The Specialist Committee on Powering Performance Prediction

Committee Chairman: Prof. Neil Bose
Session Chairman: Prof. You-Sheng Wu

1. DISCUSSIONS

1.1 Discussion to the 24th ITTC Specialist Committee on Powering Performance Prediction by Ian W. Dand, BMT SeaTech Ltd, United Kingdom

The Committee has produced an excellent and comprehensive Report on an important topic and they are to be congratulated.

The discusser was particularly interested in the detailed uncertainty analysis for all aspects of extrapolation and commends the Committee for their rigour. However, while their analysis describes how to deal with errors in prediction as well as those in full-scale trials, it would seem that one aspect has been overlooked. This is concerned with how we are to assess whether our prediction method is good, bad or indifferent. Are we to assume that if the error bands of the predicted result and those of the trial overlap then the method is satisfactory, or should we only look for perfect coincidence between prediction and trial?

In other words, could the Committee give some guidance on how we are to deal with determining whether a prediction, subject to random error, compares well with trial data, also subject to error? This question will assume some importance when any new prediction method is being assessed; it presumably addresses the question of any bias error inherent in the prediction method itself.

1.2 Discussion to the 24th ITTC Specialist Committee on Powering Performance Prediction by Jan Holtrop, Maritime Research Institute Netherlands, The Netherlands

With a lack of sufficient time, I read the Report of the Committee, a Committee of which I had the honour and pleasure to have been a Member for many years. Though the name of the Committee has been slightly changed, the topics and concerns have remained the same: the quality of the power predictions of the classical towing tank work.

It seems to have become a fashion to rely on Uncertainty Analysis to trace the weak links in the long chain of power prediction based on model experiments. In my view such methods should, however, be limited to samples in which the distributions of the errors in the data sets involved are of a comparable order. We all know that in practice this is not true, since notorious departures occur now and then in those cases where the basic assumptions underlying the methods are violated and extreme anomalies in flow regime occur. It is by no means an arbitrary matter which extrapolation method is to be used because some attenuate whereas others amplify the “departures from reality” which have been caused by severely deviating flow conditions in the model experiment. A few examples illustrate where extreme caution is to be preserved and additional measurements and RANS calculations are required to identify the causes of deviating flow conditions and to obtain suitable experimental data to be used in the extrapolation:

- Testing very full forms, prone to flow separation.
- Choosing form factors from low-speed resistance measurements with an unidentified extent of separated flow over the hull and appendages.
- The uncertainty of the form factor when throughout the low-speed range waves remain present and their effects are not well recognised in the level of the data points.

The wording "variations of details" used in the introductory Chapter 3 in describing the extrapolation procedures in use, suggests an insignificant variability being present in practice. However, the spectrum covers both methods in which form factors are determined as accurately as possible and others in which 1+k is put at 1 as a coarse simplification. In reality, the dispersion in methods used is tremendous. As in the past, there is a multitude of methods, procedures and associated empirical corrections involved. Many of our customers are forced to accept the final outcome of the power prediction as they cannot assess the merits of the various procedures and judge the consequences of the various steps which are being taken.

The Report mentions in Chapter 8.4 that the accuracy of the power prediction would benefit from relying solely on the results of the single propulsion test in which the load-variation test is an essential part. This finding confirms earlier observations and it suggests that the question should be addressed which type of testing is preferably to be done, given a certain available span of time allowed for a model experiment. Should the testing consist of some series of repeated propulsion/load-variation tests, including intermediate changing the measuring equipment to minimise both random and bias errors, or should we go on doing the classical set of three experiments, resistance, open water and propulsion, for each configuration to be examined, as required for the ITTC-1978 procedure?

My final comment concerns the comparison between various friction lines in Chapter 7.1. According to my experience it is extremely difficult, if not impossible, to derive resultant changes of the uncertainty of the power prediction by an analysis of rather small data samples. It is certainly not easy to draw justified conclusions if not all consequent changes have been properly taken into consideration. The employed simple correction method for the form factor, how attractive as it may look, treats the conversion probably in a too simple manner. The assumption has been made that at the model speed of F_n=0.1 the ratio of the two friction coefficients is equal to the form factor change. So, it ignores the complicated interpretation of the often curved lines in the Prohaska plot. Probably, the change of the form factor, when transferring to a different friction line, should be carried out by a completely new determination of the form factor by means of the Prohaska method. Hence, it is doubted if for instance, the variation of 1+k as a function of the model size, an unwanted feature of the ITTC-1957 line, one wants to get particularly rid of by going for example to the Grigson line, is accurately reflected by the simple conversion rule. From a MARIN data sample of more than 500 experiments the following empirical conversion rule has been derived to determine the ratio of the form factors on the basis of Grigson and the ITTC-1957 formulation:

$$(1+k)_{Grigson} / (1+k)_{ITTC57} = 1.38816 - 0.00753116\, [{}^{10}\mathrm{Log}\, (L_m/\nu)\,]^2$$

The length of the ship model is L_m in m and ν is the kinematic viscosity in m^2/sec.

Nevertheless, I am pleased to see that the standard deviation of the model-to-ship correlation allowance C_A appears to be lowest for the Grigson line in combination with a much-reduced average level of C_A, a conclusion which is fully in agreement with the results of an analysis I made on 325 model-ship correlations, employing a form factor correction rule similar to the one used by the Committee. Results of this study were presented in the written discussion of Grigson's 1996 RINA paper. Thanks to the further evidence given by the Committee on the basis of the analyses made, the time is near to conclude that the quality of the power prediction would be significantly improved in general by turning to Grigson's formulation of the flat-plate friction.

1.3 Comments to the 24th ITTC Specialist Committee on Powering Performance Prediction by Toshinobu Sakamoto, Nagasaki Experimental Tank, MHI, Japan

Introduction. In the Report of ITTC Specialist Committee on Powering Performance Prediction, it was concluded, even temporarily, that the uncertainty of estimated power by ITTC 1978 method is almost twice as big as that by load-varying propulsion test only, based on the results of Monte-Carlo simulation using the model test data of R-class Ice Breaker. Although we agree that ITTC 1978 method should be examined again, after its formulation almost thirty years ago, we are convinced the difference in uncertainty must be much smaller. Because both methods have been used in the practical field for a long time, if there is such a big difference, it could be noticed by experience. They must be compatible with each other.

So, the discusser examined and analyzed the model test data himself, and made power estimations by the two methods.

Data Analysis. *Resistance Test:* Resistance measurements are carried out for discrete values of advance speed, and from the results, a smooth-line relationship between Froude number, Fr and wave-making resistance coefficient, C_w is to be obtained by use of a friction line, the ITTC 1957 correlation line with form factor, in this case. This process of drawing a smooth-line is very important to obtain proper values of resistance for the analysis of propulsion test and the estimation of required power.

In this investigation, to make the calculation easy, the process of drawing a smooth line was replaced by fitting the total resistance coefficient of model, $C_{t,m}$ with the following function,

$$C_{t,m} = (1+k)\cdot C_{f,ITTC\,1957}(\mathrm{Re}_m) + a\cdot Fr^4 + b\cdot Fr^8 + c\cdot Fr^{12} + d\cdot Fr^{16} + e\cdot Fr^{20} \qquad (1.1)$$

where,
k is the form factor and
a, b, c, d and e are fitting coefficients.

The original data and the fitted line are shown in Fig. 1.1. Even if a well-trained specialist may draw a smooth-line differently, the fitted line is acceptable.

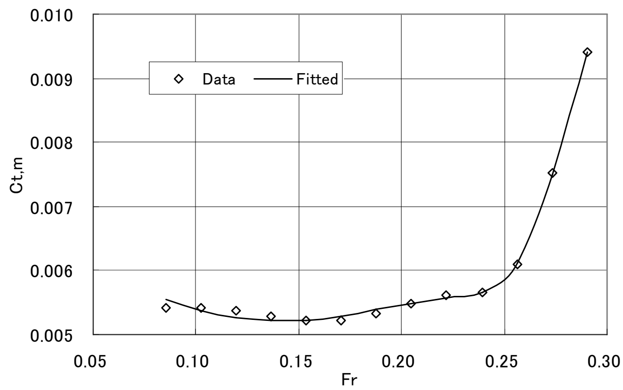

Figure 1.1- Resistance test data and fitted line.

Propeller Open-Water Test: The data of propeller open-water test are fitted values that are not directly measured values. $K_{t,m}$ and $K_{q,m}$ are calculated according to ITTC 1978 method, and plotted in Fig. 1.2. They were fitted by third power functions of J and the fitted lines are also shown in Fig. 1.2.

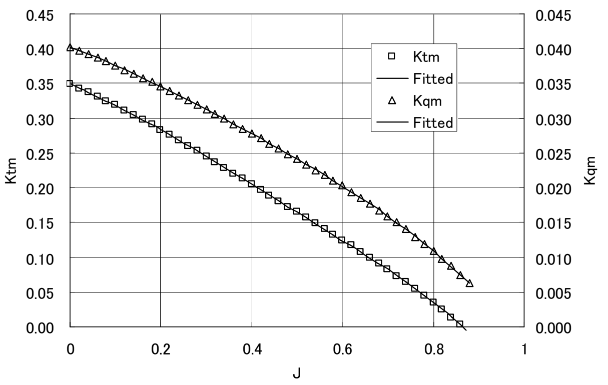

Figure 1.2- Data from propeller open-water test and fitted lines.

Propulsion Test: Load-varying propulsion tests were carried out for five values of advance speed (v_m=0.682, 1.027, 1.495, 1.726 1.957m/s), and thrusts, torques and revolutions of two propellers and towing force are measured. From the measured values, the following non-dimensional values were calculated.

$$k_t = \frac{Thrust}{\rho \cdot {v_m}^2 \cdot S/2}, \quad k_f = \frac{Towing\ Force}{\rho \cdot {v_m}^2 \cdot S/2},$$
$$k_p = \frac{Torque \cdot \mathrm{Re}\,v.}{\rho \cdot {v_m}^3 \cdot S/2}, \quad k_n = \frac{\mathrm{Re}\,v.}{v_m} \cdot \sqrt{S} \tag{1.2}$$

Here, Thrust is the total thrust, Torque and Rev. are mean values measured for the two propellers.

The values of k_t and k_p were plotted over k_n and shown in Fig. 1.3. Although all the data obtained in the test for five advance speeds were plotted, they are almost on single lines. Because self-propulsion factors show only slight variations against advance speed, it is the normal tendency of these kind of test results to be almost aligned on single lines.

The values of k_f were plotted over k_n and shown in Fig. 1.4. This figure looks quite different from Fig. 1.3, because resistance of the model is different for each value of advance speed. Then, the values of $k_f - C_{t,m}$ were calculated and plotted over k_n in Fig. 1.5.

Since $k_f - C_{t,m}$ is defined by

$$k_f - C_{t,m} = \frac{\text{Towing Force} - \text{Model Resistance}}{\rho \cdot {v_m}^2 \cdot S/2} \tag{1.3}$$

it is expected that the effect of advance speed could be eliminated and only the effect of propeller revolution would remain. However, Fig. 1.5 shows that $k_f - C_{t,m}$ vs. k_n were not aligned on a single line. When Fig. 1.3 and Fig. 1.5 are compared each other, the scatter of the plotted points in Fig. 1.5 is bigger than that in Fig. 1.3, not only among data groups of different advance speeds but also within a data group of same advance speed.

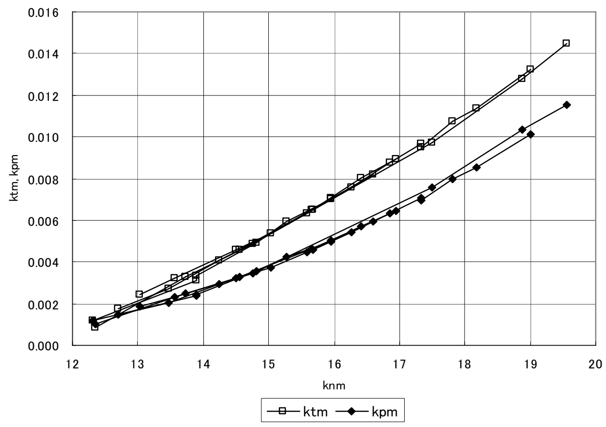

Figure 1.3- Propulsion test results (k_t and k_p over k_n).

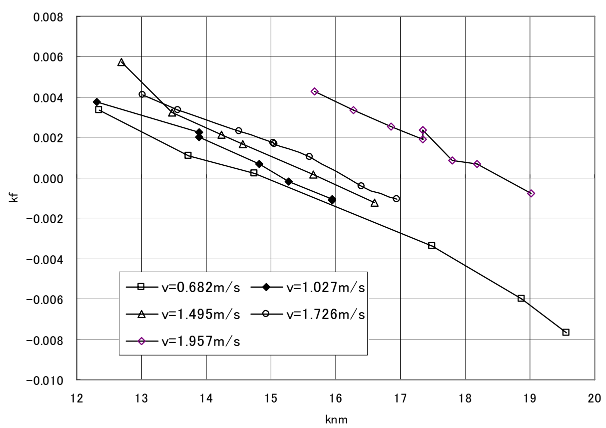

Figure 1.4- Propulsion test results (k_f over k_n).

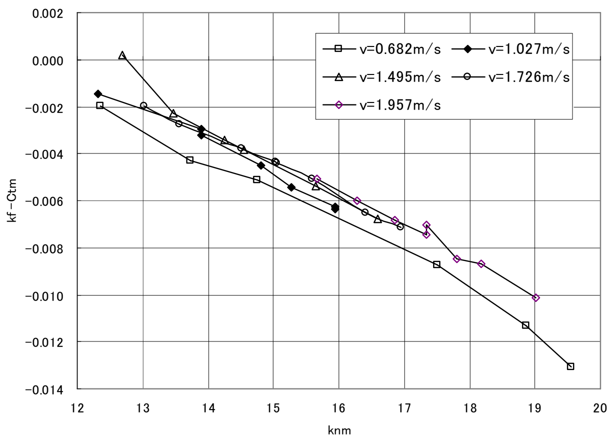

Figure 1.5- Propulsion test results (k_f-$C_{t,m}$ over k_n).

Therefore, in this model test, the towing force measurement is suspected to be less accurate than thrust and torque measurements. We usually consider the sequence of measurement accuracy is, from better to worse, towing force, thrust, then torque. But, this set of data seems to show quite different characteristics.

Propulsion Factors: Propulsion factors were calculated from each set of data and shown in Figs. 1.6 to 1.8 being plotted over k_n. The scatter of thrust deduction factor: t is much bigger than those of wake fraction: w_m and relative rotative efficiency: η_r.

Conclusion from Data Analysis: The results of the resistance test and the propeller open-water test seem to be normal. However, the results of propulsion test seem to be somewhat unusual. The obtained values of thrust deduction factor are too small in low speed, and too big in higher speed, exceeding the values of w_m. There are the following two possibilities:

1. The tendency reflects the actual characteristics of the hull form. Then, the ship has extraordinary hydrodynamic characteristics.
2. The tendency was derived by the poor measurement of towing force.

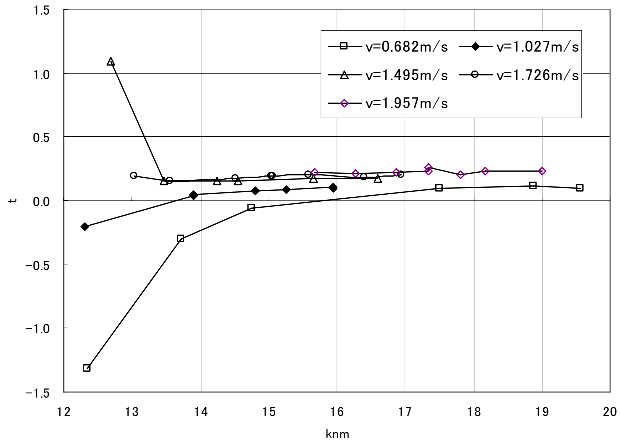

Figure 1.6- Thrust deduction factor obtained by load-varying propulsion tests.

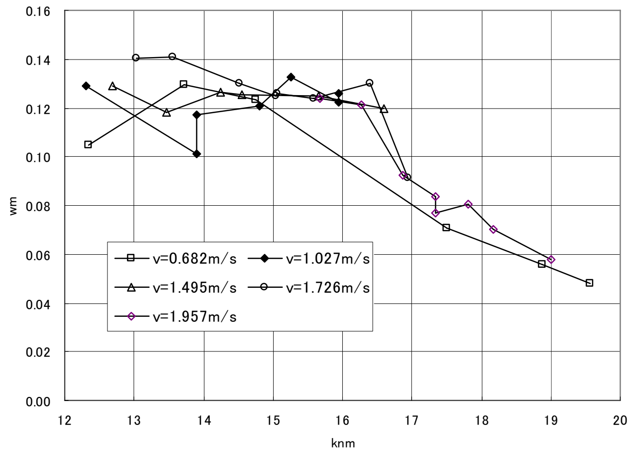

Figure 1.7- Wake fraction obtained by load-varying propulsion tests.

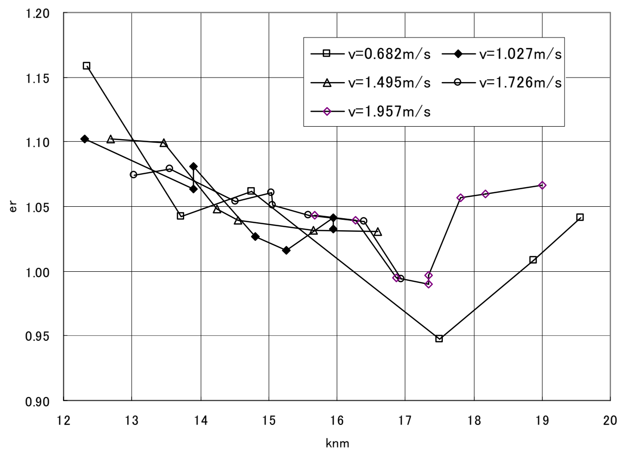

Figure 1.8- Relative rotative efficiency (η_r) obtained by load-varying propulsion tests.

Estimation of Power. *By ITTC 1978 Method:* For each set of load varying propulsion test results, skin friction correction and the value of k_f were calculated. Then, the values of k_t, k_p, k_n corresponding to the given value of k_f were obtained by interpolation.

In the following calculations, the values of thrust, torque and revolution obtained above were supposed to be obtained by the self-propulsion test. The supposed results of self-propulsion test were analyzed and self-propulsion factors were obtained as functions of Fr. The results are shown in Fig. 1.9.

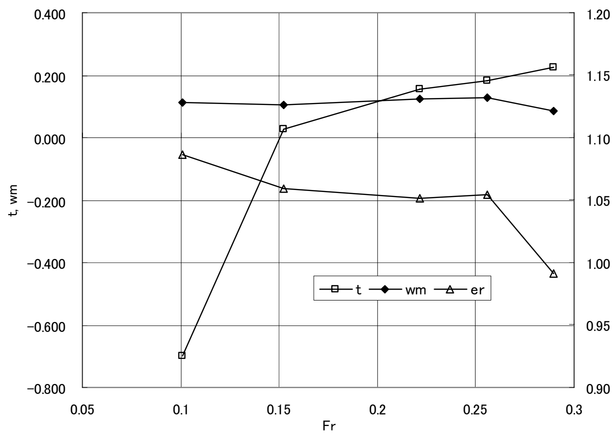

Figure 1.9- Self-propulsion factors vs. Fr.

For a given value of advance speed, total resistance coefficient: $C_{t,s}$ was calculated by the following formula and coefficients in the Eq. 1.1,

$$C_{t,s} = (1+k)\cdot C_{f,ITTC1957}(\mathrm{Re}_s) + a\cdot Fr^4 + b\cdot Fr^8 + c\cdot Fr^{12} + d\cdot Fr^{16} + e\cdot Fr^{20} \quad (1.4)$$

Self-propulsion factors were obtained by interpolation of the above results. Then, the required power and propeller revolution were estimated according to ITTC 1978 method.

By a Method from Self-Propulsion Test Only: The supposed results of self-propulsion test of k_t, k_p, k_n were given as functions of Fr. Since k_t and k_p can be written as follows:

$$k_t = \frac{C_{t,s}}{1-t}, \quad k_p = \frac{C_{t,s}\cdot(1-w_s)}{2\pi\cdot(1-t)\cdot\eta_P\cdot\eta_r} \quad (1.5)$$

and self-propulsion factors and η_P show only slight variation against Fr, k_t and k_p can be expressed by the same form as $C_{t,s}$. In this calculation not only k_t and k_p but also k_n were fitted by the following formula which is similar to Eq. 1.4.

$$k_t, k_p, k_n = a\cdot C_{f,ITTC1955}(\mathrm{Re}_s) + b\cdot Fr^4 + c\cdot Fr^8 + d\cdot Fr^{12} \quad (1.6)$$

where,
a, b, c and d are fitting coefficients

The reason why only four terms were used is that there are only five analyzed results. The analyzed results and the fitted curves were shown in Fig. 1.10.

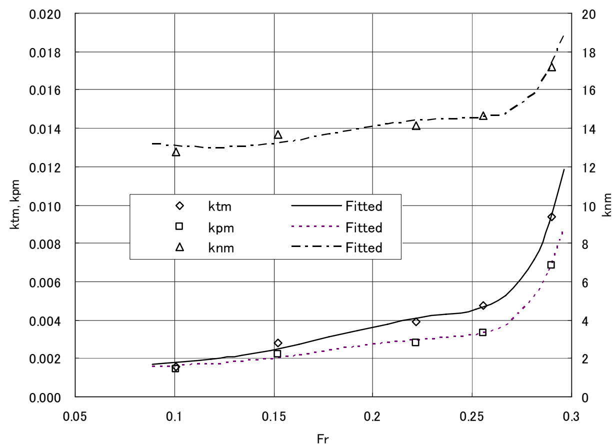

Figure 1.10- Self-propulsion test results: k_t, k_p and k_n vs. Fr.

For a given value of advance speed, k_p and k_n were calculated by Eq. 1.6 and fitting coefficients. Then, torque Q and propeller revolution N_P were calculated and the delivered power (DHP) could be estimated by,

$$DHP = BHP/\eta_T = 2\pi\times Q\times N_P \quad (1.7)$$

Monte-Carlo Simulation. *Calculation Procedure:* Because the simple use of M/S Excel was employed and repeating calculations many times was very difficult, it was decided that the estimations of DHP from the analyzed results of model test data were carried out forty times. For the each estimation of DHP, model test data were modified by the following formula and the analyzed results were used for the estimation of DHP.

Test data analyzed for the repeated calculations = Actual data×(1+a×R_{ndm}) (1.8)

where,
a is the level of uncertainty of the measured results ("a"=1.0% is used),
R_{ndm} is the Random value following Gaussian normal distribution (Average=0, Standard deviation=1).

One case of calculation is carried out by one worksheet, and forty worksheets were used together with a worksheet summarizing the whole results, where average values and standard deviations of DHP and intermediate values were calculated.

This procedure is selected because both are important for this investigation; of carrying out calculations many times and examining the calculation process and intermediate results carefully.

Results: The uncertainty ratios, that is ratios of standard deviations to average values of DHP obtained for three values of advance speed by the two methods. They were shown in Fig. 1.11. Although not the same, no significant difference is observed.

When the uncertainty ratios of $C_{t,s}$ and k_p were plotted over the uncertainty ratios of DHP, Fig. 1.12 was obtained. From this figure, it is understood that the uncertainty of DHP is almost governed by the uncertainty of $C_{t,s}$ in the case of ITTC 1978 method, and by the uncertainty of k_p in the case of a method by propulsion test only. Then, $C_{t,s}$ and k_p were calculated for various values of advance speed and the results were shown in Fig. 1.13 and Fig. 1.14. The scatter of the two coefficients seem to be similar.

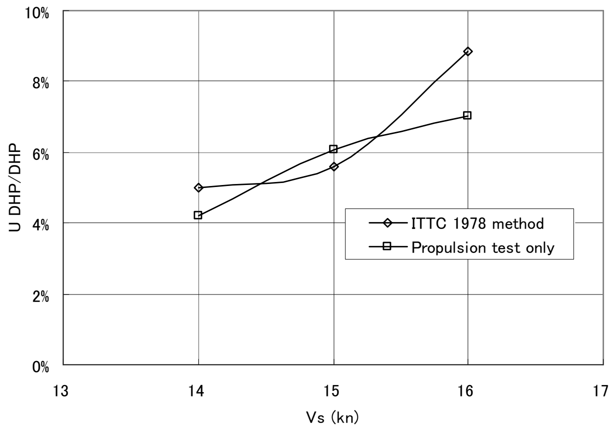

Figure 1.11- Uncertainty Ratio of DHP estimated by two methods.

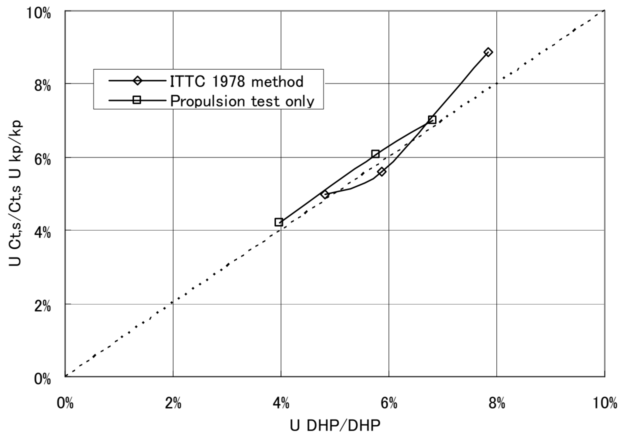

Figure 1.12- Uncertainty Ratios of $C_{t,s}$ and k_p over uncertainty Ratios of DHP.

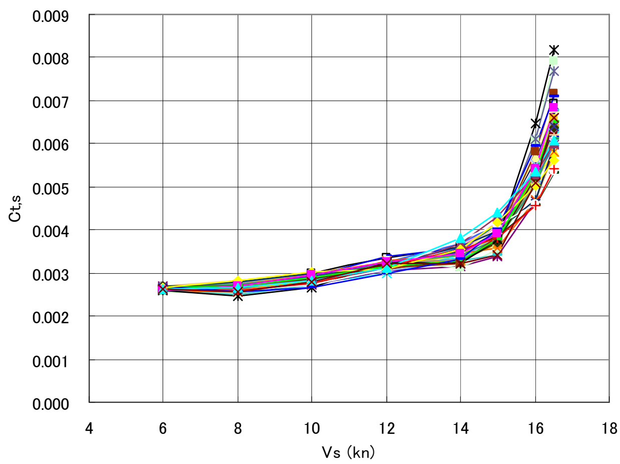

Figure 1.13- Forty $C_{t,s}$ curves obtained by Monte-Carlo simulation.

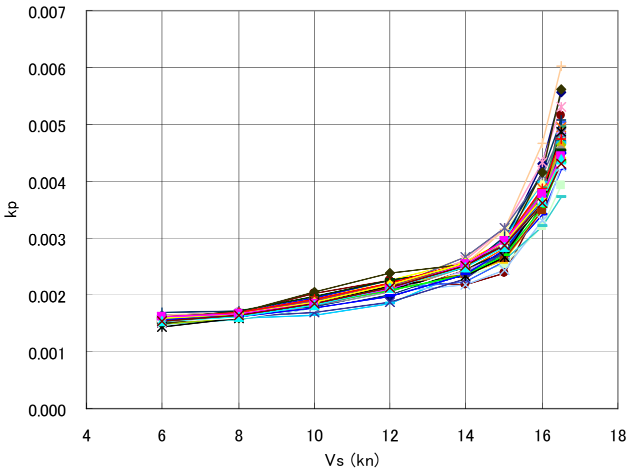

Figure 1.14- Forty k_p curves obtained by Monte-Carlo simulation.

The uncertainty ratios of $C_{t,s}$ and k_p were plotted over advance speed in Fig. 1.15. According to the Appendix,

1. The uncertainty ratio of $C_{t,s}$ is much more dependent on the uncertainty of measured advance speed than that of measured resistance.
2. When resistance is considered proportional to n-th power of advance speed as shown in the Eq. A4, the value of "n" has great influence on the uncertainty ratio of $C_{t,s}$.
3. Since the value of "n" increases with the increase of advance speed, the uncertainty ratio of $C_{t,s}$ would significantly increase with the increase of advance speed.

The values of "n" for various advance speeds were estimated from the Eq. 4 and the fitting coefficients, and the uncertainty ratios of $C_{t,s}$ were estimated by the Eq. A5. The results were shown in Fig. 1.15 by a solid line. The line well explains general tendency of the uncertainty ratios of $C_{t,s}$ and k_p vs. advance speed.

Conclusion. From the results of the investigation explained above, it can be concluded that the uncertainty ratios of DHP obtained by the two methods were of the same level.

This conclusion is considered more reasonable than the temporary conclusion of the Committee, when the following facts were reflected:

1. The uncertainty ratios of DHP were almost governed by the uncertainty ratios of $C_{t,s}$ or k_p.
2. The uncertainty ratio of $C_{t,s}$ is greatly affected by "n" in the Eq. (A4).
3. The variation of k_p against advance speed is similar to that of $C_{t,s}$, because self-propulsion factors and open-water propeller efficiency show only slight variations against the variation of velocity. So, the value of "n" for k_p must be similar to that for $C_{t,s}$.

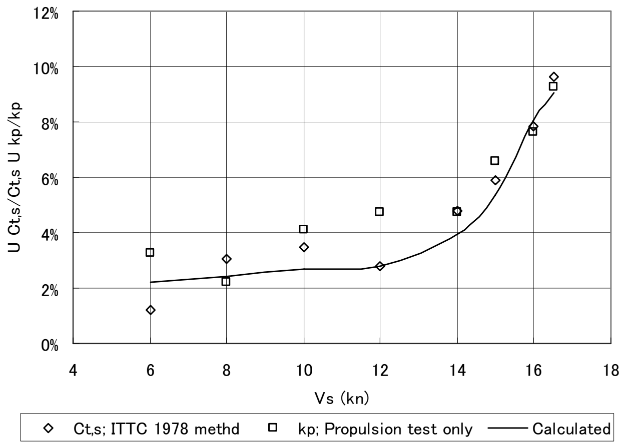

Figure 1.15- Uncertainty ratios of $C_{t,s}$ and k_p compared with the calculated results.

Appendix: Basic Formulae for the Uncertainty Analysis. The uncertainty of the value expressed by a function: U_Y

$$Y=f(x_1, x_2, x_3, \cdots, x_n) \quad (A1)$$

can be estimated by the following formula,

$$U_Y^2 = \left(\frac{\partial Y}{\partial x_1} \times U_{x_1}\right)^2 + \left(\frac{\partial Y}{\partial x_2} \times U_{x_2}\right)^2 + \left(\frac{\partial Y}{\partial x_3} \times U_{x_3}\right)^2 \ldots + \left(\frac{\partial Y}{\partial x_n} \times U_{x_n}\right)^2 \quad (A2)$$

Resistance R is supposed to be proportional to n-th power of advance speed v.

$$R = A \times v^n \tag{A3}$$

where,
R is resistance,
V is velocity,
A and n are appropriate constants.

If the resistance coefficient is defined by the following form, from the measured values of R and v (R_m and v_m),

$$C_R = \frac{R_m}{A \times v_m^{\ n}} \tag{A4}$$

we can expect C_R is independent of the variation of velocity. Then, the uncertainty of C_R is estimated from the formula (A2) as,

$$\left(\frac{U_{C_R}}{C_R}\right)^2 = \left(\frac{U_{R_m}}{R_m}\right)^2 + n^2 \times \left(\frac{U_{v_m}}{v_m}\right)^2 \tag{A5}$$

If the uncertainties of R_m and v_m are 1% of the average, the uncertainty of C_R is $\sqrt{1+n^2}\,\%$ of the average.

1.4 Discussion to the 24th ITTC Specialist Committee on Powering Performance Prediction by Kinya Tamura, Japan

First of all, I would like to express my sincere appreciation that the work on Powering Performance Prediction by this Specialist Committee has been resumed, as I think it is one of the most important issues for ITTC. I am also thankful to the Specialist Committee Members for their efforts to re-open the work after the termination at 21st ITTC.

However, I am afraid that the present Specialist Committee has not paid enough attention to the past work of the former Performance Committees. When one intends to evaluate a method and to improve it, it is important to follow the process of studies and to know how it was carried out under the situation at that time.

Since I served jointly to establish the 1978 Performance Prediction Method as a Member of the Performance Committee, I would like to express my comments as follows:

1. The full name of 1978 method is “1978 ITTC Prediction Method for Single Screw Ships” as shown in the 15th ITTC Proceedings Vol. 1, page 363. The reason why twin-screw ships were excluded was mainly for the uncertainties in appendage drag extrapolation and in the estimation of the characteristics of CPP, which was in many cases adopted to twin-screw ships.

Since 15th ITTC, the investigation was made towards these issues by every Performance Committee. For the appendage drag extrapolation, it was finally concluded at 20th ITTC (Proceedings Vol. 1 page 295) that: “The form factor method, beta method and Taniguchi's method are useful from the practical point of view. The form factor method appears to be the most promising”. Since it depends largely on the type and the shape of appendages, careful treatment is inevitable. For the characteristics of CPP, only a simple estimation procedure was referred at 15th ITTC (Proceedings Vol. 1, page 382).

The database of sea trials collected by the present Specialist Committee seems to contain a considerable number of twin screw ships. I would like to know what measures the Specialist Committee has used in order to deal with these issues.

2. The Performance Committee of 14th ITTC prepared the “Trial Prediction Test Program” and distributed it to 11 Institutions who cooperated in analyses of their own database of sea trials. The analyzed results of 833 data points of single-screw ships in total were obtained with many choices and 1978 Method was selected as the best

performance prediction method due to the smallest st. dev. and relative ease of calculation. Among the examined methods, Method 71, direct scale up of the propulsion test results, gave the largest st. dev. (Committee Report, Appendix 1, 2 and 3).

In 15th ITTC, 3 major Institutions made the analyses of their own database of sea trials. Results analyzed by 1978 Method, Standard Method of each Institution and Scott Method were shown in the table (Proceedings Vol. 1, page 364). Here again the 1978 Method gave the almost smallest st. dev. And the Scott Method gave the largest. The Scott Method corresponded to Method 71 and it was recommended at 13th ITTC that its prediction factors may be used as an interim measure for single screw ships.

In the Specialist Committee Report, however, it was concluded tentatively that overall uncertainty in powering prediction was found to be less for extrapolation based, only load varied self-propulsion tests, than for 1978 Method. How does the present Specialist Committee evaluate the above historical process?

3. Specialist Committee Report stated at the last paragraph of “8.4 Uncertainty Analysis” that the wake scaling method used in 1978 Method should be reformulated. I would like to point out, however, that 17th ITTC Performance Committee already amended the performance prediction program as $w_s = w_m$, when Δw becomes negative (Proceedings Vol. 1, page 295).

4. I am pleased to learn that sea-trial data of more than 1200 data points of single screw ships accumulated at one organization were analyzed by use of different friction line (or correlation line). The results of analysis were found to be almost independent of which friction line was used.

It is my understanding that the basic concept of this analysis is the different correlation factors correspond to the different friction line. Since ITTC 1957 Correlation Line was solely used in the course of establishment of 1978 Method, the correlation factors should be reconsidered when one intends to use a different friction line.

5. In the uncertainty analysis of the present Specialist Committee Report, the uncertainty of the friction line is considered, based on the difference between different lines. However, it is a matter of definition which line is to be used. The uncertainty should be considered not on a friction line but on correlation factors.

2. COMMITTEE REPLIES

2.1 Reply of the 24th ITTC Specialist Committee on Powering Performance Prediction to Ian W. Dand

We would like to thank Dr. Dand for his discussion. He raises an important issue, which should be followed up by the Powering Performance Prediction Specialist Committee of the 25th ITTC.

For a single trial result, the correlation must be said to be acceptable as long as the prediction and trial results, including error bands, overlap each other. For a single result, one can not distinguish the random variation within the error bands from a systematic deviation between the prediction and trial results.

The uncertainty analysis as presented by the Committee gives you primarily the precision error of the trial and prediction results. A low precision error is of course very important. The use of systematic uncertainty analysis along the lines outlined by the Committee could be a good tool to determine which prediction method has the lowest precision error. However, the bias errors are just as important.

To assess the overall bias error of a prediction method, systematic comparison with full-scale trials are essential. The correlation factor is in fact a correction for the total bias error. Just as in the early days of scientific based ship model testing, many sets of prediction and trials data are needed to establish reliable correlation factors.

The Committee collected a quite large database of comparable model test and sea trial results, and our original intention was to use this material to determine correlation factors, i.e. address not only the precision but also the bias error of the prediction methods. However, time didn't allow us to complete this part of our tasks. This work will be continued by the Powering Performance Prediction Specialist Committee of the 25th ITTC.

The bias errors determined by a correlation study will only give a value of the total bias. It seems reasonable to divide the total bias into a *facility bias*, related to the process of producing the corrected and smoothed measurements, and an *extrapolation method bias.* This distinction is probably not as clear as it might look at first sight. Determination of facility biases is an ongoing activity of the Resistance Committee, and it will probably be useful for the Powering Performance Committee of the 25th ITTC to have their conclusions as background for their work.

2.2 Reply from the 24th ITTC Specialist Committee on Powering Performance Prediction to Jan Holtrop

We thank Dr. Holtrop for his discussion and welcome his comments based on his extensive experience with the work of the Powering Performance Prediction Committees of the ITTC.

We share Dr. Holtrop's view that additional care and additional data are required to deal with extrapolation of model tests with deviating flow features in order to compare extrapolation methods.

Variations on extrapolation methods in current use by different tanks are large. Each deviation from ITTC 1978 method results in a new empirical correction based on the experience of the individual tanks. Comparison of extrapolation methods utilized in practice is hence somehow biased, due to facility practices, and experience. End users are forced to accept the results of preferred methods, as there is very limited number of comparisons for the extrapolation methods. Uncertainty analysis of collected trial data can be used for this purpose. Hence the Committee has collected a database from different tanks for such purpose and conducted model tests with these methods. Further extension of this database and careful evaluation of the database shall enable the next ITTC Committee to suggest if such conclusions are justified.

The choice of extrapolation method between load variation self propulsion tests and ITTC 1978 consisting of resistance, self propulsion and open water tests will be based on the available testing time, facility experience, and uncertainty of extrapolation method based on facilities own bias and precision errors. The Committee's first findings suggested there can be large variations on the uncertainty levels among these methods, which needs to be further investigated.

The standard deviation of correlation allowance C_A is lower when Grigson line is utilized instead of ITTC 1957 line. However the difference is small in the data set utilized in the current study. Hence the Committee was not ready to suggest to utilize Grigson line, instead of ITTC 1957, with the current state of art.

2.3 Reply from the 24th ITTC Specialist Committee on Powering Performance Prediction to Toshinobu Sakamoto

The Committee thanks Mr. Sakamoto for his careful analysis. The results are interesting, but unfortunately do not directly bear on the results presented by the Committee for the uncertainty using the two extrapolation methods described.

The discussion outlines the sensitivity of uncertainty in an extrapolation procedure to the details of the method. In the work of the Committee we were very careful to use only low order polynomials to try to avoid biases arising from this source. A study was done changing the order of the polynomial curve fits to experimental (primarily resistance) data, but this was found to have minimal effect in our calculations. Uncertainty was found to be sensitive to the interpolation of the model self-propulsion point, when load varied data is used and very sensitive to the ship propeller operating point. This is especially of relevance when using an automated computer based extrapolation procedure as was necessary when using a Monte Carlo analysis for uncertainty.

The method to analyse powering from a self propulsion test described by the discusser is not exactly the same as that used by the Committee. The latter has been documented in the references cited from the Report. With changes in the order of the polynomials of any curve fits used, the actual levels of uncertainty will vary if details of the method are changed. Therefore, calculations done in different ways will lead to different levels of uncertainty and this shows the relatively sensitive nature of the ship powering extrapolation process. As our knowledge of uncertainty analysis in the ship powering extrapolation process increases, uncertainty analysis will enable us to vary the details of the procedure to actually improve the robustness of the methods used.

Lastly, 40 iterations of the extrapolation process would not be expected to yield the same values in an uncertainty analysis as that obtained by the Committee using 10,000 iterations of the method. The calculations, spreadsheets and programs used by the Committee were checked extensively, and continue to be checked, to make sure that erroneous values do not result just through wide variation in the inputs.

2.4 Reply from the 24th ITTC Specialist Committee on Powering Performance Prediction to Kinya Tamura

We thank Dr. Tamura for his discussion and welcome his comments based on his extensive experience with the work of the Powering Performance Prediction Committees of the ITTC. His points concerning additions and updates to the 1978 ITTC Prediction Method for Single Screw Ships are noted and strongly support the work of the ITTC to enshrine its methods in published procedures.

The 1978 prediction method has of course been updated and routinely applied to all types of ships outside the ranges of those for which it was originally intended. Also, most ship powering performance extrapolation methods have a basis that is similar to the 1978 method and ascertaining the details of different methods in use was one of the first jobs of the work of the Committee which has been presented in the written Report (see Table 5.3). The experience of the user is a major factor in the effectiveness of how the extrapolation method is applied in practice, but of course this can be a disadvantage of publishing a method if less experienced users make use of the approach. The exact details of how each part of the calculations presented in the Report have been done have been explained as clearly as possible in the written Report. However, a full break down of appendage resistance is not available for the ships in the database. The methods in use by some major tanks for handling bilge keels are described in Table 5.3 of the Report. For example, the experience of the Vienna Model Basin is that the form factor approach is not recommended for the extrapolation of the drag of appendages for twin-screw ships and that the drag of these should be treated independently of the hull resistance and scaled in a proportion varied between 0.6 and 0.9 of the model appendage drag coefficient.

In terms of the uncertainty values presented in the analyses in the written Report, considerable effort has been made to treat all data in a similar manner between the different methods. Hence the tentative result that one extrapolation method gives a lower spread in uncertainty levels than another is valid, based on the assumptions used, the two calculations are directly comparable. We have not treated the data for one extrapolation method in a different way than for another extrapolation method. However, the actual levels of uncertainty may not be valid since uncertainties in the test results and other parameters were assumed as inputs. In a full analysis these would come from a full uncertainty analysis of the test results, as outlined in other parts of the Report. We have examined uncertainty in a way that, as far as we know, has not been done before. It should be emphasized that we have done an uncertainty analysis of the method, not a sensitivity analysis.

The point raised about wake scaling amendments made by the 17th ITTC Performance Committee is again evidence of the importance of enshrining methods into ITTC published procedures which the Committee strongly supports.

The analysis done using different friction lines shows that few changes result in uncertainty levels of ship powering if a different friction line is used, see Fig. 10 of the Committee Report, although as the discusser explains the correlation coefficients should be different and were different for each of the friction lines used in the analysis. The variation in correlation coefficients is indicated in Fig. 10 of the Report. The Committee has not proposed levels of correlation allowance for different extrapolation methods although this work might be attempted using the published database by a future Committee if the ITTC felt this to be important.

In the uncertainty analysis, however, an uncertainty level in the friction line itself was also considered. The level of this uncertainty is open to debate, but the friction line is not a fixed quantity. Each friction line models, in some way, turbulent flat plate friction coefficients, which are based on experimental data and/or numerical analysis which use experimental data as inputs. In addition the values are extrapolated to ship-scale Reynolds numbers, where little or no experimental data exists. The fact that there are different lines to model what is effectively the same data and information highlights this point. This uncertainty was considered as an input to the uncertainty analysis in the same way as uncertainty exists in the experimental data. Results of uncertainty in ship powering prediction were considered with and without uncertainty in the friction line included.

Uncertainty in the correlation factors can be assessed through a comparison of the powering prediction results, from the uncertainty analysis and the results from the full-scale trials. Due to time restrictions, this latter stage was not completed by the Committee and could be done by a future Committee if the ITTC felt this to be important.