scatter in the data prevented, in most cases, the establishment of a proper relationship between C_{app-m} and C_{Fm}. For the form factor method, it is essential that the increase of the form factor Δk for fitting appendages is established because of the extrapolation of the test results with the appended model. If the resistance components are made non-dimensional by using the bare hull wetted surface area the following approach can be made:

$\Delta k = 0$

(For blunt appendages with separated flow)

$\Delta k = (C_{Tm}(\text{appended}) - C_{Tm}(\text{bare hull}))/C_{Fm}$

(streamlined appendages)

The first rule supposes that scale effect is absent, whereas the second supposes that the appendage drag is proportional to the frictional resistance of the hull over the full range of Reynolds number and that the wave resistance of the bare hull and the appended model are the same. Both rules have their limitations. At low Reynolds numbers the appendage drag may be affected by laminar flow and at higher Froude numbers ($F_n > 0.4$ say) the wave resistance may be influenced by the presence of the appendages. The above formulae for the increase of the form factor may be generalised for a mixture of both blunt and streamlined appendages. Then in this general case Δk could possibly be obtained from:

$\Delta k = d(C_{Tm}(\text{appended}) - C_{Tm}(\text{bare hull}))/dC_{Fm}$

with lower limit 0 and upper limit Δk according to the rule for streamlined appendages. This procedure avoids the need for low speed testing with appended models to determine the form factor. On the other hand, this procedure requires that both bare hull and tests with an appended model are made, as with the Beta method. If the accuracy of measuring the drag of the appendages is preserved by using large models and turbulence tripping at the leading edges of the appendages, a comparison can be made with the low speed form factor according to Prohaska's procedure, as a check.

It is noted that the use of the form factor method with Δk equal to the rule for streamlined flow oriented appendages, is equivalent to the use of $\beta = C_{Fs}/C_{Fm}$

For the Lucy Ashton, the values of $\Delta C_{Ts}/\Delta C_{Tm}$ compare with that obtained using $\beta = C_{Fs}/C_{Fm}$ as is shown in the following table

$\Delta C_{Ts} / \Delta C_{Tm}$									
MODEL LENGTH	12'			16'			20'		
SPEED KNOTS	BOSS*	BRCK*	β	BOSS*	BRCK*	β	BOSS*	BRCK*	β
8.0	0.48	0.52	0.50	0.52	0.56	0.56	0.56	0.58	0.59
10.0	0.54	0.51	0.52	0.57	0.56	0.57	0.60	0.58	0.60
12.0	0.57	0.47	0.53	0.60	0.52	0.57	0.62	0.54	0.60

* values of $\Delta C_{Ts}/ \Delta C_{Tm}$ from Lackenby's paper [25].

In the statistical analysis of a sample of correlation data (see Section 4 of this report) it was concluded that using the ITTC-1978 method for this particular sample, the lowest scatter in the power correlation factor C_P was attained by increasing the Δk values by 20 per cent if the form factor method is used and by using values for Beta in the range 0.4-0.45 if the Beta method is used. These Beta values do not fully agree with the suggested value of C_{Fs}/C_{Fm}, the latter being rather more of the order 0.6. Nevertheless, the level of the scatter in the power correlation coefficient is almost the same for β equal to C_{Fs}/C_{Fm} as for the optimum value of β.

6. HIGH SPEED CRAFT - EXTRAPOLATION AND OTHER PROBLEMS

6.1 Prediction of Ship Performace from Model Experiments.

At the last ITTC, a recommendation was given to the Powering Performance Committee that it should cooperate with HSMVC to develop a method of power prediction for high speed craft. Power prediction methods for high speed craft, following three approaches, are nominated:

- ITTC-1978 method---present method extended to twin-screw ships.
- Tentative Modified ITTC method---modified method to account for the special phenomena of high speed craft.
- Propulsion Test method---this method uses a suitable tow force including various scale effects.

In this section, the first and second are described in detail, whilst the third is explained in the report of the HSMVC.

The present ITTC method evaluates by specific equations the scale effects on frictional resistance, propeller characteristics and effective wake fraction, and also the correlation allowance C_A and air resistance effect C_{AA}. The flow diagram of this method is shown in Fig. 6.1 where all symbols are referred to the manual in the last report of the PPC.

As to the applicability of the ITTC-1978 method to high speed craft which are limited to semi-displacement or semi-planing boats, the last report of the PPC concluded that the ITTC-1978 method is applicable with due consideration given to the physical aspects of the problems involved.

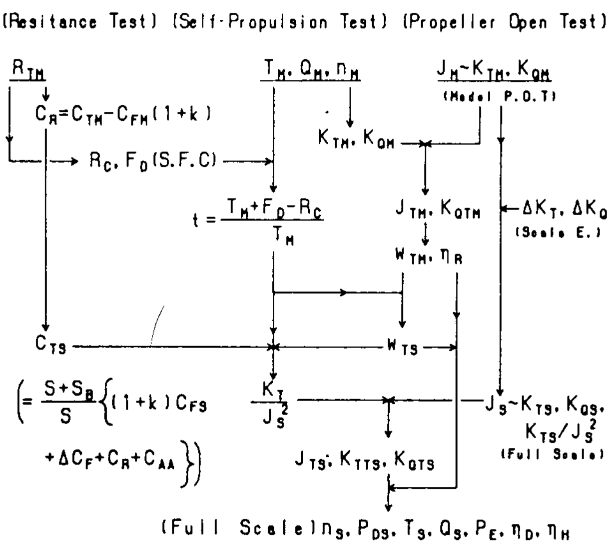

Fig.6.1 Flow Diagram of ITTC 1978 Method

In previous reports of the PPC [18th ITTC] and the HSMVC [16th,17th ITTC] the following items to be considered for high speed craft were noted:

. cavitation effect of propeller
. change of wetted surface area
. effect of shaft inclination
. scale effect of the effective wake fraction
. appendage resistance
. change of trim
. validity of the form factor
. spray resistance

Among the above items, the last report of PPC stated that the form factor approach is unsuitable, i.e. k=0 and the scale effect of effective wake fraction is negligible, i.e. $W_{TS} = W_{TM}$.

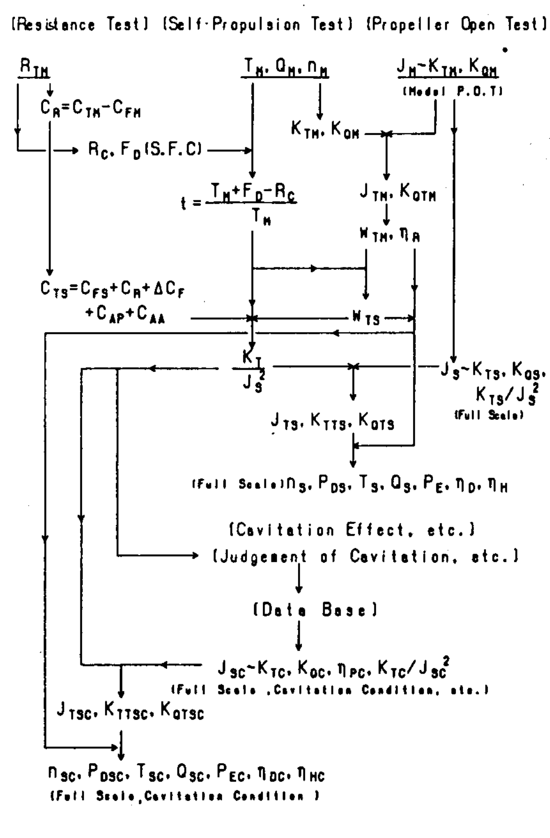

Fig.6.2 Flow Diagram of Tentative Modified ITTC 1978 Method

Based on the above considerations and flow diagrams in Fig. 6.1 and in reference [26], a tentative, modified, ITTC method is proposed as Fig. 6.2 where suffix C means the value in the cavitating condition. In this method, the change of wetted surface area is not considered, because Tanibayashi [27] and Tsukada et al [28] confirmed that such an effect on propulsive performance is rather small in the moderate to high speed range.

The upper half of Fig. 6.2 predicts the propulsive performance in the non-cavitating condition of the propellers and the lower half refers to the cavitating condition with shaft inclination. Although a definite data base is not given here, one can obtain the propeller characteristics in the cavitating condition by cavitation tunnel experiments or according to Gawn [29], for example.

As to appendage resistance, much more work should be done including each component and their interference effects [28], although Tanibayashi [27] showed that the values of the appendage resistance coefficient obtained by experiment and calculation are nearly of the same order.

Because the data from speed trials and model experiments (L_{pp} = 4.0m) of a semi-displacement, high speed passenger boat (L_{pp} = 23.2m) were published by the Shipbuilding Research Center of Japan (SRC) [30], the ITTC-1978 method was applied to that boat in the following conditions:

1. Standard condition : ITTC-1957 friction line, k=0, $W_{Ts} = W_{Tm}$, $\Delta K_T = \Delta K_Q = 0$. C_A and C_{AA} are considered using the given equations and appendage resistance is included in the total resistance.
2. Effect of ΔK_T and ΔK_Q : ΔK_T and ΔK_Q are obtained by equations. Others are same as 1.
3. Effect of W_{Ts} : W_{Ts} is obtained by equation.
4. Effect of C_{AA} : $C_{AA}=0$.
5. Effect of C_A : $C_A = C_{AA} = 0$.
6. Effect of C_{AA} : $C_A=0$, $C_{AA} = 0$.
7. Effect of k : k=0.90.

The predicted results [31] are shown in Figs. 6.3 and 6.4. Fig. 6.3 shows the comparison of delivered horsepower predicted under the above conditions against ship speed and Fig. 6.4 shows corresponding comparison of rate of revolutions of propeller.

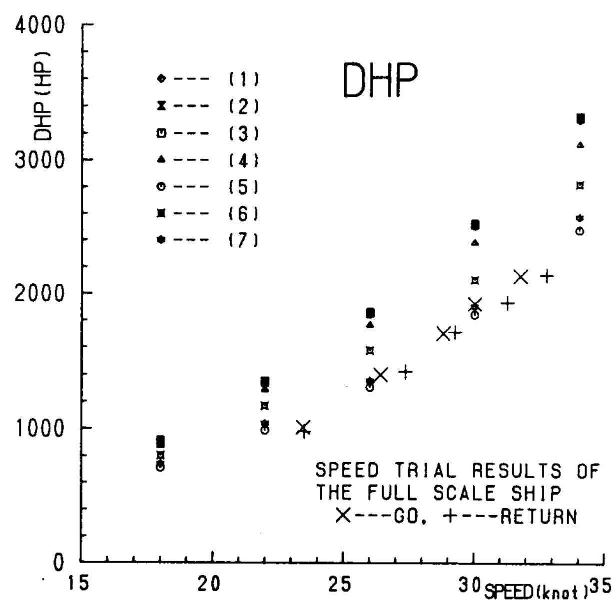

Fig.6.3 Comparison of Delivered Horse Power

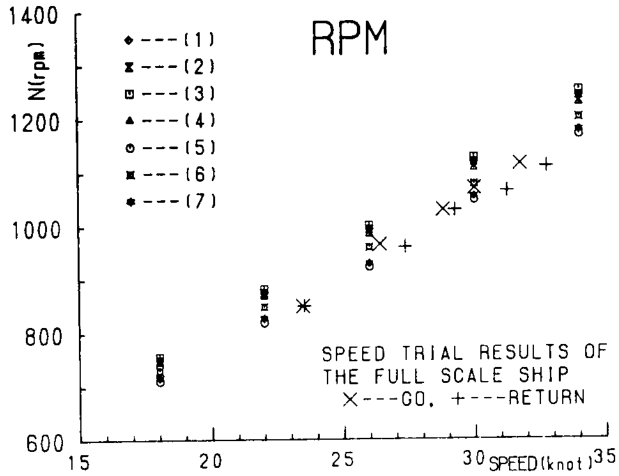

Fig.6.4 Comparison of Rate of Revolutions

Predictions under conditions 5 and 6 agree well with the trial results. It becomes clear that C_A gives too high a value and the scale effect of drag coefficient of the propeller blade ΔC_D becomes negative when the representative chord length C is less than 0.7398m. Tentative values, $C_A = \Delta K_T = \Delta K_Q = 0$ and $W_{Ts} = W_{Tm}$ may be safely assumed for the semi-displacement boat with small scale ratio. The effect of cavitation seems small below the speed of 35 knots for this kind of boat according to reference [28]. The effect of C_{AA} is also small.

The tentative modified ITTC method means the ITTC-1978 method with cavitation influence, in which $C_A = \Delta K_T = \Delta K_Q = 0$ and $W_{Ts} = W_{Tm}$ are adopted. This method should be applied to various kinds of semi-displacement boat over a wide range of ship speed accompanying the cavitation effect.

6.2 Recent work

In order to develop the power prediction method for semi-displacement high speed craft, reliable speed trial and towing tank data are necessary. The Shipbuilding Research Center of Japan [30] reported the improvement of lines of hard chine type passenger boats with one and two propellers. They showed also the effectiveness of analysis methods without form factor between trial and experimental data. Tsukada et al [28] checked the effects of change of wetted surface area on the running condition and cavitation of the propeller with inclined shaft and on the propulsive performance, and concluded that these effects are rather small in the case of the boat studied and over its speed range, say $F_n<1.2$, in spite of the variation of wetted surface area and effects of propeller cavitation. Tanibayashi [27] also checked quantitatively the influence on effective power of running trim and form factor based on the data base of Nagasaki Experimental Tank, and compared the appendage resistance between experiment and empirical formulae proposed by Hadler [32] and by Peck [33]. Tanibayashi showed that the change of effective power is less than 5% even if the wetted surface area changes by 20% from the area at rest, and we may take the form factor k=0, and the experiments and proposed formulae give the same order of appendage resistance. Nakatake and Kataoka [31] proposed a tentative, modified ITTC prediction method through direct application of the ITTC-1978 method to trial and experimental data for the hard chine, high speed passenger boat which is the same one as in reference [30]. They tentatively assumed a form factor k=0, correlation allowance $C_A = 0$, scale effects of propeller $\Delta K_T = \Delta K_Q = 0$ and the same value of effective wake fraction between model and full-scale boat.

An extensive experimental study on a systematic series of round bilge hull forms has been reported. Robson [34] described the aim and scope of the project, using 35 models typically for naval combatants and showed some results on hull resistance with emphasis on seakeeping quality. Sinnema and van Walree [35] introduced many kinds of software developed and used at MARIN, which can predict the performance, motions in waves, seakeeping quality of semi-displacement high speed craft, SES, catamarans and hydrofoils.

Osumi and Kihara [36] proposed a simple power prediction method for high speed craft ranging from displacement type to planing craft, which uses only the waterline length and displacement at rest.

Two papers reported particular features concerning high speed craft. Savitsky [37] measured the wave form behind the planing hull stern and gave a regression formula for the wave height on the centre line. Dong and Shao [38] investigated experimentally the effect of stern trimming plates on resistance and attitude of semi-displacement, round bilge models and showed that appropriate length and installation angles of trimming plates could possibly reduce resistance by 3%-10%.

7. HULL ROUGHNESS

7.1 Introduction

The Resistance and Flow Committee (RFC) also have an interest in the rough surface drag phenomenon. It was decided that the RFC would concentrate on the physics of rough surface drag whilst the PPC would consider the more practical issues of estimating the roughness penalty, especially for new ships and the implication for the ITTC model to ship correlation allowance.

The PPC encouraged the setting up of an International Workshop on Marine Roughness and Drag under the auspices of the RINA in London but since this was held on March 29 1990 only a few of the papers were available at the time of writing this section.

7.2 Measuring Hull Roughness

Hitherto there has been very nearly exclusive use of one height parameter $R_t(50)$ and its averages, mean hull roughness (MHR) and average hull roughness (AHR), measured by one instrument, the original BSRA wall gauge which developed into the Hull Roughness Analyser. The procedure for a hull survey has been standardised and is well known [39].

All authorities agree that for a hull surface which has deteriorated noticeably in service, a height measure alone, is inadequate to correlate with its added drag and some measure of surface texture is required. Accordingly developments of the Hull Roughness Analyser have been designed in which the stylus instrument will record the surface digitally for subsequent statistical analysis either 'on-the-spot' or later in the laboratory [40,41].

Grigson has proposed [42] that the process for estimating added drag from sample surface recording be short circuited by taking an adequate number of surface replicas and measuring their roughness functions directly in some suitable laboratory rig: the vexed question of the correlation between surface statistics and the consequent roughness function is then avoided. This procedure may prove impractical however for routine assessments under the usual pressure to flood the dock immediately after painting when curing is only partially complete.

7.3 Correlation of Added Drag with Surface Statistics

Townsin and Dey have suggested [43] that for relatively smooth painted hull surfaces, characteristic of new ship finishes, $R_t(50)$ and its averages are adequate to correlate with their added drag.

By a re-analysis of published studies of painted surfaces by Musker[44], Todd[45], Walderhaug[46], Johansson[47], Dey[48], Okuno, Lewkowicz and Nicholson[49], Musker and Sarabchi[50] they also showed [43] a correlation between the measured roughness functions and a roughness Reynolds number for the generality of hull painted surfaces, where the equivalent height is given in terms of the spectral moments m_n:

$$h = m_o \sqrt{m_4/m_2} \qquad \text{..... eqn. (7.1)}$$

but the spectral moments have to be calculated with a long wavelength cut-off which itself is a function of $m_o m_2$ at 50 mm cut-off.

It is shown in ref. [43] that for the surfaces with $R_t(50)$ 230μm the correlation of the roughness function with $R_t(50)$ is as good as with $m_o \sqrt{m_4/m_2}$.

7.4 Estimating the New Ship Roughness Penalty

In ref. [43] further support is provided for an approximate formula previously published [51]:

$$10^3 \Delta C_F = 44\left[(AHR/L)^{1/3} - 10 R_n^{-1/3}\right] + 0.125 \qquad \text{..... eqn. (7.2)}$$

The support comes from work by Johansson [47] who calculated the added resistance ΔC_F for a containership and a tanker using his own measured roughness functions; from calculations by Kauczynski and Walderhaug [52] for Johansson's tanker, which show that all but the roughest of their 7 surfaces predict a similar penalty to that calculated by Johansson and eqn.(7.2); from recently released reports [53,54] of tests at MARIN on 9 replicated and laboratory painted hull surfaces, the smoothest 8 of which, when extrapolated to $R_n = 10^9$ for a length of 100m, gave ΔC_F values closely represented by eqn.(7.2); and finally, from work by Baba and Tokunaga [55], who used the method of Sasajima and Himeno [56] to extrapolate to a length of 220m at 15 knots, results of their own rough flat plate tests, those of Todd [45] and flume tests on rough plates reported by Townsin et al [57], all of which when plotted as ΔC_F against $(h/L)^{1/3}$ were closely represented by eqn.(7.2).

All the above work confirms for the smoother painted surfaces the linearising influence of $(h/L)^{1/3}$ which otherwise has limited theoretical justification; demonstrates the importance of a Reynolds number influence; and confirms the level and slope of eqn.(7.2).

7.5 Roughness and the Correlation Allowance

The original Bowden and Davison formula [58], adopted as the ITTC Correlation Allowance, was derived from model tests and loaded trials of 10 single screw ships from 157m to 267m in length and with AHR varying from 144 μm to 211 μm. Whilst the 10 ships were selected for the accuracy of the model tests and trials, the roughness surveys were less satisfactory. This deficiency is explored by Townsin [59] by adding results from 7 sister tankers [60], one of which is one of Bowden's 10 ships, and reanalysing their roughness surveys, which were contemporary with the surveys of Bowden's ships.

The reanalysing and supplementation [59] confirms the level of the ITTC Correlation Allowance (see fig. 7.1) and the linear trend of C_A with $(AHR/L)^{1/3}$. Bowden's formula is a plausible interpretation of the extended data.

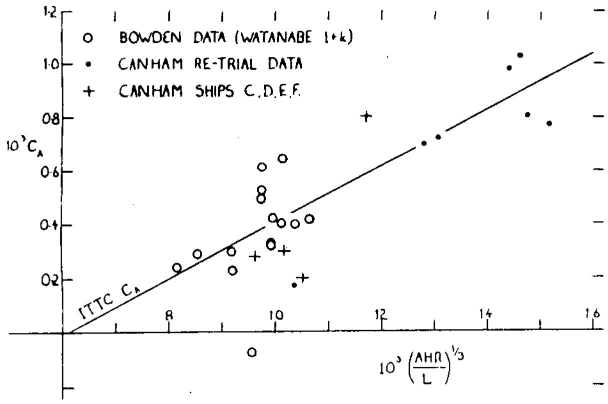

FIGURE 7.1

If eqn.(7.2) is used to calculate the roughness influence in this case, the remainder of the correlation allowance, $C_A-\Delta C_F$, generally reduces with increasing Reynolds number, see Fig. 7.2 from [59], but the data is dispersed, partly due to the inadequacies of the roughness surveys.

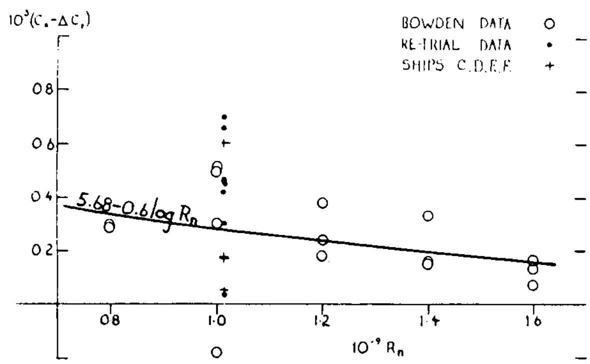

FIGURE 7.2

Fig. 7.2 has added to it, here, the Reynolds number dependent correlation allowance, C_A-ΔC_F, when ΔC_F is calculated by eqn.(7.2), and which was derived from the MARIN data base by the correlation study reported in section 4.

The ITTC Correlation Allowance C_A, which at present is the Bowden and Davison formula with AHR set at 150 µm, could be replaced by the sum of eqn.(7.2) for ΔC_F which accounts for the roughness and

$$10^3(C_A - \Delta C_F) = 5.68 - 0.6 \log R_n \quad \ldots \text{eqn.}(7.3)$$

Eqn.(7.3) is virtually suggesting a small change in slope of the ITTC extrapolator. In section 4 it was shown that an improvement on eqn.(7.3) could be an allowance in terms of L V raised to different powers which implies a small F_n influence; however a small change to the slope of the extrapolator seems open to a more reasonable physical argument.

Bearing in mind that the interrogation of the MARIN data base was without benefit of any roughness measurements and that the correlation allowance is only based on a few ships, even with the supplementation of [59], two issues stand out clearly:

- the measurement of hull roughness by the standard procedure should be seen as an important integral part of any ship trial
- there is a pressing need for more model to ship correlation analysis including adequate assessment of hull roughness.

The Committee's view is that, whilst the present Correlation Allowance may be replaced by eqns.(7.2 and 7.3), no further progress can be made until the above two requirements for more roughness and trial correlations have been met.

The Committee's view is also that, whilst Fig.7.1 reaffirms the present Correlation Allowance, (and AHR is put equal to 150 µm), where roughness measurements are available, as they should be, it would be better to use eqns.(7.2 and 7.3).

8. SCALE AND ROUGHNESS EFFECTS ON PROPELLER CHARACTERISTICS

8.1 Introduction

The previous ITTC Powering Performance Committee stressed the need for further work in this area because in routine power and rotation rate prediction on the basis of model tests, an accurate assessment of these scale and roughness effects is essential for accuracy.

The current ITTC-1978 power prediction method incorporates a simple correction rule based on scale effects on the drag of the section only. The simple ITTC-1978 method appears to give unreasonable figures for scale effects when the scale ratio approaches 1, a situation encountered if relatively small full scale propellers are subjected to model testing. Moreover, the ITTC-1978 rules for propeller scale effect ignore the difference in extent of the laminar flow over the propeller blades at model scale.

Essentially, there are two approaches:

- to control the flow over the propeller blades by e.g. turbulence tripping, and to define a scaling procedure based on turbulent flow.
- to develop a more accurate scaling procedure than the ITTC-1978 rules, accounting in a better way for the mixed type of flow.

Both approaches require that the scaling rules incorporate the effect of the different Reynolds number on the lift.

As to tripping the flow to turbulence, it was concluded earlier that such methods should be treated with care and that these procedures are not yet recommended for application in routine practice.

The most popular turbulence tripping technique is the roughening of the leading edges of propeller blades using carborundum grains. This stimulation technique has succeeded in reducing the scale effect on cavitation inception, but the full scale propulsive characteristics still can not be deduced directly from tests on the roughened model propeller.

In general, as a result of the turbulence tripping, the thrust coefficient K_T decreases and the torque coefficient K_Q increases.

The results of model tests with turbulence stimulation techniques still require scale correction to predict the full scale propeller characteristics. Unfortunately, such a correction method is not available as yet.

The roughness added to the model propeller surface increases the propeller section drag and decreases the section lift due to the decambering effect of boundary layer stimulation [61,62]. So far there has been no certain answer for the questions of whether the drag of a roughened propeller section is the drag of the turbulent section at model Reynolds number and of whether the lift of a roughened propeller is the full scale propeller lift coefficient.

The Committee recommends that further studies as e.g. [63], are carried out and results of model tests with turbulence tripping be correlated to full scale trials to support the development of a scaling procedure. Another prerequisite for the introduction of leading edge roughness is a consistent application technique.

8.2 Influence of R_n on C_L for Smooth Propellers

The problem of the Reynolds number influence on the lift coefficient C_L has been discussed in several past ITTC PPC reports. Nevertheless, at present, this problem is far from being solved.

The collected experimental data, the progress in calculating viscous flow characteristics around flat-pressure profiles and the power of contemporary computers allow scale effect evaluation, regarding both $C_L(R_n)$ and $C_D(R_n)$ relationships. A theoretical method for calculation of the scale effect including influence of R_n on both C_D and C_L is presented in [64].

The method refers to a flat section hypothesis and the mutual interaction between potential outer flow and boundary layer viscous flow around the treated propeller blade section. Fig. 8.1 presents calculation results for the $C_L(R_n)$, $C_D(R_n)$ relations valid for a NACA-66 a=0.8 profile. It is evident that with the transition from ideal to viscous flow there is a variation of both $dC_L/d\alpha$ and α_o. It must be noted, that the above calculations refer to hydrodynamically smooth full-scale propeller blade surfaces, i.e., any machining or other roughness is not taken into account. The main difference of the above procedure in comparison with the ITTC-78 approach is that the former predicts greater scale effect on K_T and η_o coefficients (through consideration of $C_L(R_n)$) and minor scale effect on $C_D(R_n)$, whilst according to the latter the scale effect is mostly attributed to $K_Q(R_n)$ variation (through consideration of $C_D(R_n)$ only).

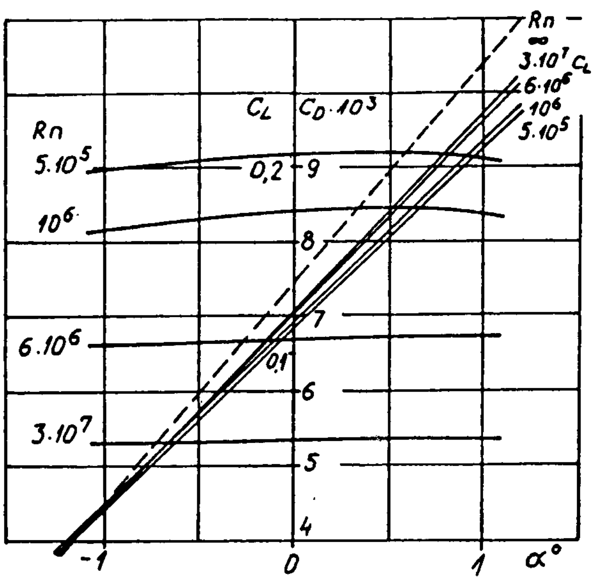

Figure 8.1 Hydrodynamic characteristics of NACA-66m Profile (a = 0.8, t/c = 0.5, δ_c = 0.01 — —ideal fluid

A similar theoretical approach is presented in [65] in which is developed a modification of the familiar Lerbs equivalent profile method using propeller lifting line theory. According to the author his lifting line equivalent profile method is theoretically more correct and moreover it is insensitive to the choice of the approximate relations and the value of the equivalent radius needed. Therefore, it can be used irrespective of the propeller geometry, loading and C_D/C_L distribution.

In the 15th ITTC PPC report for corrections due to scale effects on the lift Aucher proposed:

$$\Delta K_{TL} = b\ (C_{DM} - C_{DS}) \qquad \dots (8.1)$$

$$\Delta K_{QL} = b/2\pi (P/D)\ (C_{DM} - C_{DS}) \qquad \dots (8.2)$$

where b is a function of c/D, Z and J_A. Another approach formulated in the Report is to determine ΔC_L separately, and further to derive again ΔK_{TL} and ΔK_{QL} corrections using the obtained ΔC_L value. The main disadvantage of the above approach is the difficulty in obtaining correct ΔC_L values.

On the basis of the theoretical calculations, performed in [66] it seems possible to obtain a direct practical equation for the ΔC_L correction [62], for a family of profile sections. Making an approximation to the results from systematic calculations a formulation is proposed in [62] for ΔC_L, for this specific series of profiles. The approximations are valid for profiles with mean line NACA-66, a=0.8 and thickness distribution NACA-66-m and $0<t/c<0.10$, $0<\delta_c<0.03$, $-0.1<C_L<0.3$, $Rn>10^5$. ΔC_L is given by:

$$\Delta C_L = C_{Ls} - C_{Lm}$$

C_{Ls} amd C_{Lm} are calculated from equations involving viscosity and profile thickness allowances on both lift curve gradient and zero lift angle. Solution of the equations is facilitated by an equivalent profile assumption.

Thrust and torque corrections are calculated by the formulae proposed in [4]:

$$\Delta K_{TL} = (0.733 + 0.132\ J^2)\ Z\ (c/D) DC_L/A \quad .. \ (8.3)$$

$$\Delta K_{QL} = (0.117 + 0.021\ J^2)\ Z\ (c/D) DC_L/A \quad .. \ (8.4)$$

where $A = \sqrt{1.0 + 0.180\ (P/D)^2}$

Finally full scale propeller hydrodynamic characteristics are derived:

$$K_{Ts} = K_{Tm} - (\Delta K_{TD} + \Delta K_{TL}) \quad ... \ (8.5)$$

$$K_{Qs} = K_{Qm} - (\Delta K_{QD} + \Delta K_{QL}) \quad ... \ (8.6)$$

The corrections ΔK_{TD} and ΔK_{QD} are calculated in accordance with the standard ITTC-78 procedure. It should be noted that the above procedure does not take into account the influence of propeller surface roughness on profile lift coefficients.

8.3 Influence of Full Scale Propeller Surface Roughness on Propeller Performance.

As with the problem of relating painted hull roughness to the associated drag penalty, the measurement and definition of the roughness characteristics of a propeller blade surface are equally as important as the determination of the roughness function to which they relate. Propeller surface roughness has characteristics different from painted hulls and requires separate study, see Mosaad [67]. A standard procedure for measuring average propeller roughness (APR) has been proposed [68] which is a radially weighted equivalent to AHR. The same reference also provides a simple method to estimate power penalties either from measurements of propeller surface roughness by stylus instrument or estimates of condition using a Rubert comparator gauge. Use is made of Lerbs' equivalent profile method to convert the enhanced section drag into a power penalty. The paper also discusses the vexed question of calculating the effect on power of a rough propeller working behind a rough hull. The weakness of the work lies in lack of roughness function data for propeller surfaces to which need ref. [67] responds.

Valuable experimental information is presented in [69,70]. Experimental results with rotating bronze disks having variable surface roughness are approximated regarding the roughness function. R_a is adopted as the basic roughness height parameter.

Using the approximated roughness functions, theoretical calculations based on Lerbs' equivalent profile method are made to obtain the influence of surface roughness on the propeller hydrodynamic characteristics. The results compared with the standard ITTC-78 procedure may be summarised in the following table:

TABLE 1 η_s/η_m %

Model	Full scale			
	R_a=0	R_a=2.5μm	R_a=70μm	ITTC-78
100	107.3	105.9	102.2	103.2

The roughness function has been approximated by the following equation :

$$B(hu_*/\nu) = 5.2 - 1/\kappa \ln[1 + C_1 hu_*/\nu + C_2 hu_*/\nu \exp(-C_3 hu_*/\nu)] \quad \ldots (8.7)$$

where h - roughness parameter (in this case equal to R_a)

u_* - dynamic velocity in the boundary layer

ν - kinematic viscosity coefficient

κ - Karman's constant

C_1, C_2, C_3 - empirical constants, characterizing the influence of the specific roughness.

Constants C_1 through C_3 for different propeller blades surface conditions are presented in table 2.

The efficiency of the propeller of a tanker, "Pobeda", has been calculated using the above roughness conditions [70]. Additionally, surface fouling with height h = 4 mm has been included in the calculations. As a result it is concluded that the efficiency of the full scale propeller with roughness conditions in accordance with table 2 is higher than the model propeller efficiency because of the Reynolds number scale effect. Only in the case with fouled blades is the efficiency lower than the model efficiency.

Since much of the inspection of propellers is carried out underwater, the technicians assessing the surface condition use the Rubert propeller roughness comparator throughout. The Rubert gauge has become widely accepted in recent years as the most practical field measurement tool presently available. The technical surfaces A-F (smoothest-roughest) have been extensively measured and correlated with values in R_q, R_a, R_t and R_z as well as Musker's h' [68,71].

An extensive literature review with practical examples of the influence of the machining and in-service roughness on the propeller hydrodynamic characteristics are presented in [72,61,68].

An interesting and extensive study of turbine blade roughness is reported in [73] by Acharya et al. This work has direct relevance to propeller surface roughness but only a limited account of the top ography of the rough surfaces is provided.

TABLE 2

propeller blade surface condition	R_a [μm]	C_1	C_2	C_3
new propeller, polished in radial direction	2.50	0.74	-1.042	1.666
newly cast propeller	3.18	6.05	-6.665	1.100
after dry-dock polishing in arbitrary direction	5.00	0.53	-0.951	1.666
in-service propeller with cathod deposition	2.55	1.58	0.18	1.110

9. SHALLOW WATER EFFECTS ON THE PERFORMANCE OF SHIPS

Since the last ITTC only a few publications have appeared concerning ship performance in restricted water and extrapolation of model test results to full scale.

The influence of shallow water on the nominal wake and its components is investigated in [74] for Series 60. The results show that:

- the nominal velocities are reduced with decreasing water depth, the reduction being predominant for the axial velocity component;
- the displacement wake fraction Wd_r (subscript "r" denotes real flow) is found to increase with decreasing water depth. The application of potential flow techniques with account taken of depth restriction in order to estimate wake fraction Wd_i ("i" denotes ideal flow) is found to be appropriate for the preliminary estimate of displacement wake fraction in real flow (see Table 1);

TABLE 1

H/T	Wd_r	Wd_i
∞	0.114	0.112
2.0	0.127	0.127
1.5	0.143	0.145

The frictional wake fraction W_f is found to be almost independent of water depth at H/T > 2.0 and subjected to significant depth influence at H/T < 2.0 i.e. has shown an attitude similar to the form factor dependence on water depth, Fig. 9.1.

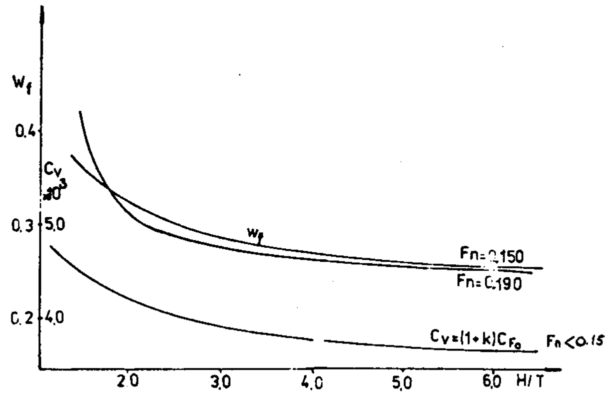

Figure 9.1

A relation between C_{FO} and W_F in deep and shallow water is proposed:

$$\frac{WF_\infty (1 - WF_\infty)}{WF_h (1 - WF_h)} = \frac{(1 + k_\infty)\, CF_o}{(1 + k_h)\, CF_o},$$

where $k_h = f(F_n)$

Its structure is based on the assumption of equality of the viscous resistance coefficients determined by a 3-D extrapolator and from measurements in the ultimate wake.

An experimental investigation of scale effect on wake and wake components (displacement Wd_r and frictional WF) at the propeller disk is reported in [75]. A series of three, fine-form, geosim models (of Series 60 - C_B = 0.6 hull) to scales λ = 15, 20 and 26 are used. The tests are conducted at relative depths H/T = ∞, 2.0 and 1.5. The results show, that in the transition from deep to shallow water the influence of scale effect on wake fraction (nominal and effective) decreases (see Figs. 9.2, 9.3) at H/T = 1.5 being insignificant (see Fig. 9.4).

In shallow water, as in deep water, the displacement wake fraction Wd_r is almost independent of scale and depends very little on Froude number (see Figs. 9.5,9.6). It can be evaluated within acceptable limits of accuracy by applying the potential flow technique with account taken of depth restriction. In shallow water the scale effect problem is mainly concerned with the frictional wake fraction WF.

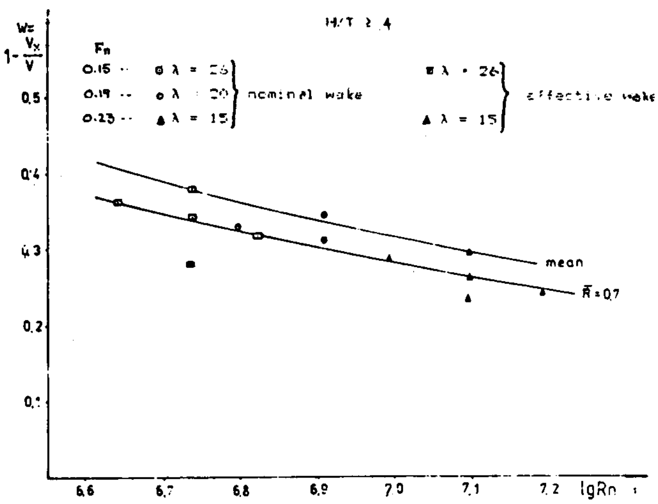

Figure 9.2

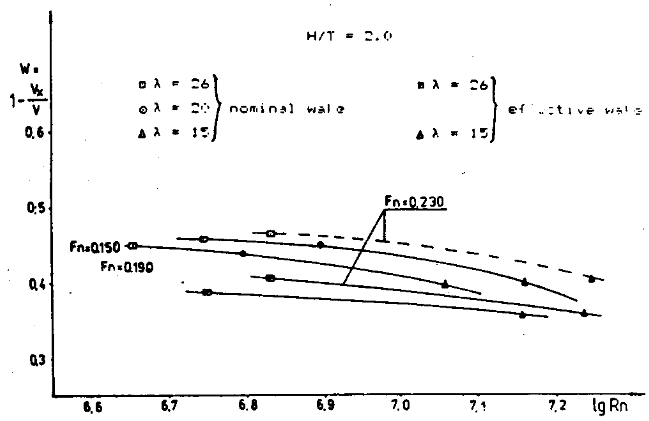

Figure 9.3

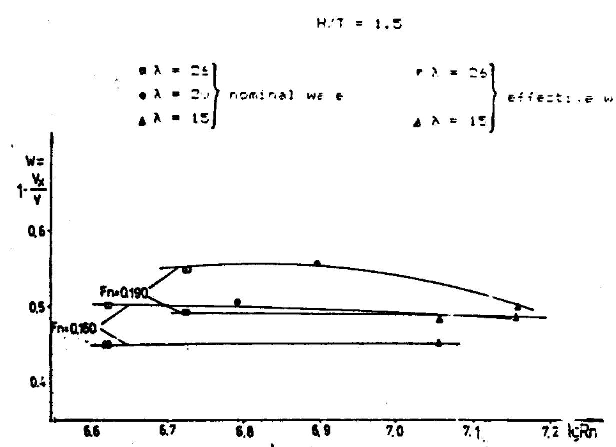

Figure 9.4

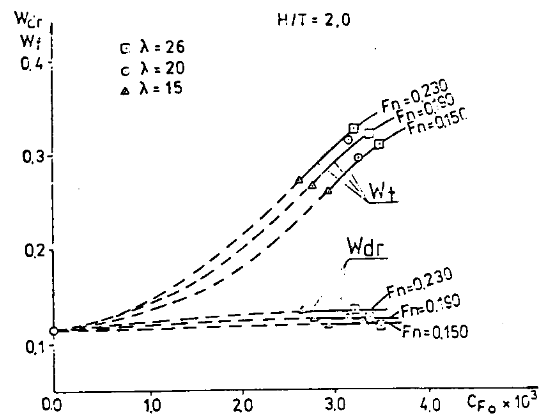

Figure 9.5 Wake fraction components of Series 60 (C_B=0.6) geosim models as a function of C_{fo} - shallow water (H/T = 2.0)

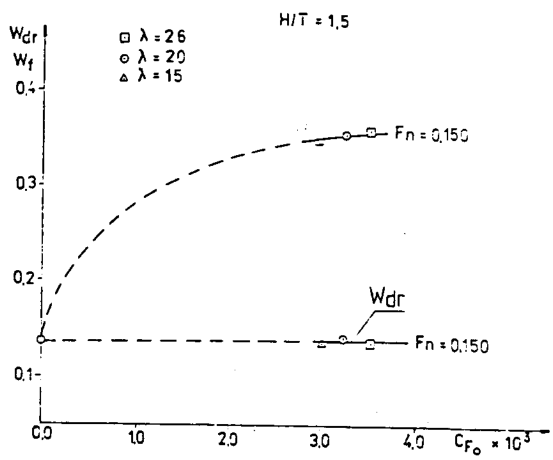

Figure 9.6 Wake fraction components of Series 60 (C_B=0.6) geosim models as a function of C_{fo} - shallow water (H/T = 1.5)

Similar tendencies of nominal wake dependence of scale in shallow water, are outlined also in [76]. The experimental investigation was made on two geosim models of an HSVA hull, to scales 40 and 33.3, at three relative water depths H/T = 4.0, 2.0 and 1.5. It is concluded that for H/T > 4.0 the shoal influence on nominal wake is insignificant, which allows the implementation of appropriate ship-model wake correlation procedures elaborated for deep water conditions. Whether any scale effect on the thrust deduction fraction exists in shallow water is difficult to appreciate, as reported in [77], because of the considerable experimental scatter.

In [78,79] the velocity stability at the propeller disk in shallow water, is investigated. Low frequency local velocity pulsations amounting to 20% of its mean value in very shallow water, are observed. This indicates that the measuring period at propulsion tests, especially at H/T < 1.5 should be taken as large as possible.

Miyazawa [80] presents an experimental study of a bauxite carrier operating in a shallow water region at full load and in a ballast condition. The author comments that change of thrust deduction for full load condition with respect to the water depth is not monotonic, which seems to disagree with the generally held opinion. On the other hand, in the ballast condition, the effect of shallow water on thrust deduction is not obvious. The wake fraction increases in both full load and ballast conditions, as depth increases.

The effect of shallow water on the form factor has been measured and analysed by Millward [81]. From seven ship models of different form and fullness, run both in deep and various shallow water conditions, the form factors were determined from low speed resistance tests. A regression analysis provided the following simple relationship for the increase of the form factor as a function of the draught/water depth ratio, irrespective of the form coefficients and other characteristics of the hull form:

$$\Delta k = 0.664\ (T/H)^{1.72}$$

10. REVIEW OF VALIDATION

Towards the end of 1988 the ITTC Validation Panel circulated a document [82] to the technical committees of the ITTC with guidelines for analysis of the uncertainty in prediction for typical areas of concern to the members of the ITTC. According to the Powering Performance Committee an assessment was needed of the accuracy of the classical problems of speed and rotation rate prediction from model tests.

The task outlined in [82] requires determination of a confidence range for the values predicted on the basis of the experiments. In the present case the predictions concern basically two parameters:

- The speed the ship will attain through the water at a certain power supplied to the shaft.
- The rotation rate at which this power is absorbed by the propulsor.

Some work in this area was done by member organisations [83] and also in previous committees some work was presented and discussed on the subject of error transfer from measurement to predicted values of power and shaft rotation rate by various extrapolation procedures, [84]. A review of possible errors in this type of work was presented to the 15th ITTC in 1978, [85]. In [85] the same manner of analysis is followed as intended for the present task. This survey led to the unsatisfactory conclusions that the total error in the correlation factors could not be explained by the measurement errors, both on model and full scale. Apparently, the shortcomings of the numerical model used to extrapolate the model test results to well defined conditions for the ship (including e.g. hull roughness effects) is an important error source. The sample used was small and error data coarse and incomplete.

An attempt has been made first to determine the uncertainty in the model resistance coefficient C_{Tm}. The example chosen was a Series 60 model of 2.5 metres tested in the Towing Tank of Kyushu University. The results of this analysis show that each individual data point should have to be presented with a margin for uncertainty and that by doing so an appropriate value of the form factor can not be chosen for this particular small model, Fig. 10.1.

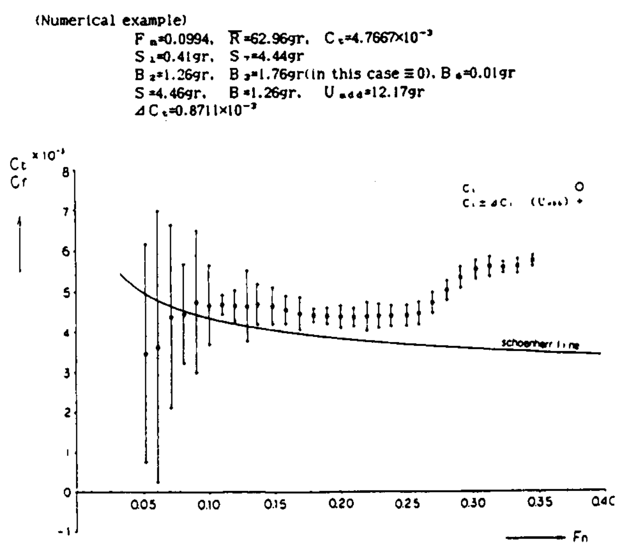

Figure 10.1

Further problems encountered are associated with the identification of the errors and their sources. There appears to be a need for simpler procedures for this work.

Next, a study was made of the uncertainty of the speed and rotation rate of another typical example. The results of this study, [86], pertain to a model of a bulk carrier and further studies are needed to cover the type of hull forms and propulsors investigated nowadays to produce data with a wider scope of applicability.

For the routine model experiments examined, the error sources were reviewed. A factor which makes error examination more complex is that even by subdividing the sources of error, the magnitude of the errors involved can only be estimated coarsely because the experiment involved is neither repeated a sufficient number of times to check statistically the total error, nor extended with supplementary measurements of parameters which are governing the errors of various kinds.

Other problems encountered in preparing the list of error sources are the effects of accuracy enhancement through a gradual adaptation of correlation coefficients to compensate for systematic errors which are permanently present in measuring and extrapolation systems and the data handling through which some random errors are reduced. Curve fitting effects and statistics of correlation allowances have been left aside from the analysis because their magnitude is unknown. Only an estimate of their contribution is given when they vary from experiment to experiment due to changes in geometry or speed. In those cases, e.g. tank blockage effects, an estimation of the variable part in the error contribution was given, thus assuming that the average blockage effect is accumulated in an unknown adaptation of the correlation factors used after some period.

The estimation of the errors involved was made by a group of some well experienced workers in the field of data analysis of calm water experiments on ship models. Percentages are given as estimated standard deviations for the particular model scale under the assumption that there is no serious flow separation and that a 'normal' propeller could be selected from the stock. Some errors are given, not as percentages of the model resistance, but pertaining to related parameters such as propeller torque, thrust, towing force or shaft power. Error transfer through the extrapolation method was determined for a modern form factor method similar to the ITTC-1978 procedure. Further it was realised that some errors could not be expressed as simple percentages, because their magnitude does not depend on the level of the measured variable. (E.g. possible instrument errors are expressed rather as a fraction of the full range). Here, all errors are nevertheless given as percentages applying to a loading corresponding approximately to 'service speed'.

In this particular case it was assumed that the basis of the experiment is the normal propulsion experiment, extended by some additional measurements to measure the effect of changes in the propeller load. In an earlier simulation study [84], errors in the magnitude of other variables propagated to the power and rotation rate prediction were assessed.

In [84] it was found that for this particular model the following transfer of errors could be applied if the errors are fully systematic within each test as shown in Table I:

3. The effect on the level of 1+k reduction of 0.1(1+k)) was included in the analysis of the towing force error.

4. $N(P_S)$ represents the rotation rate prediction at the preset power absorption.

5. P_S is the shaft power at a certain fixed value of the speed.

Bias errors are supposed to be fully cancelled by the empirical correlation factors determined from a large enough sample of corresponding tests on model and full scale.

TABLE I

Error in propulsion/ load variation test	Level of predicted value in per cent P	N	$N(P_S)$	T
No error	100	100	100	100
Vm + 10 per cent	79	92	100	86
F - 0.1($F+T_m$)	86	96	101	89
Nm + 10 per cent	110	110	107	100
Tm - 10 per cent	99	100	100	90
Qm + 10 per cent	110	100	97	100

Notes:

1. 1+k is supposed to be determined here from the propulsion test extrapolated to the zero thrust condition and by taking the limit of the towing force data divided by 1.02 R_{Fm} for zero Froude number according to Prohaska's procedure.

2. In the simulated error of the towing force F an artificial reduction of 10 per cent of the resistance of the ship model was represented.

Individual random errors in single data points are supposed to have a negligible contribution to the level of the values considered here thanks to fairing and curve fitting of the data. Both assumptions are probably wrong. The form factor is quite sensitive as regards the constellation of individual data points and the much larger errors at low speeds in comparison with those given in the table above. In Table 2 are the accumulated variances for the various groups considered:

TABLE 2

	sum of variances (in per cent squared)	
	P_D	$N(P_S)$
Model geometry	2.16	0.40
Flow conditions	0.29	0.09
Test conditions	0.11	0.01
Instrumentation	9.01	0.09
Data handling	0.00	0.00
Extrapolation	7.39	0.59
Total variance model scale	18.96	1.18

Because many of the individual error contributions in the table presented are rather uncertain it is interesting to compare these errors with those experienced in statistical correlation studies. This requires that the errors made in sea trials and the uncertainty in the corrections are known or can be derived from statistical analyses of ship trial data of sister ships. To this end figures taken from [85] have been used. There it is concluded that the standard deviation in power is about 4 per cent and the standard deviation of the rotation rate is about 1.2 per cent in full scale measurements.

For the investigated method of analysis for single-screw ships, the standard error between predicted and measured power at constant speed is 6.7 per cent and the standard error of the predicted and measured rotation rate at power and speed identity, is 1.6 per cent, the analysed sample containing 135 data points, [18]. This leads to the figures in Table 3:

TABLE 3

	Variance in per cent squared	
Total variance model scale	18.96	1.18
Full scale measurements	16.00	1.44
Total variance	34.96	2.62
Variance in correlation of model and full scale tests	34.81	2.56

The agreement is considered good, taking into account the uncertainty of the errors in many of the various components, in particular the approximate estimations of the uncertainty in the full scale trials.

The variances of 18.96 and 1.18 correspond to standard errors of 4.4 per cent in the power prediction and to 1.1 per cent in the prediction of the propeller rotation rate.

This leads to the following 95 per cent confidence range under the assumption of Gaussian error distribution for this class of ship model, tested with equipment and instruments considered here. The true value will thus lie with a 95 per cent chance between the predicted value + or - 8.6 per cent of the power at a certain speed and the rotation rate in the range of + or - 2.2 per cent around the predicted value, at a certain power absorption.

Apart from the exercises above there are evaluations in open literature on the merits, shortcomings and future prospects of model test techniques, the role of computational procedures in power prediction and the value of empirical/statistical methods. An example is [87] where Sadov et al present an interesting review of error sources, criteria for geometric accuracy of ship models, measuring procedures, waiting times between runs and criteria for the duration of the measurements. For the resistance experiment investigated they conclude that the major error source is due to the instability of the carriage speed and fluctuations in the measurement set-up. This committee considers a discussion as e.g. [88,90,90,91] of high value. Although the outlook for future developments is by no means uniform, some definite trends in model experiments in the field of ship propulsion can be indicated from those papers and the discussions involved:

- There is a growing interest in parametric studies by means of computational procedures.
- The computational procedures which are becoming available these days must be validated/correlated thoroughly because their accuracy is usually not better than the experimental verification.
- The role of model tests shifts towards critical designs and towards the verification of desk studies and computational procedures.
- In complex propulsors and fuel saving devices, the role of model experiments is often of a limited character owing to limitations of a hydrodynamic nature, e.g. laminar flow and serious scale effects in the flow conditions upstream. Testing of propulsor components then becomes more and more important.
- There is a need for higher quality of measurement.
- There is uncertainty as regards accuracy of full scale measurements.

11. REFERENCES

[1] Townsin R.L.: Boundary layer separation from ship models - a note on its detection and suppression with some examples. Trans.RINA 107, 1965.

[2] Lauro, G. and Miranda, S.; "Analysis and Comparisons of the Form Factor Determination According to the ITTC 1978 Method", Proc. 18th ITTC, 2, 1987.

[3] Lindgren, H. and Dyne, G.; "Ship Performance Prediction", Int. Symp. on Advances in Marine Technology, Trondheim, 1979.

[4] Nawrocki, S.; "The Correlation of Tanker Performance with Model Test According to the ITTC Recommendation", Schiff und Hafen/Kommandobrücke, Heft 1-2, 1987.

[5] Mewis, F.; "Experience in Using the Form Factor Method", SMSSH '88, Varna, 1988.

[6] Yin, Z. and Lin, J.; "Correlation of Propulsion Performance and Arbitrary Loading Method of Propulsion Test", Second Symposium of Ship Powering Performance, China, 1988.

[7] Cen Changyi and Lin Jiayun; "An Improvement on the 1978 ITTC Performance Prediction Method and the Arbitrary Loading Method of Propulsion Model Test", Int. Symp. on Ship Resistance and Powering Performance, Shanghai, April 1989.

[8] Grigson, C.W.B.; "The Ocean Trials of a Large Merchantman in Ballast and Their Correlation with Model Data", Trans. RINA, 1987.

[9] Abkowitz, A. and Gengshen, Liu; "Measurement of Ship Resistance, Powering, and Maneuvring Coefficients from Simple Trials During a Regular Voyage", Trans. SNAME, 96, 1988.

[10] Schmiechen, M.; "Wake and Thrust Deduction from Quasisteady Ship Model Propulsion Test Alone", Publication by the Versuchsanstalt fur Wasserbau und Schiffbau, 1987.

[11] Yang, S.I.; "Improvement of Hull Form Design Using Propeller Load Variation Tests", Int. Shipbuilding Progress, June 1987.

[12] Yang, S.I.; "The Power Prediction of a Container Ship in Waves Using Propeller Load Variation Tests", Seminar on Ship Hydrodynanmics, Seoul, May 1988.

[13] Goranov, S., Lazarov, S. and Genov, E.; "Systematic Experimental Investigation on the Influence of Trim on a Medium Tonnage Ship Propulsive Qualities, Applying the New NSMB Method", 15th SMSSH'86, Varna, 1986.

[14] Bogdanov, P., Genov, E., Kostov, D., Lazarov, S., Papazov, A., Lipis, V. and Petrov, A.A.; "Systematic Experimental Investigation of Trim Influence on the Propulsive Characteristics of High-Speed Merchant Ships", 14th SMSSH, Varna, 1987.

[15] Grigson, C.W.B.; "Screws Working in Behind and the Prediction of the Performance of Full Ships", Working Paper presented to the ITTC Powering Performance Committee, Spring 1988.

[16] Grigson, C.W.B.; "A Controversial Assumption Concealed in Performance Prediction", The Naval Architect, July/August 1989.

[17] Stierman, E.J.; "The Influence of the Rudder on the Propulsive Performance", Int. Shipbuilding Progress, 1989.

[18] Holtrop, J. and Mennen, G.G.J.; "An Assessment of Four Different Extrapolation Methods", MARIN Report 50306-3-VT, April 1983.

[19] Holtrop, J.; "Additional Correlation Calculations for Twin-Screw Ships", MARIN Report No. 50306-5-VT, July 1983.

[20] Holtrop, J.; "Additional Correlation Calculations for Single-Screw Ships using the ITTC-1978 Method", MARIN Report No. 50505-2-VT. April 1985.

[21] Townsin, R.L. and Dey, S.K.; "The Correlation of Roughness Drag with Surface Characteristics", RINA Int. Workshop on Marine Roughness and Drag, London, March 1990.

[22] Holtrop, J.; "A Statistical Resistance Prediction Method with a Speed Dependent Form Factor", SMSSH'88, Varna, Bulgaria, Oct. 1988.

[23] Report on the High-Speed Marine Vehicle Committee, 17th ITTC, Vol. 1 (pp.368-376).

[24] Holtrop, J.; "Scale Effect on Appendage Drag", MARIN Rep. No. 50902-3-SP, 1989.

[25] Lackenby, H.; "B.S.R.A. Resistance Experiments on the Lucy Ashton" Part III. Trans. INA Vol. 97, 1955.

[26] Takekuma, K. and Baba, E.; "Hydrodynamic Design and Development of High Speed Craft in MHI", MTB154, 1982 (pp 1-12).

[27] Tanibayashi, H.; "Contribution to Prediction of Powering Performance of High Speed Boats", Trans. of the West Japan Society of Naval Architects, No. 79, 1990.

[28] Tsukada et al; "Some Considerations on Powering of Small High Speed Boat", Abstract Note of the 54th General Meeting of Ship Research Institute, 1989.

[29] Gawn, W.L. and Burrill, L.C.; "Effect of Cavitation on the Performance of a Series of 16 in. Model Propellers", TRINA, Vol. 99, 1957 (pp 690-728).

[30] The Shipbuilding Research Center of Japan, Investigation on Higher Performance of Small Passenger Boat, 1989.

[31] Nakatake, K. and Kataoka, K.; "On Application of ITTC 1978 Power Prediction Method to a High Speed Boat, T West-Japan S.N.A., No. 79, 1990.

[32] Hadler, J.B.; "The Prediction of Power Performance on Planing Craft", Trans. SNAME Vol. 74, 1966 (pp 563-610).

[33] Peck, R.W.; "The Determination of Appendage Resistance of Surface Ships", AEW Technical Memorandum 76020, May 1976.

[34] Robson, B.L.; "Systematic Series of High Speed Displacement Hull Forms for Naval Combatants", TRINA, Vol. 129, 1987.

[35] Sinnema, M.F. and van Walree, F.; "Prediction of Powering Performance of High-Speed Marine Vehicles", Proceedings of 4th PRADS'89, 1989.

[36] Osumi, M. and Kihara, K.; "A Proposal for Prediction of Propulsive Performance of High Speed Craft", T. West-Japan S.N.A. Vol. 75, 1988 (pp 36-51).

[37] Savitsky, D.; "Wake Shapes behind Planing Hull Forms", Proceedings of International High-Performance Vehicle Conference, 1988.

[38] Dong, Z. and Shao, Z.; "Effect of Stern Trimming Plate on SpeedPerformance of Semi-Displacement Craft", Proceedings of International High-Performance Vehicle Conference, 1988.

[39] Townsin, R.L., Byrne, D., Svensen, T.E. and Milne, A.; "Estimating the Technical and Economic Penalties of Hull and Propeller Roughness", Trans. SNAME 89, 1981.

[40] Chuah, K.B., Dey, S.K., Thomas T.R. and Townsin, R.L.; "A Digital Hull Roughness Analyser", Proc. Int. Workshop on Marine Roughness and Drag, RINA, London, March 29, 1990.

[41] Fitzsimmons, P. and Ellis, J.; "A Two-Parameter Roughness Analyser and Performance Monitoring Software", Proc. Int. Workshop on Marine Roughness and Drag, RINA, London, March 29, 1990.

[42] Grigson, C.W.B.; "The Full Scale Viscous Drag of Actual Ship Surfaces and the Effect of Quality of Roughness on Predicted Power", SNAME JSR 31, 1987.

[43] Townsin, R.L. and Dey, S.K.; "The Correlation of Roughness Drag with Surface Characteristics", Proc. Int. Workshop on Marine Roughness and Drag, RINA, London, March 29, 1990.

[44] Musker, A.J.; "Turbulent Shear Flows Near Irregularly Rough Surfaces with Particular Reference to Ships' Hulls", PhD Thesis, Univ. Liverpool, 1977.

[45] Todd, F.H.; "Skin Friction Resistance and the Effects of Surface Roughness", Trans. SNAME 59, 1951.

[46] Walderhaug, H.; "Paint Roughness Effects on Skin Friction", Int. Shipbuilding Progress 33.382, 1986.

[47] Johansson, L.E.; "The Local Effect of Hull Roughness on Skin Friction. Calculations Based on Floating Element Data and Three-dimensional Boundary Layer Theory", Trans. RINA 127, 1985.

[48] Dey, S.K.; "Parametric Representation of Hull Painted Surfaces and the Correlation with Fluid Drag", PhD Thesis, Univ. Newcastle upon Tyne, 1989.

[49] Okuno, T., Lewkowicz, A.K. and Nicholson, K.; "Roughness Effects on a Slender Ship-Hull", Proc. Second Int. Symp. on Ship Viscous Resistance, Goteborg, 1985.

[50] Musker, A.J. and Sarabchi, K.; "Wall-friction and Profilemetry Aspects of Coating an Irregularly Rough Surface", Int. Shipbuilding Progress, 27, 1980.

[51] Townsin, R.L., Medhurst, J.S., Hamlin, N.A. and Sedat, B.S.; "Progress in Calculating the Resistance of Ships with Homogeneous or Distributed Roughness", NECIES Centenary Conf. on Marine Propulsion, 1984.

[52] Kauczynski W. and Walderhaug, H.; "Effects of Distributed Roughness on the Skin Friction of Ships", Int. Shipbuilding Progress 34, 389, 1987.

[53] Brook, A.K. and Byrne, D.; "Comparison between Experimental and Theoretical Skin Friction Coefficients for Smooth and Rough Flat Plates", BSRA Report W1223 (NSMB Cooperative Res. Hull Roughness Working Grp. Rep. HR 46), 1984.

[54] Byrne, D.; "Analysis of Surface Roughness of Nine Test Plates", BSRA Report W1222 (NSMB Cooperative Res. Hull Roughness Working Grp. Rep. HR 47), 1984.

[55] Baba, E. and Tokunaga, K.; "Approximate Calculation of Ship Frictional Resistance Increase due to Surface Roughness", Weighart retirement meeting, April 1982. J.Soc.N.A. Japan 152, 1982.

[56] Sasajima, H. and Himeno, Y.; "Scale Correction for Roughness Effect", J. Soc. N.A. Japan 118, 1965.

[57] Townsin, R.L., Byrne D., Milne, A. and Svensen T.E.; "Speed, Power and Roughness : The Economics of Outer Bottom Maintenance", Trans. RINA 122, 1980.

[58] Bowden, B.S. and Davison, N.J.; "Ship Resistance and Hull Roughness", NPL Ship TM 356 July 1973, and "Resistance Increments Due to Hull Roughness Associated with Form Factor Extrapolation Methods", NPL Ship TM 380 Jan. 1974.

[59] Townsin, R.L.; "The ITTC Correlation Allowance : The Evidence Re-examined and supplemented", Proc. Int. Workshop on Marine Roughness and Drag, RINA, London, March 29 1990.

[60] Canham, H.J.S. and Lynn, W.M.; "The Propulsive Performance of a Group of Intermediate Tankers", Trans. RINA 104, 1962.

[61] Witmer, D.J., Whiteside, R.M.; "In-Service Propeller Polishing", Proceedings of Propellers'88 Symposium, Virginia Beach, Virginia, September 20-21, 1988, pp 12.1-12.7.

[62] Minchev, A.D. and Varsamov, K.G.; "Prediction of Propeller Open Water Hydrodynamic Characteristics Scale Effect including Scaling of C_L Coefficient", BSHC Report No. PD-89-251, November 1989.

[63] Kuiper, G.; "Boundary Layer Effects on Propeller Performance", Proc. ISRP, 1989.

[64] Droblenkov, V.V., Kanevskiy, G.I., Karaulina, M.M., Mishkevitch, V.G.; "Lift and Drag of Screw Propeller Profiles in Viscous Flow and Scale Effect on Propeller Hydrodynamic Characteristics", Collected Papers on Ship Design Problems, Vol. 32, Leningrad, 1982, pp 93-102 (in Russian).

[65] Politis, G.K.; "A Lifting Line Equivalent Profile Method for Propeller Calculations", National Technical University of Athens, Department of Naval Architecture and Marine Engineering Report No. 2/1984.

[66] Bavin, V.F., Zavadovskiy, N.Yu, Levkovskiy, Yu.L, Mishkevitch, V.G.; "Screw Propellers. Modern Design Methods", Sudostroenie Publ. House, Leningrad, 1983, pp 128-133, (in Russian).

[67] Mosaad, M.; "Experiments and Applications on the Effects of Propeller Surface Roughness", Int. Workshop on Marine Roughness and Drag, RINA, London, March 29 1990.

[68] Townsin, R.L., Spencer, D.S., Mosaad, M. and Patience, G.; "Rough Propeller Penalties", Trans. SNAME 93, 1985.

[69] Kanevskiy, G.I., Lobachov, M.P.; "Investigation of the Propeller Blades Surface Condition Influence on the Propeller Hydrodynamic Characteristics", Collected Papers on Ship Design Problems, Vol. 41, Leningrad, 1984, pp 57-62, (in Russian).

[70] Kanevskiy, G.I., Kruglova, S.N., Lobachov, M.P.; "Investigation of the Blades Roughness Influence on the Propeller Hydrodynamic Characteristics", Collected Papers on Ship Design Problems, Vol. 4, Leningrad, 1987, pp 11-16, (in Russian).

[71] Svensen, T.E. and Medhurst, J.S.; "A Simplified Method for the Assessment of Propeller Roughness Penalties", Marine Technology 21, Jan. 1984.

[72] Wilkinson, C.P.; "Reduction in Fuel Consumption as a Result of In-Water Propeller Polishing", Proceedings of Propellers'88 Symposium, Virginia Beach, Virginia, September 20-21, 1988, pp 11.1-11.20.

[73] Acharya, M., Bernstein, J. and Escudier, M.P.; "Turbulent Boundary Layers on Rough Surfaces", Experiments in Fluids 4, 33-47, 1986.

[74] Lazarov, G., Georgiev, S., Chikolov, P.; "A Study of the Wake at Propeller Disk at Different Water Depths", BSHC, 17th session "Unconventional Methods and Approaches in Ship Hydro-and Aero-dynamics", vol. 2, 1988, Varna.

[75] Lazarov, G., Georgiev, S., Chikolov, P.; "On the Scale Effect of Nominal Wake of a Full Form Ship in Shallow Water", VIII Int. Symposium on Ship Hydrodynamics 20-22 Nov. 1989, Wroclaw.

[76] Lazarov, G., Georgiev, S., Chikolov, P.; "Experimental Investigation of the Scale Effect on Nominal Wake of Series 60 Geosim Models in Shallow Water", 18th session Actual Problems in Ship Hydro-and Aerodynamics, vol. 1, 25-30 September 1989, Varna.

[77] Georgiev, S.; "Propeller-Hull Interaction in Shallow Water", Diploma Thesis, Higher Ins. of M & E Eng., 1988, Varna.

[78] Marinov Zh., Chikolov, P.; "A Study of Velocity Stability at Propulsor Disk in Shallow Water", 4th International Congress IMAEM'87, vol. 5, 1987, Varna.

[79] Marinov, Zh., Chikolov, P., Georgiev, S.; "A Study of Velocity Field Stability at Propeller Disk of Series 60 Model in Deep and Shallow Water", BSHC, 17th session "Unconventional Methods and Approaches in Ship Hydro-and Aerodynamics", vol. 3, 1988, Varna.

[80] Miyazawa, M.; "Hydrodynamic Design of Full Ship for Shallow Water Service", 4th International Congress IMAEM'87, Vol. 1, 1987, Varna.

[81] Millward, A.; "The Effect of Water Depth on Hull Form Factor", International Shipbuilding Progress, Vol. 36, No. 404, 1989.

[82] "Guidance to Technical Committees of the 19th ITTC on the Application of Procedures to Assess Uncertainty in Measurement and Prediction", Interim Statement by the ITTC Validation Panel, September 1988.

[83] Yamasaki, T. and Tsuda, T.; "Accuracies Ensured by Towing Tank Tests", Translation from the Textbook of JTTC Symposium in 1983.

[84] Holtrop, J. and Mennen, G.G.J.; "The Influence of Measuring Errors on the Power and Rotation Rate Prediction in Various Extrapolation Methods", MARIN Report No. 50505-1-VT, April 1985.

[85] "Report of the Performance Committee of the 15th ITTC", Proceedings, Part 1, The Hague, 1978.

[86] Holtrop, J.; "The Validation of Model Experiments for Trial Speed and Propeller Rotation Rate Prediction", MARIN Report 50902-1-SP, March 1989.

[87] Sadov, A.N., Bazilevskiy, Yu.S., Lupanov, V.A., Lyutov, N.R. and Stephanov, S.D.; "Some Possibilities of Increasing the Accuracy and Reliability of the Measurement Results of Still Water Towing Tests", 18th SMSSH, Varna, Bulgaria, September 1989.

[88] Morgan, W.B. and Lin, W.C.; "Ship Performance Prediction Computational Fluid Dynamics and Experiments", Schiffstechnik, Bd.36, 1989.

[89] Broberg, H. and Bjoerklund, J.; "Scale Model Testing of Ships", The North East Coast Institution of Engineers and Shipbuilders, Vol.105, Part 3, 1989.

[90] Schneiders, C.C.; "The Prediction of Ship Performance by Calculation or by Measurement ?", 7th Lips Propeller Symposium, Noordwijk-on-Sea, September 1989.

[91] Van Hees, M. Th. and Kuiper, G.; "Calculated Measurements and Validation of Calculations by Measurement", 7th Lips Propeller Symposium, Noordwijk-on-Sea, September 1989.

III. CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS OF THE COMMITTEE

1.1 The questionnaire

Although only 1/4 of ITTC institutions responded, it is known that a number of major institutions which did not respond, do in fact use the ITTC 1978 method. Therefore the relatively low return should not necessarily indicate a lack of enthusiasm for the method. Strictly, since from the sample of 17 respondents who are active in ship propulsion testing, 5 use the method for more than 10% of tests, it may be deduced that 30% of major tanks use the method on over 10% of occasions. The PPC was sceptical of this application to the whole population and would be interested to deduce at the Conference itself the validity of the sample result.

1.2 Form factors

Since the form factors are difficult to determine in some cases, wrong conclusions may be drawn about the effect of a hull modification or draught and trim changes.

1.3 Propulsion testing

From the Committee's review of novel techniques in section 3, all seem to have merit but before such procedures are introduced into routine experiments they need thorough testing and validation.

1.4 Correlation study

1.4.1 From the correlation study using the ITTC-1978 method it is concluded that either the Beta method or the form factor method may be used resulting in a comparable degree of accuracy.

1.4.2 The introduction of a more physically justified hull roughness penalty predictor requires an associated correlation allowance depending principally upon Reynolds number, to achieve comparable degrees of level and accuracy with current procedures.

1.4.3 Whilst the correlation study did not identify a form factor dependence on Froude number the Committee concludes that it is still an open question.

1.5 High speed craft

The tentative, modified, ITTC method proposed for power prediction of semi-displacement or semi-planing craft under the effect of moderate propeller cavitation, deserves further development and application.

1.6 Hull roughness and the correlation allowance

1.6.1 Since there are still problems relating the rougher surface topographies to associated drag the use of more advanced stylus instruments and replication techniques should be pursued.

1.6.2 Independent experimental evidence supports the view that a single height parameter is adequate to correlate with added drag for the smoother ship painted surfaces; that $(AHR/L)^{1/3}$ is approximately linear with ΔC_F; and that there is a Reynolds number dependency.

1.6.3 Whilst the Committee recognised the inadequacy and limitations of the 10 ship data upon which the Bowden-Davison formula was based, especially as regards the roughness measurements, supplementary data confirms the general level of their correlation allowance.

1.7 Propeller roughness

More roughness function measurements from replicated propeller surfaces are required.

1.8 Validation

The accuracy of some of the components is difficult to assess and a simpler and perhaps less rigorous procedure may facilitate further studies. Whilst the study has not revealed new features it has served to reinforce existing ideas of accuracy in power prediction and rotation rate.

2. DRAFT RECOMMENDATIONS TO THE CONFERENCE

2.1 Form Factors

Consideration should be given to the practical suggestions made in section II.2 of this Report. Attention is drawn to the analysis of propulsion tests with a view to determining form factors and to detect unusual flow phenomena e.g. separation.

2.2 Propulsion testing

ITTC should encourage the authors of the novel techniques reviewed in section 3 to establish contact with a member institution in order to test and validate their proposal.

2.3 Appendage drag extrapolation

When using the form factor method for scaling the drag of appendages it is recommended that the form factor increase due to fitting of appendages be determined from test results at higher speeds to avoid effects of laminar flow. When using methods without a form factor a useful estimate of the beta factor is

$\beta = C_{Fs}/C_{Fm}$

2.4 High speed craft

Members should try the proposed, modified, ITTC method and report their experience to the Powering Performance Committee.

2.5 Hull roughness and the correlation allowance

2.5.1 The measurement of hull roughness by a standard procedure should be defined as an integral part of any ship trial.

2.5.2 Members should undertake further model to ship correlation studies including adequate assessments of hull roughness.

2.5.3 Where roughness measurements are available the present correlation allowance should be replaced by the equations in sections 7.4 and 7.5.

2.6 Propeller scale and roughness problems

2.6.1 Further experiments and correlation studies should be carried out with turbulence-tripped propeller models.

2.6.2 Little further progress can be made in assessing propeller roughness penalties until a data bank of appropriate roughness functions is built up and more roughness measurements are made using a standard procedure.

3. DRAFT RECOMMENDATIONS FOR THE FUTURE WORK OF THE COMMITTEE

3.1 Alternatives should be developed for parameter ranges and hull types beyond the applicability of the ITTC 1978 method, rather than attempting to extend it. The issues of importance in this connection are:

3.1.1 The problem of appendage drag extrapolation.

3.1.2 The improvement of power and rotation rate prediction for separation-prone forms.

3.1.3 Extrapolation methods for high speed craft.

3.2 The re-introduction of standard models for quality control and validation purposes should be considered by the Committee.

3.3 Notwithstanding recommendation 1 an improvement to the ITTC 1978 method should be considered which introduces lift based propeller scale effects.