The Specialist Committee on Powering Performance Prediction

Final Report and Recommendations to the 25th ITTC

1. EXECUTIVE SUMMARY

The committee obtained and analyzed additional geosim model series data that corroborates the Garcia-Gomez claim that model size influences form factor.

A study of different friction formulations showed that the form factor scale effect can be significantly reduced by changing from ITTC'57 to another friction formula. However, it was also found that a change of friction formula is not likely to improve the quality of powering predictions significantly.

A load-varying propulsion test only method is not included in the updated powering performance prediction procedure.

The ITTC database of model and full scale trials data was found to have insufficient quality data to be used in a study of improving powering prediction methods

A method to predict the sea margin of ships is included in the procedure for predicting powering margins.

2. INTRODUCTION

2.1 Membership

The 24th ITTC appointed the Specialist Committee on Powering Performance Prediction with the following membership

- Sverre Steen, (Norway) Chair, Norwegian University of Science and Technology
- Maria Bobo (Spain) Secretary, Canal de Experiencias Hidroninámicas de El Pardo
- Gabor Karafiath, (USA) Naval Surface Warfare Center – Carderock Division
- Mustafa Insel, (Turkey) Istanbul Technical University
- Richard Anzböck, (Austria), Vienna Model Basin
- Jinho Jang, (Korea) Samsung Heavy Industries.
- Naoji Toki, (Japan) Mitsubishi Heavy Industries
- Dexiang Zhu, (China) CSSRC, Shanghai Branch
- Wei Qiu, (Canada), Memorial University of Newfoundland.

At the first meeting Maria Bobo was elected Secretary of the Committee.

2.2 Meetings

Meetings were held as follows:

- China Ship Scientific Research Centre, Shanghai Branch, November 2005.
- Istanbul Technical University, Turkey, October 2006.
- Norwegian University of Science and Technology, Norway, September 2007
- Memorial University of Newfoundland, Canada, March 2008.

3. TASKS SET FROM THE 24TH ITTC

1. Review and update the Speed/Power Prediction procedure (7.5-02-03-01.4),
   a. Make use of the dataset of over 120 ships, which has been collected,
   b. Complete the outstanding set of resistance, open water and load varying self propulsion tests initiated by the 24th ITTC
2. Make the Speed/Power Prediction (7.5-02-03-01.4) and the Predicting Powering Margins (7.5-02-03-01.5) procedures consistent with the Analysis of Speed/Power Trial Data (7.5-04-01-01.2).
3. Review and update the procedures for predicting the resistance and propulsion of high speed marine vehicles, including multihull vessels (7.5-02-05-01 / 02) to assess power requirements, taking into account drag reduction, hull appendage interactions, hull/propulsor interaction and hydrodynamic loads in waves.

4. FOREWORD

The committee was tasked with review and update of four procedures:

1. 1978 ITTC Performance Prediction (7.5-02-03-01.4)
2. Predicting Powering Margins (7.5-02-03-01.5)
3. Resistance tests of HSMV (7.5-02-05-01)
4. Propulsion tests of HSMV (7.5-02-05-02)

The Propulsion Committee was also given the task of updating the Propulsion test for HSMV procedure, and in discussions with the propulsion committee it was decided that the propulsion committee would take the lead in the update of this procedure.

The committee was tasked with making the Speed/Power Prediction (7.5-02-03-01.4) and the Predicting Powering Margins (7.5-02-03-01.5) procedures consistent with the Analysis of Speed/Power Trial Data (7.5-04-01-01.2). We chose not to change the Analysis of Speed/Power Trial Data, and to make the two other mentioned procedures consistent.

The philosophy of the committee with respect to updating procedures has been that:

- A change should reflect a proper balance between current practice and state-of-the-art.
- A change should reflect physical aspects correctly.
- A change should have a significant impact on the predicted power.

The report discusses the update of each procedure sequentially, as they are listed in the tasks given to the committee.

5. POWERING PERFORMANCE PREDICTION

5.1 Review of state of the art

The Specialist Committee on Powering Performance Prediction has been tasked with revising the ITTC recommended procedure for predicting ship speed and power from model tests – currently known as the ITTC 1978 Powering Prediction Method, and the procedures for testing and extrapolating resistance and propulsion of High Speed Marine Vehicles. The revision is based on a balance between reflecting current practice and the results of the most recent developments in the field of model testing and ship power prediction. To get an overview of current practice a questionnaire has been distributed, and the results are summarised in the next section.

Questionnaire

To get an overview of current practice with respect to powering performance prediction both for conventional and high speed vessels, a questionnaire with 27 questions was distributed to most ITTC-members. The questionnaire is divided in one part for conventional ships and one part for High Speed Marine Vehicles.

42 replies have been received. These replies will not be made known outside the committee. A short summary of the questionnaire results is presented here. Some organizations use more than one methodology listed in the questionnaire, and some institutions didn't reply to all questions, so the number of replies doesn't always add up to 42.

Conventional Ships

1. 41 of 42 organizations conduct model resistance tests.
2. 37 org. conduct model propulsion tests (the questionnaire does not consider waterjets or surface piercing propellers)
3. 31 org. use form factor to predict resistance from model test data:
   25 use Prohaska's method (or similar)
   14 determine the form factor by towing at very low speed
   5 use an empirical formula to calculate k, and
   1 uses its empirical database to find the value of k
4. 20 org. use form factor in the formulation of the tow force for the model self propulsion test and 19 do not.
5. 29 org. use the ITTC friction line as the standard
   8 use Schoenherr's
   2 use Prandtl-Schlichting's
   1 uses Hughes (for full ships)
   1 uses Karman-Schoenherr's
6. 36 org. apply a roughness correction to the full scale frictional resistance:
   13 of them use the formula in ITTC 78 method
   13 included the roughness correction in the coefficient CA
   13 use other corrections: Yazaki(1); ITTC mod.(1); Marin statistical method (2); Empirical formula (3); Empirical Database(3); DRT correction(1); Townsin's formula (1); 0.0004 (1)
7. 32 org. scale the wake of single-screw vessels:
   21 use Tanaka Sasajima method (the original ITTC 78 method)
   11 use other methods: Yazaki(3); Tanaka(1); ITTC mod.(1); Marin statistical method (2); Own Database (3); Vol. mean wake (1)
8. 20 org. scale the propeller open water characteristics:
   17 use the method as given in the ITTC 78 method
   3 use other methods: ITTC modified.; Influence of C_V on C_L ; Lerbs-Meyne
9. 20 org. usually scale the wake of twin-screw vessels and 3 only for twin-skeg:
   14 use Tanaka Sasajima method (the original ITTC 78 method), and
   9 use other methods: Yazaki(1); Tanaka(1); ITTC mod.(1); MARIN statistical method (2); Own Database (2); Formula (1); $w_S = w_M$ when $w_S > w_M$ (1)
10. 4 org. have a different practice for twin-screw ships regarding form factors:
    They use a value of $k = 0$
11. 22 org. make a special correction for scale effect on appendages (like propeller shafts, brackets and so forth).
    12 do this by testing with and without appendages and then scaling using a standard scaling factor (for instance 0.5)
    5 calculate the viscous appendage resistance in model and full scale using a friction line, local Re, and assumed form factor of each appendage
    4 use other methods: k for each append.(2); Taniguchi (1); $R_{wBH} = R_{wAH}$ (2)

12. 23 org have ship trials data to compare to their standard powering prediction method for models or projects that they have tested

13. 5 of the 23 org. that have ship trials data want to share the comparison with the rest of the ITTC

14. 12 org. apply the propulsion test only method instead of resistance, propulsion and open water tests. Of them:
4 do this occasionally, as a supplement to the conventional method
3 as the standard method
5 only for research purposes

<u>High Speed Marine Vehicles</u>

15. 37 organizations conduct model resistance tests on High Speed Marine Vehicles

16. 25 org. conduct model propulsion tests on High Speed Marine Vehicles
(the questionnaire does not consider waterjets or surface piercing propellers)

17. 10 org. use form factor to predict resistance from model test data:
3 of them determine the form factor by towing at very low speed
4 use Prohaska's method (or similar)
3 use an empirical formula to calculate k
1 uses a three-dimensional extrapolation method, and
1 uses CFD analysis to find the value of k

18. 3 organizations use form factor in the formulation of the tow force for the model self propulsion test.

19. 27 organizations use the ITTC friction line as the standard
4 use Schoenherr's
2 use Prandtl-Schlichting's
1 uses Karman-Schoenherr's

20. 26 org. apply a roughness correction to the full scale frictional resistance:
3 of them use the formula in ITTC 78 method
15 included the roughness correction in the coefficient CA
7 use other corrections: ITTC mod.(1); MARIN statist. method (2); 0.0004 (1); Empirical formula (1); DRT correction (1); Own Database (1)

21. 11 org. scale the wake of High Speed Marine Vehicles:
6 use Tanaka Sasajima method (the original ITTC 78 method)
5 use other methods: ITTC modified (1); Marin statistic method (1);
Own Database (2); Empirical formula (1)

22. 11 org. scale the propeller open water characteristics:
9 use the method as given in the ITTC 78 method
2 use other methods: Marin statistic method (1) ; Lerbs-Meyne (1)

23. 19 org. make a special correction for scale effect on appendages (like propeller shafts, brackets and so forth).
10 do this by testing with and without appendages and then scaling using a standard scaling factor (for instance 0.5)
7 calculate the viscous appendage resistance in model and full scale using a friction line, local Re, and assumed form factor of each appendage
3 use other methods: k for each append.(1); Testing with and without appendages(2)

24. Regarding the method of accounting for Air Resistance:
13 org. make no special corrections
5 test with a modeled superstructure
21 correct the resistance by calculation (part of the scaling procedure)
None correct the trim effect by shifting weights in the model

25. 14 organizations have ship trials data to compare to their standard powering prediction method for models or projects that they have tested

26. 2 of the 14 organizations that have ship trials data want to share the comparison with the rest of the ITTC

27. 6 organizations apply the propulsion test only method instead of resistance,

propulsion and open water tests for High Speed Marine Vehicles:
4 do this occasionally, as a supplement to the conventional method
2 as the standard method

The results of this questionnaire show that there is a significant variation in the details of the powering predictions in use at the 41 facilities that replied to the questionnaire. However, a large majority of 29 out of the 41 uses the ITTC'57 correlation line. The other uses a variety of friction lines, but none reports to be using the Grigson line. Also form factor is used by a large majority of the institutions, 31 of 41. Of those 25 is using the Prohaska method. When it comes to roughness allowance, most institutions (36 of 41) use that, but there is not a single method that stands out as more common as the others. It could be noted that only 13 organizations use the formula in the previous version of the ITTC'78 method. From this it can be concluded that although there is a significant variation of methods, the ITTC'57 line can still be considered current practice. The same can be said about the use of form factor and the application of a roughness allowance. Propulsion test only methods are reportedly in use by 12 of 37 institutions, but of these only 3 use this as their standard method.

For HSMV, ITTC'57 is also by far the most used correlation line, just as for conventional ships. However, when it comes to form factor, that is not so commonly applied for HSMV, only 10 of 37 use a form factor. Of those 10, 7 determine the form factor experimentally, while the other three relies on CFD or empirical method. 26 out of 37 applies a roughness allowance, but only 3 of those use the Bowden Davidson formula included in the original ITTC'78 method. It is not clear from the questionnaire what the other institutions do to correct for roughness on HSMV. Propulsion test only methods are reportedly in use by 6 of 25 institutions performing propulsion test on HSMV, but of these only 2 use this as their standard method.

Literature survey about powering prediction methods

The literature on the load varying self-propulsion only method is limited. We have not found any contributions since the previous ITTC.

There are mainly two extrapolation techniques for full scale ship powering prediction from model experiments based on the results from load varying self-propulsion tests only.

One approach is based on Schmiechen's (1991) "rational theory" which also described in the report of the Specialist Committee on Unconventional Propulsors of the 22nd ITTC. In this method, two overload tests are done at the same steady speed in different values of overload. The speed must be steady to avoid significant acceleration/inertia forces in the longitudinal momentum equation. The carriage speed, shaft rotational speed, shaft thrust, torque and the towing force need to be measured. A summary of the method can be found in the 22nd ITTC report. Schmiechen (1991) presented comparisons between the model and full scale parameters for tests on Meteor. For this vessel, some parameters such as $K_T, K_{QL}, \eta_{JP}, C_E, \eta_{EP}$ and η_{EJ} were found similar for the model and for the full scale ship. Small variations are found for other parameters.

A more straightforward method was proposed by Holtrop (2001) and further investigated by Bose and Molloy (2001) and Molloy (2006). This approach was summarized in the report of the Specialist Committee on Powering Performance and Prediction of the 24th ITTC. The uncertainty of this method was estimated with Monte Carlo method by Molloy (2006) and was compared with that of the ITTC 1978 method. Studies were carried out for an icebreaker. It was found that the uncertainty in ship powering prediction by the ITTC 1978 extrapolation method is approximately two times of that from an extrapolation method based on the load varied self-propulsion tests only for the ice breaker. However, this conclusion was argued by Sakamoto (2005) who concluded that the uncertainty of DHP obtained by the 1978 method and the self-propulsion test only method for the ice breaker was nearly the same.

It is difficult to draw conclusions from the limited literature on which method we could recommend. However, comparing the two methods, the latter one seems more straightforward to apply. The following recommendations could be made from the brief literature review:

1. Applying the two methods to more ships with model and full scale test data available. Since the method proposed by Holtrop (2001) is straightforward to incorporate, we may focus on this method.
2. Further studies should be carried out to compare propulsion test only methods with the ITTC 1978 method.

5.2 Results of a set of load varying tests and how they justify a method to construct load varying propulsion data

Using the ITTC-78 prediction method for predicting full scale performance of ships it is commonly assumed that the thrust deduction factor t and the relative rotative efficiency η_R remain the same for the model and the full scale ship.

The method proposes

- to use the ITTC-57 friction line
- to use a k-factor in addition to the ITTC-57 friction coefficients although they already include a k-factor by comparison with the friction coefficients for a flat plate as derived by Hughes; as the experimental definition of k-factor has its limits, the prediction method provides a formula to calculate the k-factor;
- to use a roughness allowance to be calculated following a formula provided by the method.

A questionnaire circulated by the committee showed that many members of the community use the ITTC-78 prediction method but only one member organization is using it without any modification; many member organizations do use the ITTC-57 friction line but set k to zero, many also use a roughness allowance but following their own experience and using the roughness allowance more as a correlation factor than really as a factor allowing for the roughness of the hull or for different paint systems.

As it is a common aim of all member organizations which carry out self propulsion tests to simulate the full scale propeller load as closely as possible during the self propulsion test, a series of overload tests were carried out with two models of two different conventionally designed passenger vessels, where a huge number of sea trial data were available for both designs, collected under various environmental conditions.

On the basis of the results of these tests a method is proposed in the following to construct load varying propulsion data instead of carrying out tests.

The tests showed that the thrust deduction factor t varies within very small limits when calculated at one speed for various propeller loads. Further the η_R-values remain more or less constant for a constant speed and various propeller loads. Finally the evaluation of the load variation tests showed that, as expected, the sum of (F_D+T) varies only within extremely small limits.

It therefore seems appropriate to postulate that t, η_R and (F_D+T) remain constant at one speed for various propeller loads.

The following procedure can be used to define correlation coefficients from full scale trial results:

- Use only sea trial results carried out under weather conditions corresponding to wind and waves not higher than Beaufort 2.
- Subtract the measured shaft power for the effects for wind and bilge keels:

  $$P_{\text{Dcorr}} = P_{\text{D}} - P_{\text{AA}} - P_{\text{Bilge Keels}}$$

  Reference is made to ITTC recommended procedures 7.5-02-03-01.4 and 7.5-04-01-01.2 for how to calculate P_{AA} and $P_{\text{BilgeKeels}}$
- Calculate the "power factor" $f_{p,m}$ for the model from the full scale trial results:

  $$f_{p,m} = \frac{75 \cdot 136 \cdot 100 \cdot P_{\text{Dcorr}}}{1.025 \cdot \lambda^{3.5} \cdot 2\pi \cdot \eta_R} \qquad \text{[kpcm/s]}$$

- Use (F_{D}+T) from the model tests at corresponding speeds
- Calculate

  $f_{p,m} = Q_{\text{M}} \cdot n_{\text{M}}$

  by use of the propeller open water diagram of the used stock propeller in the following way:

  For each speed:

  (F_{D} + T) [known from model tests]
  w [known from model tests]
  vary n_{M} (that means: vary "J" in the propeller open water diagram of the used stock propeller
  Take readings from K_{T} and K_{Q} at various "J"-values for single speeds.
  Calculate
  $f_{p,m}{'} = Q_{\text{M}}{'} \cdot n_{\text{M}}{'}$
  for various propeller loads at various speeds
  Calculate
  $F_{\text{D}}{'} = \left(\left(F_{\text{D}} + T \right) - T{'}_{\text{M}} \right)$
  for various propeller loads at various speeds
  Plot diagram $f_{p,m}$' over F_{D}' with the ship's speeds as parameters
  Read correct F_{D} from the diagram by setting $f_{p,m} = f_{p,m}$'
  Calculate C_{A}'

By consistent use of the proposed method it should be possible to make use of the ITTC Data Base at least as far as it concerns C_{A}'-values for correct propeller loads. The following example shows that a similar calculation can also be done put slight corrections on the k-factor.

Example

For the example the sea trial data of two twin screw passenger vessels of 130m length were used. Both sea trials were carried out in the North Sea at water depths over 45 m and at weather conditions corresponding to Beaufort 0 to Beaufort 2 so that it was not necessary to apply any correction to the measured results except the allowance for mechanical losses in the gear boxes and shaft bearings which were assumed to be 3.5 % of the measured shaft power.

The sea trial results of the two ships were as follows:

"Ship 1":

V_{S} [Kn]	P_{B} [kW]
20	7789
21	9874
22	12033

"Ship 2":

V_{S} [Kn]	P_{B} [kW]
20	7783
21	9721
22	12121

The mean of the two measurements, which differs in the order of about 1.5 to 2 % is as follows:

V_S	P_B
[Kn]	[kW]
20	7786
21	9798
22	12077

The means of the measured values were reduced allowing for the effects of mechanical losses (3.5 %) and bilge keels (1 %). Further the influence of the relative rotative efficiency was taken into account. Finally, from the averaged and corrected sea trial results the following power figures were derived:

V_S	P_D
[Kn]	[kW]
20	7013
21	9357
22	10899

The power coefficients were calculated to:

V_S	$Q_M\, n_M$
[Kn]	[kpcm/s]
20	163.84
21	205.92
22	254.63

From the overload tests No. 26621, 26622, 26640, 26641 and 26642 (numbers referring to test numbers in the ITTC database of model and full scale trials) the following F_D-values were found to be used to achieve correct propeller loads:

V_S	F_D
[Kn]	[kp]
20	2.130
21	2.318
22	2.485

Assuming the k-factor to be zero per definition the following correlation coefficient values C_A' were found:

V_S	C_A'
[Kn]	[-]
20	$-0.2167 \cdot 10^{-4}$
21	$-0.2109 \cdot 10^{-4}$

The mean of the two values is $C_A' = -0.2138 \cdot 10^{-4}$.

As a check, this C_A -value leads to full scale powering predictions that are within +/- 1 % of the trials data. The ITTC 78 - prediction method was used with $k = 0$ and with the ITTC 57 friction line.

Using the k-factor estimated for the fully appended model $(1 + k) = 1.155$ and setting C_A to zero the following F_D-values were calculated:

V_S	F_D
[Kn]	[kp]
20	2.1458, compared to 2.13 from overload tests
21	2.3401, compared to 2.318 from overload tests

The differences between the F_D-values derived from two sides are 0.74% and 0.94% respectively.

Using the measured k-factor of the fully appended model and further using the ITTC 78 -method the difference to the averaged full scale measurements is less than +/- 1 %.

5.3 The utilisation of the database of 120 ships

Introduction: Aims and expectations

The basic initial idea was to compare the predicted powering from a data base of about 120 ship model tests to the powering achieved during sea trials and find ways to minimize possible differences between prediction and trial results.

Measures to improve the quality of predictions such as

- the use of different prediction methods (e.g. ITTC 78 and its variations, Holtrop-method, Self Propulsion Test only method),
- the use of various friction lines, to make predictions match with full scale trial results,
- the use of *k*-factors modified to make predictions match with full scale trial results,
- the use of correlation allowances adjusted to make predictions match with full scale trial results,

were considered for investigation.

With regard to full scale trials, both the ITTC as well as the ISO recommend methods to correct for the influence of wind, sea states, current, water temperature, water depth, change of draughts (and displacement). However, the magnitude of these trial conditions (wind, sea state, water depth etc) are often not documented and therefore only those ships out of the data base where the sea trials were carried out under “ideal” trial conditions can be used for powering comparisons to model predictions. Ideal trial condition are. practically no wind (no more thanBeaufort 2), deep and calm sea, no current, and where the draught of the full scale ship during trials was equal (at least comparable) to what was tested in the model basin.

A common aim of all members of the society who carry out model self propulsion tests is to simulate the propeller load as realisticly as possible by applying the friction deduction as a towing force to the model. The formula to calculate the friction deduction generally includes a *k*-factor (casually set zero), friction coefficients for the model and for the full scale ship, casually a roughness allowance and a factor which considers the scale effects on the model appendages and occasionally a correlation factor C_A.

Investigations therefore obviously should concentrate on

- the preferable way in which the self propulsion test should be carried out and on the preferable prediction method,
- the modifications of the *k*-factor,
- the use of different friction lines,
- the use of roughness allowances,
- the methods of appendage scale effect corrections, and on
- the correlation factor.

The committee decided to concentrate on an investigation whether small deviations between trial prediction and sea trial measurements could be minimized by the systematic application of correlation factors

Unfortunately a careful check of the ITTC-data-base showed that this data base is incomplete, and that important information is missing so that a reliable investigation was not possible. There were 12 ships found where it was known that the sea trials were carried out at ideal weather conditions and acceptably deep water in the trial area; nevertheless in none of the cases was there any information on the full scale propeller geometry or characteristics. The attached diagrams show the correlation factors C_A calculated for the 12 ships at various speeds plotted over the Reynolds-number *Re*. The scattering of the points is so much that any systematic formulation seems neither reasonable nor helpful to the community.

The committee is of the opinion that a more complete data base would lead to more useful information.

Standards for a Suitable and Complete Data Base

Full Scale Sea Trial Data

Full Scale Ship Data

Main Dimensions such as length, breadth, draught and displacement during trials, the condition of the hull, and information concerning paint system.

> Remark: ideally the hull as well as the propeller(s) should be inspected prior to the trial runs; Hull and more importantly propeller roughness should be measured. At a minimum, information should be given concerning the time period the hull had been in the water before the start of the sea trials.

Description of the ship, e.g. what kind of appendages, bow- and/or stern thrusters (number and short description), openings in the hull (e.g. for stabilizers), bilge keels (if, how long and where (at least: in accordance with the design drawings or in line with what was fitted to the model), remarkable attributes (if any), and a description of the propulsion system;

> Remark: such information, together with the necessary information concerning the model, is helpful to judge whether and in which way the influence of the appendages on the performance of the full scale ship was considered.

Full Scale Propeller Data

Number of propellers, fixed or controllable pitch propellers, number of blades, area ratio, propeller diameter, propeller pitch (in case of CP-propellers the pitch at each run during trials), propeller open water characteristics with reference to the respective pitch;

Weather Conditions during the Trial Runs

Information concerning wind and wind direction at each single run, estimated wave heights, current (if any);

> Remark: such information should be given anyway, even the sea trial data included in the data base are corrected for the influence of wind, sea states and current; in case the speed and power values are corrected information should be given in regard to correction method that was used.

Environmental Conditions

Information concerning water depth, density of the sea water and temperature of the sea water.

> Remark: such information should be given anyway, even when the sea trial data included in the data base are corrected for the influence of water depth, water temperature and density of sea water; in case the speed and power values are corrected accordingly the correction method should be documented.

Sea Trial Data

Uncorrected values of speed, torque and rpm;

> Remark: in case the weather conditions and/or the environmental conditions were such that corrections had to be applied and uncorrected values are no longer available the correction methodology should be documented for each single effect.

<u>Model Data</u>

Main Dimensions

A short description of the model, e.g. what kind of appendages, bow- and/or stern thrusters (number and short description), openings in the hull (e.g. for stabilizers), bilge keels (if, how long and where (at least: in accordance with the design drawings or in line with what was fitted to the full scale ship), remarkable attributes (if any), description of the propulsion system;

Information such as model scale, tested draught(s) and displacement(s), length(s) in the water line, wetted surface(s), all information concerning the model test(s)) should be provided

Propeller Data

Information should be given whether stock propellers or design propellers were used during the model tests. In case design propellers were used no further information is required except a remark on whether the model propellers were CP-propellers, were manufactured as such with controllable pitch in model scale or not, or their pitch was adjustable at model scale. Information should be provided concerning the pitch actually set during the test runs together with a respective propeller open water diagram (propeller open water data). In case stock propeller(s) was/were used the following information is required: propeller with fixed or controllable pitch, diameter, pitch, number of blades, area ratio, propeller open water characteristics (for the pitch adjusted to the propeller for the model tests)

Test Data

Information should be provided on the following: water temperature, carriage speed, model speed (corrected for tank (wall) effects), rpm, torque, thrust, friction deduction used;

> Remark: a short description should be given how the friction deduction values were achieved (which friction line was used, was a roughness allowance considered and if how was it calculated, was a correlation factor used and if, the figure should be provided, was the scale effect of any appendage drag considered and if in which way for what appendages)

Prediction Data

The full scale prediction values should be provided; the method used to achieve the predicted values should be named and in case the method is not common it should be briefly described.

<u>Remarks on the ITTC-Data Base</u>

The spread sheet as proposed by the Powering Performance Group of the 24th ITTC is in Appendix A. Although this spread sheet gives a lot of information, a few essential information elements are still missing:

Ship Data:

- Information concerning the type of ship
- Information and/or description of the appendages (e.g. number and kind of brackets, description [including wetted surface and length] of bossings, type of rudders used on the full scale ship, bilge keels [area of wetted surface, position and length])
- Description of openings in the hull (e.g. stabilizer openings, bow thrusters, stern thrusters)
- Description of the propellers in use on the full scale ship (FP or CP).

Model Data:

- Description of the appendages used on the model
- Type of propellers in use on the model
- Information concerning
  - Appendage correction (if any)
  - ΔC_F
  - C_A, if any is used
  - friction line used
  - k-factor, if any is used and how this factor is determined

<u>Conclusion</u>

Unfortunately the data collection shows only a few ships where sea trials were carried out at conditions close to ideal ones; altogether only 12 ships out of 70 were found where the environmental conditions were such that neither corrections for wind, sea states and/or shallow water had to be applied to the data measured during sea trials; nevertheless the data of these ships should not be considered as representative for a serious research as no full scale propeller data were available.

An investigation on correlation factors between trial prediction data and full scale trial results based on the data of these 12 ships (Figure 1) showed a neither useful nor satisfactory result.

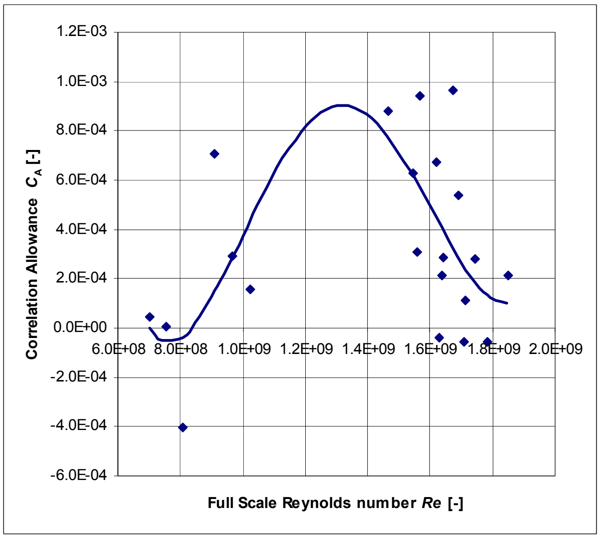

Figure 1 Derived correlation factors for 12 ships from the ITTC-Data Base.

5.4 Form Factor Scale Effect

It is commonly assumed that the form resistance coefficient is the same for ship and model, if the geometry of the both is similar. But the form resistance is a part of the viscous resistance which is governed by the Reynolds number, different for ship and model. It has been argued previously, for instance by Tanaka (1979), that there is a scale effect on the form factor

The results of the tests of several geosim families (Klemm and Buckingham, (1998), and Steen (2006)) whose main characteristics are given in Table 1, have been analysed in order to check the form factor dependency on the scale, using the ITTC and the Grigson correlation lines. The results of the geosim tests of the Lucy Ashton (Conn, Lackenby, Walker (1953, 1955)) have also been reanalysed and included in this study. The models of each family were not only required to be “geometrical similar models” but also “hydrodynamic similar models”. From the point of view of the resistance, it is not correct to assure that a series of models is a geosim family only because they correspond to the same ship made at different geometrical scales. Their hydrodynamic qualities must also be checked. Iso-Froude lines will permit to select the models that have a similar hydrodynamic behaviour.

Ship data	Symbol	Dim.	LPG Carrier Marintek	USN 710 DTMB
Length between perpendiculars	L_{PP}	[m]	160.0	116.74
Length in waterline	L_{WL}	[m]	164.8	116.74
Breadth on waterline	B	[m]	28.2	12.31
Draught at Lpp/2	T	[m]	10.3	4.18
Trim	t_s	[m]	0	0.305
Block Coefficient (Lpp)	C_B	[-]	0.7106	0.5273
Volume displacement	∇	[m^3]	33023.3	3167.6
Wetted surface incl. rudder	S	[m^2]	6322.1	1631.1
Wetted surface excl. rudder	S_{BH}	[m^2]	6255.3	1603.9

Table 1. Main dimensions of analysed geosim models

We have determined the form factor for every model according to Prohaska’s method, with n = 4 and 0.12 < *Fr* < 0.20. In all the cases considered we have obtained the mean square regression line by evaluating the experimental points included in this range and by disregarding those with an anomalous behaviour. When this method is applied, the determination of the regression line depends on the particular parameters chosen when analysing the experimental results. Due to the inevitable scattering of the test data, a good criterion is to select the test values that give a regression coefficient R^2 higher than 0.95 and keep C_W values well faired.

The determination of the form factor of the smallest models of some geosim families had less precision than the rest and therefore these models have not been considered in this analysis. The form factor for the full scale ship has been estimated from the tendency line of model values.

The form factor has also been determined for models with appendages using two methods:

1.- Applying Prohaska's method directly to the experimental results as in the case of the bare hull models. However the resistance tests at very low speeds with appended models are not useful to determine k_{ap} due to the possibility of laminar flow over the appendages.

2.- When the appendages are present in the model, the form factor can be determined equating the wave resistance values to those of the naked hull in the range of Froude Numbers between 0.1 or 0.2 and 0.4, given that in this range it is assumed that the appendages do not modify the wave resistance.

$$R_{\mathrm{WMap}} = R_{\mathrm{WMBH}}$$

The form factor is then calculated using formula (1)

$$1 + k_{\mathrm{ap}} = \frac{C_{\mathrm{TMap}} - C_{\mathrm{WMBH}} \cdot \dfrac{S_{\mathrm{BH}}}{S_{\mathrm{ap}}}}{C_{\mathrm{FM}}} \qquad (1)$$

The calculations that have been carried out show that, when the ITTC correlation line is applied, there is a scale effect on the form factor which predicts a higher value of the form factor for the full-scale ship than for the models. In contrast, when the Grigson correlation line is employed the form factor has an opposite tendency (Lucy Ashton bare hull models), or remains almost constant with the scale (DTMB-710 models and Lucy Ashton models with bossings). This would indicate that the scale effect is partially included in the line of friction.

As an example among the geosim families studied, the variation of the form factor with the scale of the Lucy Ashton models is shown in Figure 2 and Figure 3. Form factors have been calculated for the bare hull models and for the models with bossings, using the ITTC and Grigson correlation lines.

The form factors, k_M, obtained for the bare hull models of all geosim families using the ITTC correlation line are shown in Table 2 as well as the values of k_S extrapolated to the ship. The values of k_S-k_M of all families have been plotted in Figure 4 as a function of the scale ratio. The form factor for the full scale ship can also be estimated from the model form factors using Garcia's formula (2) (García-Gómez Amadeo. (2000))

$$k_{\mathrm{S}} - k_{\mathrm{M}} = 1.91 \cdot (\lambda - 1) \cdot 10^{-3} \qquad (2)$$

This line is also plotted in Figure 4. As can be seen this prediction line is very close to the correlation line of the experimental values of k_S-k_M obtained in this study.

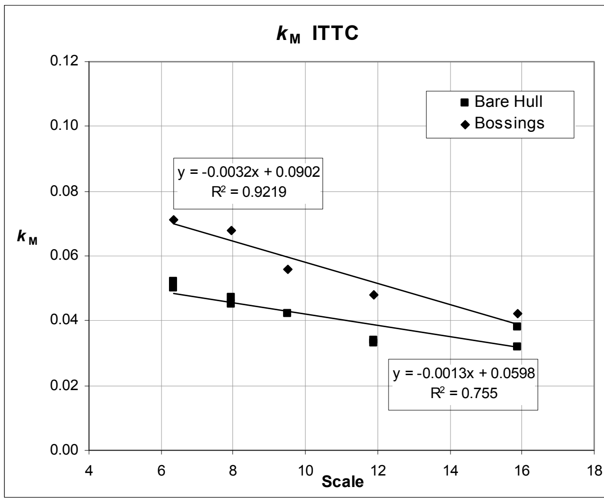

Figure 2 Form factor for Lucy Ashton models, determined using Prohaska's method and ITTC'57 correlation line

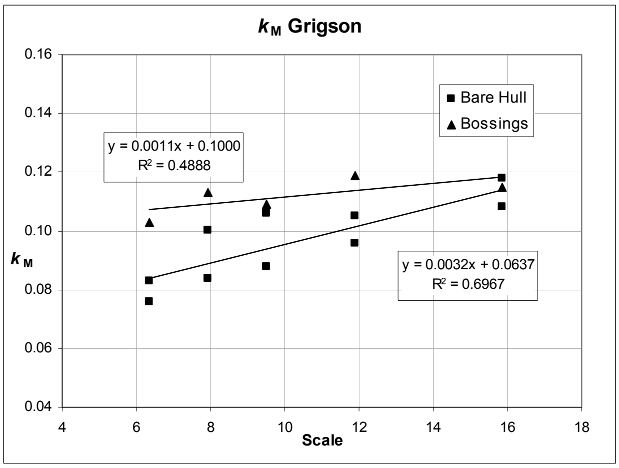

Figure 3 Form factor Lucy Ashton models, determined using Prohaska's method and Grigson correlation line

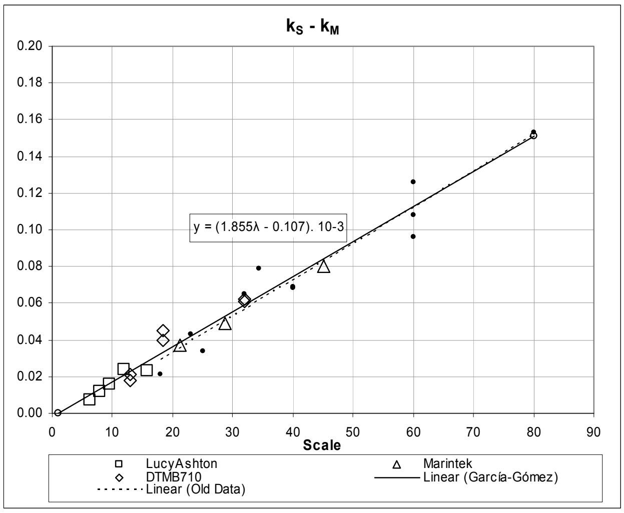

Figure 4 k_S - k_M as function of scale ratio for all geosim families considered in this study

	Scale	k_M	k_S	$k_M - k_S$
	1.000			0.000
Marintek	45.000	0.167	0.247	0.080
	28.634	0.198	0.247	0.049
	21.311	0.210	0.247	0.037
DTMB	13.000	0.189	0.210	0.021
710	18.450	0.170	0.210	0.040
(B.H.)	31.915	0.148	0.210	0.062
Lucy	6.350	0.051	0.058	0.007
Ashton	7.938	0.046	0.058	0.012
	9.525	0.042	0.058	0.016
	11.906	0.034	0.058	0.024
	15.875	0.035	0.058	0.023
	21.167	0.029	0.058	0.029

Table 2. Form factor for different scale models, determined using Prohaska's method and ITTC'57 correlation line

The results of this study confirm the dependency of the form factor on the scale and thus on the Reynolds Number. Nevertheless, it is important to keep in mind that the scale effect on the form factor as stated here is related to the ITTC correlation line.

Other friction lines will show different scale-effect tendencies. If the form factor remains constant using a correlation line different from that proposed by the ITTC it is due to the fact that the scale effect is being introduced in the basic friction line instead of in *k*.

The extrapolated values from the model form factors to the full scale ship obtained from the test results of the new geosim families agree well with the line proposed by García especially in the case of the bare hull models. Thus, a practical formula to estimate the value of the form factor for the ship has proven to be useful.

Extrapolation To The Ship

The values of the tests of the Lucy Ashton models have been extrapolated to the full scale ship according to the ITTC and Grigson correlation lines.

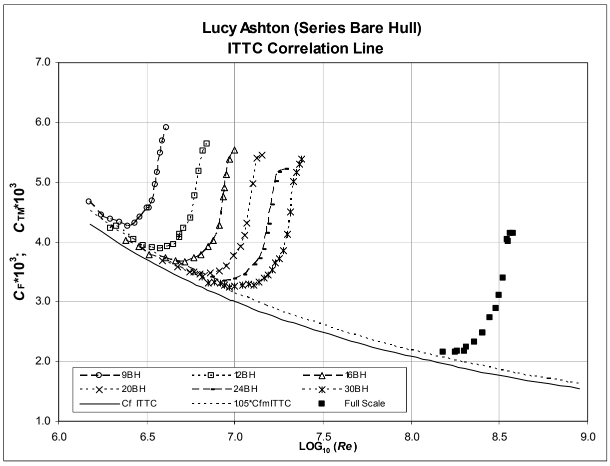

Figure 5 C_{TM} values of all six models of the Lucy Ashton family and C_{TS} values from sea trials. Bare hull condition.

In Figure 5, the C_{TS} values obtained from the sea trials and the C_{TM} values of the six models of the Lucy Ashton family for one of the series of the tests of the bare hull condition, have been plotted against the $\log_{10}$ of the Reynolds number.

The full scale form factor has been calculated in two different ways:

1. - Extrapolating from the form factors of the models.

The values of k_S for the bare hull models have been obtained from the regression lines of Figure 2 and Figure 3.

ITTC correlation line,

k_{SBH} (ITTC) = 0.0598

Grigson correlation line,

k_{SBH} (Grigson) = 0.0637

2.- Directly from the sea trial data according to Prohaska's method with n = 4 and $0.12 < Fr < 0.20$ (Figure 6).

ITTC correlation line,

k'_{SBH} (ITTC) = 0.0604

Grigson correlation line,

k'_{SBH} (Grigson) = 0.0230

As can be seen, the k_S values from the sea trial data agree well with the extrapolated values of the models form factors in the case of the ITTC correlation line but are different when Grigson correlation line is used.

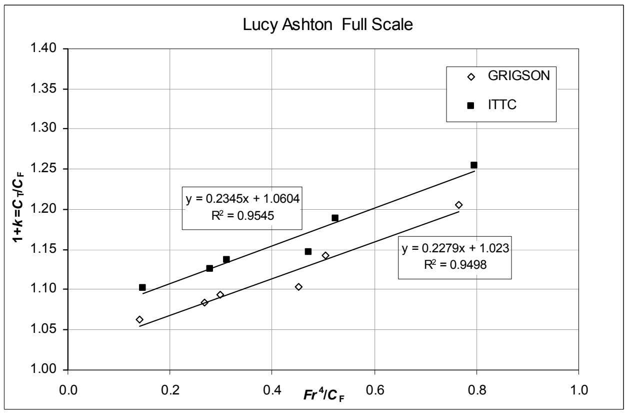

Figure 6 Determination of form factor from Lucy Ashton full scale data, Bare Hull

SEA TRIALS					ITTC		GRIGSON	
V_S (Kn)	R_{TS} (tons)	P_E (HP)	C_{TS}*10^3	R_N*10^-6	C_{FS}*10^3	C_W*10^3	C_{FS}*10^3	C_W*10^3
6.0	0.476	20	2.255	153.89	1.959	0.050	2.032	-0.043
7.0	0.628	30	2.242	179.54	1.917	0.082	1.992	-0.013
8.0	0.828	45	2.276	205.19	1.882	0.153	1.958	0.057
9.0	1.091	67	2.360	230.84	1.852	0.268	1.929	0.172
10.0	1.438	99	2.496	256.48	1.826	0.432	1.903	0.335
11.0	1.895	143	2.686	282.13	1.803	0.647	1.881	0.549
12.0	2.497	206	2.954	307.78	1.782	0.937	1.860	0.839
13.0	3.291	293	3.392	333.43	1.763	1.396	1.842	1.297
14.0	4.338	417	4.001	359.08	1.745	2.023	1.825	1.924
15.0	5.717	588	4.175	384.73	1.730	2.213	1.810	2.114

Table 3. Sea trial results and ITTC and Grigson correlations

The published data of the resistance experiments on the Lucy Ashton with the results of the tests of six geosim models and the measured full-scale resistance of the ship allow us to make a a direct comparison of the effective power between full-scale results and the extrapolation of the model results.

C_{WS} values extracted from the sea trials are plotted in Figure 9 and Figure 10 together with the C_{WM} values of the six models obtained using the ITTC and Grigson correlation lines. The scatter between the tests and sea trials is as can be expected due to experimental errors.

P_E values obtained from the models with k_{SBH} (ITTC) = 0.060 and k_{SBH} (Grigson) = 0.064 have been compared with the sea trial results of Table 3. The graphs with the relative differences in P_E values between tests and full-scale results are shown in Figure 7 and Figure 8. The greatest differences correspond to the smallest model which was disregarded when the model tests were analysed.

It can be said that when the ITTC correlation line is applied, there is a good agreement between full-scale measurements and models extrapolation.

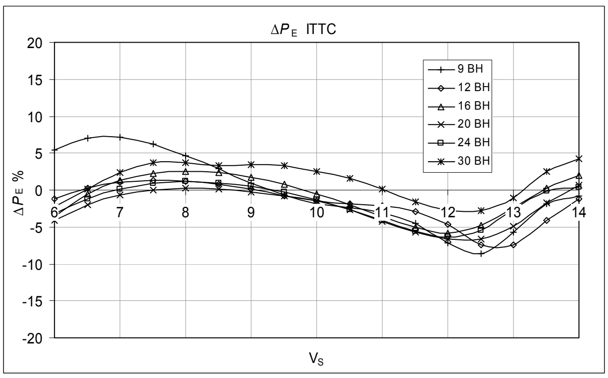

Figure 7 Relative difference in effective power between model test prediction and full scale test result, using ITTC'57 correlation line.

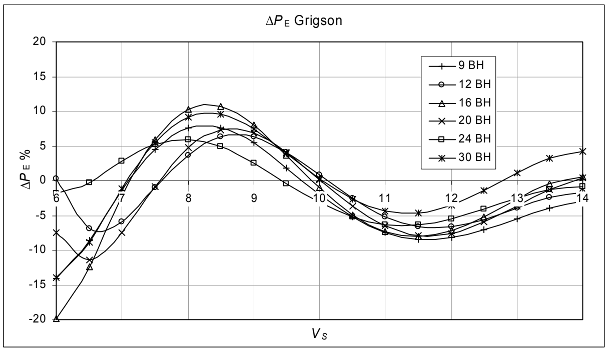

Figure 8 Relative difference in effective power between model test prediction and full scale test result, using Grigons friction line.

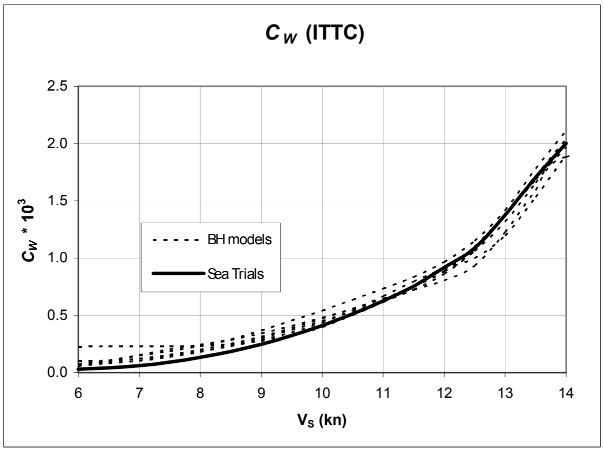

Figure 9 Wave resistance coefficient extracted from sea trials, compared to values from model tests. Using ITTC'57 correlation line.

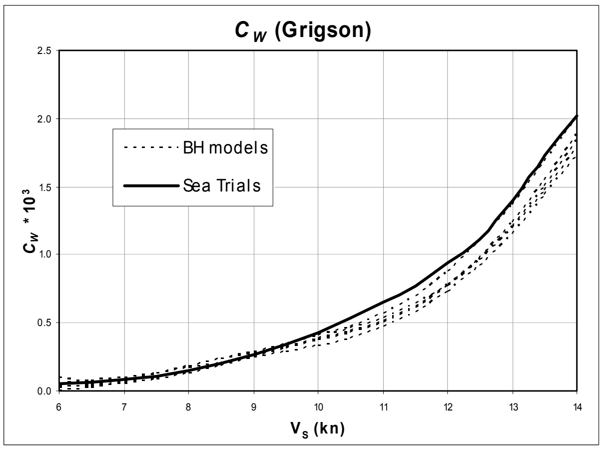

Figure 10 Wave resistance coefficient extracted from sea trials, compared to values from model tests. Using Grigsons friction line.

5.5 Discussion on friction line

If the form factor determined from the model test results by use of ITTC 1957 line has model scale effect, then one option is to modify the correlation line in order to remove or significantly reduce the scale effect. The committee made a thorough study of this issue.

At first, it was confirmed that the Geosim model test results obtained in 1950s give almost model scale independent residual resistance coefficients (C_R) when analysed by two-dimensional analysis using ITTC 1957 Line. According to the Report of Skin Friction Committee of 8th ITTC(1957), it was the intention of the committee to propose the line of such characteristics.

As an example of the results shown in Figure 11, where mean line of Fr-C_R relation is drawn by fitting the data for Fr>0.11 by the following function.

$$C_R(Fr) = C_{R,0} + a \cdot Fr^4 + b \cdot Fr^8 + C \cdot Fr^{12} + d \cdot Fr^{16} + e \cdot Fr^{20} \cdots \quad (3)$$

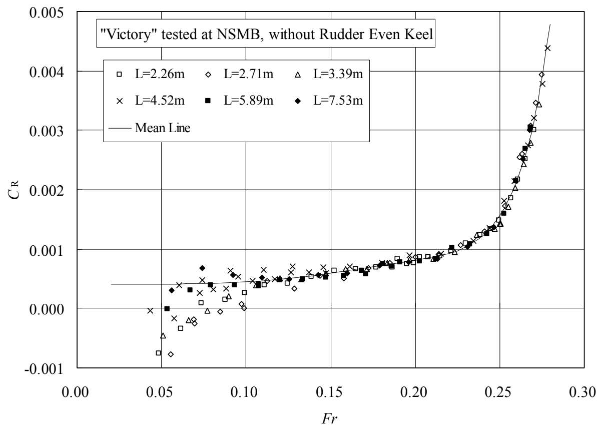

Figure 11 An example of result of two-dimensional analysis of Geosim test data

The C_R curve tends to a certain positive value when Froude number tends to zero. Then, it is quite natural that we would have model scale effect on form factor when three-dimensional analysis is applied using the same friction line. The reason can be explained schematically by Figure 12, where three total resistance coefficient (C_{TM}) curves for small, medium and large models were drawn together with frictional resistance coefficient (C_F) curve. If the distances of the left ends of C_{TM} curve above the C_F curve are equal, form factor: k for large model must be bigger than that of small model because C_F value for large model is smaller than that of small model.

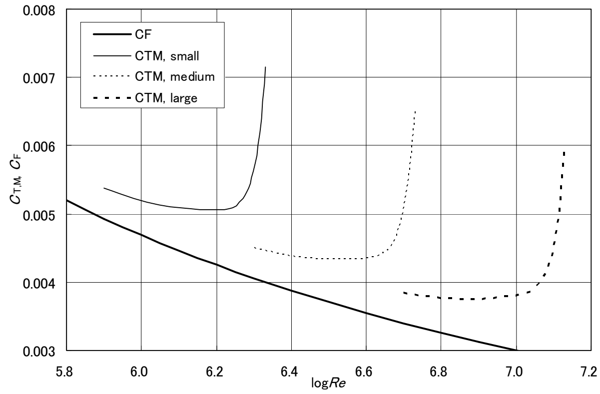

Figure 12 Schematic expression of Geosim test results

As we can write total resistance coefficient of the series model, using $C_R(Fr)$ given by the mean line in the Figure 11, as

$$C_{T,M}(Re, Fr) = C_{F,ITTC}(Re) + C_R(Fr) \quad (4)$$

This formula gives the over-all characteristics of resistance of whole Geosim models. By using this formula, we can estimate the form factor of each model in the Geosim series. The results are shown in Figure 13, and it shows the magnitude of form factor scale effect.

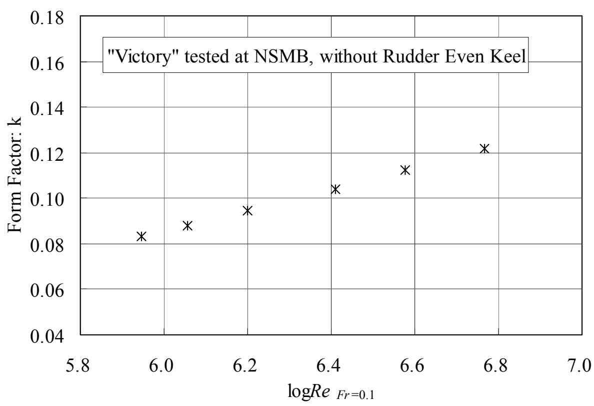

Figure 13 Estimated form factor scale effect (ITTC 1957 Line)

Next, a series of friction lines were defined as shown in Figure 14, which have different values of slope at model Reynolds number and almost the same C_F values as ITTC 1957 Line (Schoenherr Line, too) at full-scale Reynolds number. The series are defined by using C_F value at $\log_{10}Re$=6 as a parameter. Then, sets of Geosim model test results were analysed by using the series.

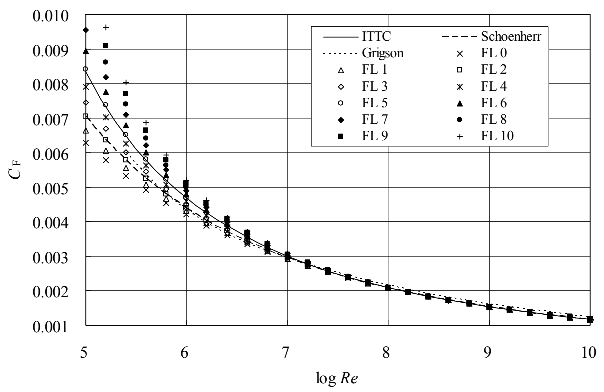

Figure 14 Series friction lines defined for the analysis

When C_R values were calculated by use of i-th friction line for a set of Geosim model test results, they were fitted by using the formula(3) and mean curve of C_R was defined. Then, the value of deviation index of C_R values around the mean line was calculated by the following formula, where M is number of tested models N_j is number of analysed data for j-th model.

$$\text{Deviation Index}_i = \frac{\sum_{j=1}^{M} \frac{\sum_{k}^{N_j} (C_R \text{ Dev.}_{i,j,k})^2}{N_j}}{M}$$

$$C_R \text{ Dev.}_{i,j,k} = C_{R\ i,j,k} - C_{R\ \text{mean line}}(Fr_{j,k})$$

The values of deviation index were obtained for all the series of friction lines, and plotted over a parameter of the series lines (C_F value at $\log_{10}Re$=6), as shown in Figure 15.

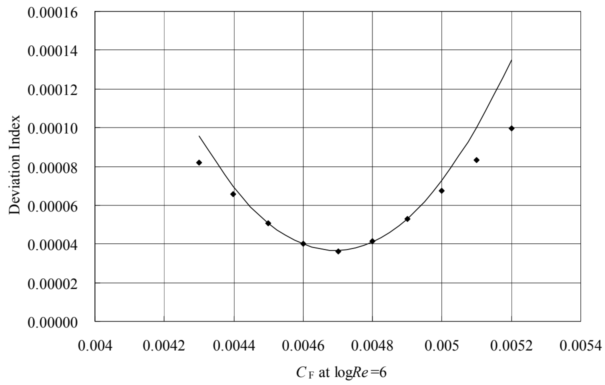

Figure 15 Deviation index vs. Parameter of series friction lines

Then, from the results, it is quite reasonable to consider the friction line corresponding to the value of parameter which gives minimum value of the deviation index is the most suitable one for the Geosim models. Thus, we can identify the most suitable friction line for each of Geosim model set analysed.

In the case three-dimensional analysis was applied, a kind of iteration procedure was followed to avoid the effect of scatter of the form factor obtained by the analysis of the experimental data.

When a friction line of the series and assumed value of form factor are used, we can analyse a set of Geosim test data and get the values of C_R. They are fitted by the formula (3) and the value of $C_{R,0}$ is obtained, This process is repeated for a few assumed values of form factor so as to obtain positive and negative value of $C_{R,0}$. Then, by the interpolation, we can obtain the values of deviation index and form factor by use of which C_R curve that tends to zero when Fr tends to zero is obtained. Performing the analysis for all friction lines in the series, we can get the plot similar to Figure 15 for three-dimensional analysis, and then the most suitable friction line for the Geosim test data is obtained.

The parameters (C_F value at $\log_{10}Re$=6) corresponding to the most suitable friction line for the analysed Geosim test data are shown in Figure 16 for the cases of two- and three-dimensional analyses, being plotted over the value of form factor estimated by an empirical formula (a function of hull form characteristics), which was used as a parameter showing the fullness of hull forms.

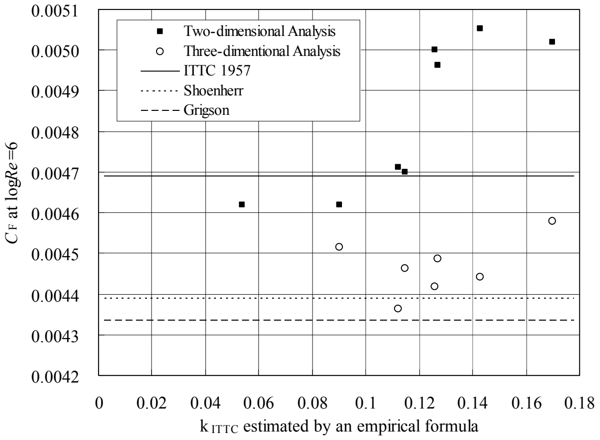

Figure 16 Parameters corresponding to the most suitable friction line for the analysed Geosim data sets

From Figure 16 it can be concluded;

(1) When two-dimensional analysis is applied, the most suitable correlation lines for fine hull forms have the values of parameter, which roughly coincide with the one of ITTC 1957 Line, however for fuller hull forms, there is a clear tendency that the value of parameter gets greater.
(2) When three-dimensional analysis is applied, the values of parameter of suitable correlation lines remain in relatively narrow area, smaller than that of ITTC 1957 Line.
(3) The above results seem to support the concept of three-dimensional analysis.
(4) By taking the average value of the results of three-dimensional analyses, the following friction line is obtained, which is expected to produce minimum scale effect of model size on form factor.

$$C_F = 0.30478/(\log Re - 0.4763)^{2.4705} \quad (5)$$

By applying this new line, the form factor of each model in the particular Geosim series was estimated. An example corresponding to Figure 13 is shown in Figure 17. As expected, the scale effect of model size on form factor was almost eliminated for this particular Geosim series. For the other series, increasing or decreasing tendency along the increase of Reynolds number may remain, however form factor scale effect could be minimized as a whole by the introduction of the new line.

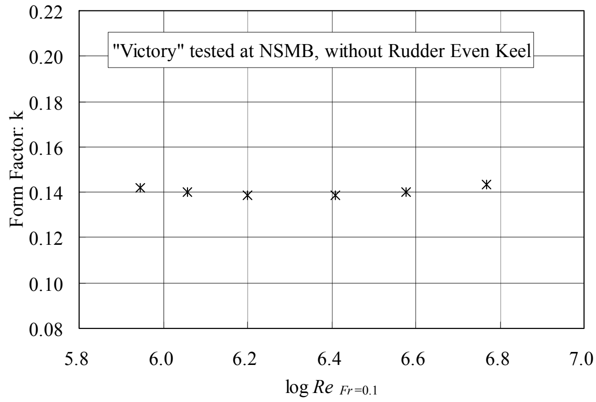

Figure 17 Estimated form factor scale effect (The proposed line)

The particular Geosim test data were analysed by use of ITTC 1957 Line and the proposed line and total resistance coefficients were estimated for full scale ship. The results were compared, as shown in Figures 18 and 19.

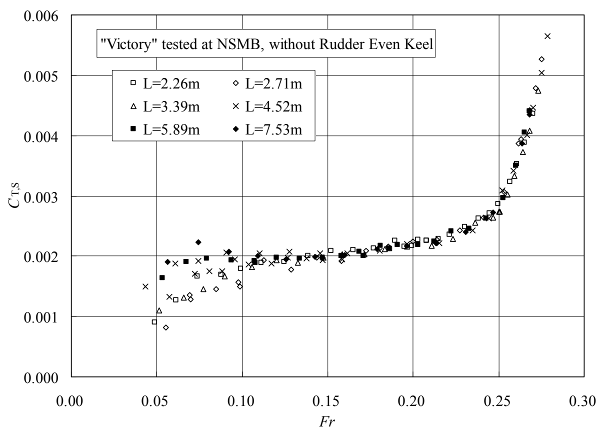

Figure 18 Estimated total resistance coef ficients of full scale ship (ITTC 1957 Line)

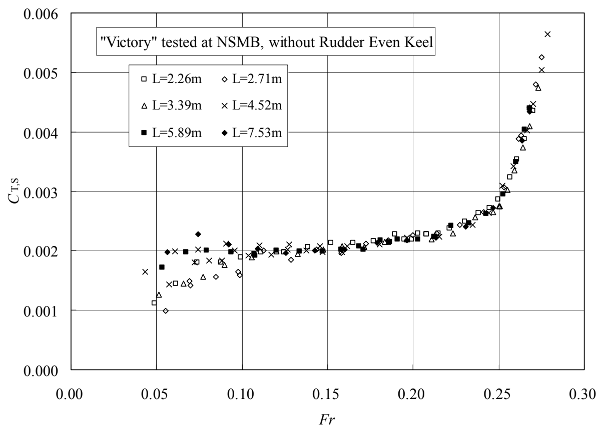

Figure 19 Estimated total resistance coef ficients of full scale ship (The proposed line)

From these figures one can conclude that the new friction line produces no improvement with regard to the scatter of the estimated results while there is a small difference in the mean level.

The small difference of the mean level is created by a change in the balance between frictional and residual components of resistance brought about by the change in the friction line, and the effect on the estimated full-scale performance cannot be neglected. However, if we revise the friction line, we have to reanalyse the full-scale trial results by using the revised friction line and the values of a model-ship correlation factor shall be changed. Then, we can expect that the estimated full-scale performance will remain the same as before the revision.

We tried to revise ITTC 1957 Line because we supposed that the balance between frictional and residual components of resistance given by the line may not be appropriate. And the investigation as summarised above indicates that the balance given by the proposed line seems to be more appropriate. We then expected that some part of the scatter associated with the ITTC 1957 prediction would be reduced by the use of the new friction line If it occurs, it results in the reduction of uncertainty of the estimated performance and can be evaluated as a significant improvement.

However, from the results shown in Figure 18 and Figure 19, the reduction of the scatter is almost negligible. It means that there is another source which creates much more scatter than that created by the inappropriate characteristics of ITTC 1957 Line. Apparently, it is the scatter of the measured results by the model tests.

The conclusions made by the committee are as follows;

(1) For three-dimensional analysis, a correlation line very similar to Shoenherr or Prandtle-Schlichting Lines is more appropriate than ITTC 1957 Line. By the introduction of the newly proposed line, we can improve form factor scale effect.
(2) However, the scatter of the estimated total resistance coefficients of full scale ship remains almost the same, and almost no improvement of the estimated full scale performance can be expected.
(3) We have to try more seriously to reduce the scatter of the measured results by model tests, before discussing the modification of ITTC 1957 Line.

Raven et.al. 2008 discussed calculated results of viscous resistance of two hull forms at Reynolds numbers corresponding to model and full scale. Their results indicate that Grigson or Katsui line is appropriate to minimize scale effect of form factor. It may sound to be contradictory to the conclusion above, however actually not. The difference is caused by the difference of points of focus.

The committee focused on the tendency within the range of model Reynolds number, considering the fact that various sizes of model are used in ITTC community, and concluded the formula (5) is appropriate there.
On the other hand, Raven et.al. compared the calculated results for a model and the corresponding full scale ship with C_F values calculated by various lines. Because the calculated result of C_F value for full scale ship is relatively larger than that estimated by Shoenherr line, the better correspondence was

obtained by Grigson line. Grigson line gives distinctively larger C_F value at full scale Reynolds numbers than the other friction lines, including Katsui's line.

The committee considers the discussion on C_F value at full scale Reynolds number is very important. However, as there is only very limited data, we have to continue researches from every possible directions, as one example is shown by Raven et.al.

5.6 Roughness allowance

In this section we give a review of roughness correction for the performance prediction from the previous ITTC reports.

Roughness Correction in the ITTC'78 Performance Prediction Method

It is well known that the Bowden-Davison formula (6) was proposed in 1974 on the basis of analysis results of loaded trials of 10 single screw ships from 157m to 267m in length and with AHR varying from 144 μm to 211 μm conducted in fair weather condition as NPL/BSRA correlation data. This correlation formula was accepted at the 15th ITTC as the expression of correlation allowance ΔC_F intended for use when extrapolating ship resistance using 1978 ITTC performance prediction method (14th ITTC).

$$\Delta C_F \times 10^3 = 105(\kappa_S/L)^{1/3} - 0.64 \qquad (6)$$

In the above equation, κ_S is the mean apparent amplitude of hull roughness over 50 mm cut-off length and L is the ship length, which should not exceed 400 m. For the subsequent investigations of the ITTC performance prediction method, standard amplitude of $\kappa_S = 150\times10^{-6}$ m was assumed, since roughness values were not available for many of the ships in the data sample.

This relationship was established from an analysis of thrust measurements taken during sea trials. The total resistance coefficient C_{TS} is calculated from

$$C_{\mathrm{TS}} = \frac{2D^2}{S}\left(\frac{K_T}{J^2}\right)_{\mathrm{S}}(1-t)(1-w_{\mathrm{TS}})^2 \qquad (7)$$

and the roughness allowance ΔC_{F} from

$$\Delta C_{\mathrm{F}} = C_{\mathrm{TS}} - (1+k)C_{\mathrm{FS}} - C_{\mathrm{R}} - C_{\mathrm{AA}} \qquad (8)$$

The thrust deduction t and the form factor k are assumed to be the same for the ship and the model. It was suggested in 14th ITTC performance committee that reasonable trends could be established when extrapolating ship resistance using a form factor method together with the ITTC 1957 line., although the accuracy of ship thrust measurements is sometimes questionable and the results showed a considerable scatter.

Other Roughness Corrections for the Performance Prediction

Since 1983 a number of new formulae of increasing complexity have been proposed by Himeno, Townsin et al., Collatz, Walderhaug, and Wright. Each investigator proceeded on the basis of theoretical boundary layer calculations and used empiricisms derived from available laboratory and full scale measurements of ship roughness and roughness drag, as described in the proceedings of the 16th and 18th ITTC.

The formulae proposed by Himeno and Townsin et al. were derived from integral 3-D boundary layer methods including Reynolds number dependency as follows:

Himeno's formula:

$$\Delta C_{\mathrm{F}} = 0.0180 \times 10^{-3} \left(\frac{k}{L}\right) Rn^{0.75} \tag{9}$$

Townsin et al.'s formula:

$$\Delta C_{\mathrm{F}} = 0.044\left[\left(k/L\right)^{1/3} - 10Rn^{-1/3}\right] + 0.000125 \tag{10}$$

The implicit formula of Collatz was developed for roughness on a flat plate and is referenced to the Schoenherr's friction line in the smooth case. It includes both Reynolds number and "texture" dependency as follows.

Collatz's formula:

$$\Delta C_{\mathrm{F}} = \frac{\left(0.99375 + 0.057/r\right)/\left(15 + r\right)}{\log^2\left[Rn\left(C_{\mathrm{F0}} + \Delta C_{\mathrm{F}}\right)/\left(0.49 + 0.42r\right)\right]} - \frac{0.6625}{\log^2\left(Rn\, C_{\mathrm{F0}}/0.49\right)} \tag{11}$$

C_{F0} is the smooth plate frictional resistance coefficient and $r = Rn\, k_m / m\nu L$ is a roughness Reynolds number, with the Grigson roughness texture parameter m and k_m the maximum roughness height. A prescription for the determination of m is not given by Collatz.

The formula proposed by Wright includes ship geometric parameters as well as Reynolds number effects. It was derived empirically to give a somewhat better fit than is given by the formula of Townsin et al. to all of the ship trial data analyzed by Townsin. Wright's formula, which is similar in form to Himeno's formula with regard to dependence on k and Rn, is given by:

Wright's formula:

$$\Delta C_{\mathrm{F}} = 0.00103\left(k/\nabla^{1/3}\right)^{0.717} Rn^{0.575}\left(B/T\right)^{-0.683}\left(T/\nabla^{1/3}\right)^{3.758} \tag{12}$$

The formula proposed by Walderhaug includes "texture" effects as well as Reynolds number and ship geometry dependency. It is given by:

Walderhaug's formula:

$$\Delta C_{\mathrm{F}} = 0.0005\left(\frac{k_E}{L} \times 10^6\right)^{0.2} \left[\ln\left(1 + \frac{k_E}{L} Rn\left(\ln Rn\right)^{-1.2}\right)\right]^{0.7} \left[1 + \left(C_{\mathrm{B}} - 0.75\right)^2/0.49\right] \tag{13}$$

k_E is an effective roughness height defined by

$$\boldsymbol{\frac{k_E}{L} = \left(k/\lambda\right)_1 \cdot \left(k - k_A\right)/L} \tag{14}$$

$\left(k/\lambda\right)_1$ is the roughness mean apparent amplitude over a length $\lambda = 1$mm but the theoretical basis for the form, which includes the $\left(k/\lambda\right)_1$ term, is not clear.

k_A is the sublayer thickness given approximately by

$$\boldsymbol{\frac{k_A}{L} = 2.5\frac{\left(\ln Rn\right)^{1.2}}{Rn}} \tag{15}$$

where 2.5 is a "texture" value for painted surfaces.

Prediction values of ΔC_{F} by several research results were compared with the ITTC'78 formula and presented in the proceedings of the 16th, 18th, and 19th ITTC. From these comparisons, the ITTC 1978 formula is not likely to be an accurate hull roughness penalty predictor and it seems to overestimate the resistance increment by hull roughness. However, according to the report of 19th ITTC powering performance committee, it has been shown that the ITTC'78 formula can be still a plausible interpretation of the reanalyzed data in view of the correlation allowance including both the resistance increment due to hull roughness and the component caused by other phenomena from the results of reanalysis and supplementation of Bowden's ship data (Townsin, 1990). In this case, the remainder of the correlation allowance is shown in equation (16) if the Townsin's formula (6) is used to calculate the roughness influence and the mean apparent amplitude of hull roughness is set at 150μm in the ITTC'78 formula.

$$\left([\Delta C_{\mathrm{F}}]_{by\ ITTC\,1978} - [\Delta C_{\mathrm{F}}]_{by\ Townsin} \right) \times 10^3 = 5.68 - 0.6 \log Rn \qquad (16)$$

Accordingly, the 19th ITTC powering performance committee's view was that the ITTC'78 formula may be replaced by the Townsin's formula (6) and equation (16) if adequate roughness measurements by the standard procedure are available. The present committee has followed their advice and replaced formula (6) with formula (10) in the ITTC'78 performance prediction procedure. Following the advice of the 19th ITTC, we have also included formula (16) in the procedure.

5.7 Update of the 1978 powering prediction method

The following updates have been made to the ITTC standard procedure 7.5-02-03-01.4 1978 ITTC Performance Prediction Method:

- Removed the parts of the procedure on how to perform the involved model tests and analyze the model scale data, as that is now covered in separate procedures.
- Changed the calculation of the residual resistance coefficient to account for air resistance and appendage resistance in model scale. Separation of appendage resistance from residual resistance is considered optional in the procedure.
- Changed the calculation of the full scale resistance coefficient to account for air resistance in the same way as in the procedure 7.5-04-01-01.2 Analysis of Speed/Power Trial Data.
- Changed the calculation of full scale resistance coefficient to account for separate scaling of appendage resistance. Separation of appendage resistance from residual resistance is considered optional in the procedure.
- A description of how to make a prediction using torque (power) identity is included, since one of the listed alternative correlation methods requires this method.
- A section on how to calculate appendage resistance is added. It is noted that both 7.5-02-02-01 Resistance tests and 7.5-02-03-01.1 Propulsion test addresses appendage resistance scale effect. The treatment in the two procedures is not in direct conflict, but it is still the view of the committee that the treatment of appendage resistance and appendage resistance scale effect should be more consistently treated. If the ITTC decides to make the treatment of appendage resistance more consistent, that work should also include this procedure.
- Roughness correction and correlation allowance are separated in two factors. The recommended roughness allowance is according to Townsin's formula. A formula is given for the correlation allowance that together with the roughness allowance will give approximately the same correction as the previous combined roughness and correlation allowance. The mean apparent roughness height of 150 μm has not been changed. This change is done based on the recommendations of the Powering Performance Prediction Committee of the 19th ITTC. The committee decided to make this change in order to separate the physical effect of increase of frictional resistance due to roughness, and the "include-all" correction factor termed correlation allowance. Especially since the different institutions usually use different values of the correlation allowance, it seemed appropriate to separate the correlation allowance from the roughness correction. It should also be mentioned that the

roughness allowance should be further investigated, in light of the current rapid development in new anti-fouling paint technology.

- Some misprints and omissions have been corrected to make the inclusion of twin screw propulsion more clear. It should be noted that the procedure is valid for single and twin screw conventional propulsion. The procedure can easily be adapted to cover also ducted propellers and podded propellers, as well as more than two propellers, including differently loaded propellers. However, this is not covered in the procedure at present.
- The formatting of the procedure has been changed to make it more consistent with the other procedures, adding a chapter containing the data reduction equations and list of symbols.
- A flow chart has been added to aid in the understanding of the use of the powering prediction method described in the procedure.

Calculation of tow rope force F_D

In the previous version of the ITTC 1978 Performance prediction procedure, the formula for the tow rope force F_D did not include a form factor. The committee investigated this with the authors of the original ITTC'78 method, and it was confirmed that this was really an error, and that a form factor should be included in the calculation of F_D when a form factor is used to extrapolate the resistance. In the present version of the procedure, a formula for F_D is no longer included, since it is included in the recommended procedure 7.5-02-03-01.1 Propulsion Test. In this procedure, the formula for F_D is given both with and without form factor.

Wake scaling

The concept for wake scaling has not been changed. After some discussion, the committee decided to keep Tamura's formula without an explicit exception for twin-screw vessels, but keeping the restriction that in case the formula results in $w_S > w_M$, then w_S is set equal to w_M. This is in lack of more information or better methods available. It is, however, noted in the procedure that it is common practice not to scale wake of twin screw vessels, since the wake scale effect of such vessels usually is small.

Form factor

Analyses of the available geosim hull data supports that using a form factor in the extrapolation process is appropriate, especially on full ship models. It was also found that for less full ships, good results are obtained using the ITTC'57 correlation line without form factor, and it is recognised that in many cases this can be a good solution, since the uncertainty and complication of an experimental determination of the form factor is avoided. It can be noted here that the use of an empirical expression for the form factor is kind of a compromise, since it removes the complication and uncertainty of form factor measurement, and still includes the physical form effect in an approximate manner.

The analyses of the geosim hull series also showed that there really seems to be a scale effect on the form factor, and that when the ITTC'57 correlation line is used, it agrees well with the formula proposed by Garcia-Gomez (2000). However, for typical model scales, the magnitude of the scale effect has not much importance for the final prediction – in the order of 1% on power, and since ignoring it is a systematic error that will be corrected for by a proper correlation factor, we have found that we will not recommend the introduction of a form factor scale effect in the 1978 ITTC powering performance prediction procedure.

Friction line

From analyses of geosim data we have shown that there seems to be a scale effect on the form factor when the form factor is determined using the ITTC'57 correlation line. We have also shown how this scale effect can be minimised by changing the slope of the correlation line in the range of model Reynolds numbers. However, our analyses show that changing the correlation line in this way didn't reduce the scatter in the predicted full scale resistance. The change in the level of the predicted full scale resistance was also small, and the average change is anyway compensated for by the correlation factor.

On this basis, we do not recommend a change of the correlation line at this stage.

Our study of modification of the correlation line focused on the slope at model scale Reynolds numbers. We did not address the level of C_F at full scale Reynolds numbers.

6. PREDICTING POWERING MARGINS

The committee was tasked with making the 7.5-02-03-01.5 Predicting Powering Margins consistent with the 7.5-04-01-01.2 Analysis of Speed/Power Trial Data. It was not entirely clear to the committee what was the inconsistency, and why the Predicting Powering Margins procedure was marked as an interim guideline only. The procedure focuses on the prediction of the sea margin, which is a margin to account for the average environmental condition the ship will encounter, as well as increase of roughness and fouling over time. The procedure refers to the 7.5-04-01-01.2 Analysis of Speed/Power Trial Data when it comes to calculation of added resistance, but it stopped short of giving a method for predicting the margin. Instead it just states that the margin is usually set to 20%. Thus, it seemed clear that what was missing was a method to actually predict the margin when the added resistance due to wind, waves and roughness/fouling is known. We have also made a general update of the procedure. In the following, the updates are discussed in order of appearance.

6.1 Procedure updates

Purpose: The purpose has been changed to say that the margin procedure presents recommendations, procedures and methodologies for estimating the power margin. The procedure gives examples of power margins and ways of estimating these margins that can be adopted at the owner's discretion.

Definition of powering margins- the following have been defined

- Calm Water Power Margin is the additional power above the tow tank prediction to ensure that a calm water speed requirement is met.
- Sea Margin is the same as the previously defined Powering Margin. The term Powering Margin is the general title of the procedure and is an all encompassing term.
- Engine Operation Margin. The definition and meaning has been kept the same.

Calm water powering margin, new section 4.1.1.0

- A powering prediction with the "correct" calm water correlation allowance, C_A, and with no calm water power margin, will predict 50% of ships to exceed the calm water speed, and 50% to fall short of the predicted speed. With the recommended calm water powering margin all U.S. Navy ships (Karafiath, 1997) met their calm water speed requirements.

Resistance Increase Due to Shallow Water

- Referenced ITTC procedure 7.5-04-01-1.2 and ISO standard 1506
- Added reference to Hoffman and Kozarski (2000) to provide a quick estimation methodology

Calculation of sea margin

A method to actually calculate the sea margin is introduced, see separate section below.

Propeller Fouling

Section 4.2 is updated with a documented (Jessup, 1998) U.S. Navy report

Additional references

The reference list is expanded from 5 to 14 references. Those references not already mentioned deal with discussions regarding margins and the importance of the anticipated ship service factors (trade route, ocean temperatures, time in port etc) and specific owner/operator's assessment with regard to the economic importance of maintaining speed and the type of financial analysis that should be undertaken to choose a margin.

6.2 Calculation of sea margin

A new chapter has been added that describes a particular method that can be applied to calculate the sea margin. The proposed method to calculate the increase of power due to waves and ship motions is based on the work of Faltinsen and Minsaas (1984), and follows the principles used in software for routing of ships. The method is based on the calculation of the powering margin as a weighted sum of power increase for individual combinations of wave height and wave period that is taken from scatter diagrams for the areas of operation. A similar method is used by Tsujimoto and Takekuma in their 2004 paper on the calculation of sea margin for a coastal chemical tanker. Except for the study by Tsujimoto and Takekuma, it seems that sea margin is still mainly taken to be a standard value, in the range of 15% to 35% on power, as discussed by Stasiak (2004). Stasiak (2004) also proposes a calculation procedure with the same principles as we have proposed in the updated procedure, except that he uses only the added resistance, not the reduction in propulsive efficiency. Thus, we find that our proposed method represents the "state-of-the-art" with respect to prediction of powering margins. However, there is one weakness in the prediction that is mentioned so that it might be addressed in later ITTC work:

- The procedure doesn't provide formulas for calculation of added resistance due to increased roughness and fouling in service. The reason for this is that the committee hasn't found any well-recognised formulas or methods for this purpose. The current rapid change in anti-fouling paint technology means that the need for an update on the knowledge in this field is even more important. The committee recommends that increase of resistance due to roughness be investigated further by the next ITTC. It should be noted that since the prediction of powering margins assumes constant speed, the effect of roughness and fouling is easy to add to the method, since it could be assumed independent of the wind and wave condition, given that a suitable formula exists.

7. RESISTANCE OF HIGH SPEED MARINE VEHICLES

7.1 Literature survey

A literature survey was carried out in order to check for new developments since the procedure was issued in 2002, and to get an overview of state of the art. An overview of current practice was provided by the questionnaire (see section 5.1 for details). The literature survey had a special emphasis on drag reduction methods, since that was suggested in the committee Terms of Reference to be included in the updated procedure.

It has been found that most papers discuss the resistance of high-speed catamarans. The report of 19th ITTC (1990) mentioned that the number of catamarans built was growing. This trend has been clearly observed in the recent years. Many papers are also on fast mono-hulls.

There are only a small number of papers on planing hulls and other types of hulls. The literature review shows that there is no significant progress in aspects of the resistance test of HSMV such as air resistance, appendage drag, turbulence stimulation, wetted surface area estimation, and form factor, etc. Details on the review of these aspects can be found in Qiu (2007).

With respect to drag reduction methods, micro-bubble systems have been used in high-speed vessels for drag deduction. Latorre et al. (2002) studied a micro-bubble drag reduction system for a 40-60 knot high-speed catamaran. The model was tested at NASA/Langley seawater towing tank with free trim, yaw and roll. The model sinkage and trim were measured. The wetted surface area was determined by photographs. The micro-bubble system operation seems not to change the model sinkage or trim, the model air cavity pressure and the wetted surface.

Although the exact mechanism for micro-bubble drag reduction has not been fully understood, it has been identified that bubble-turbulence interaction, bubble deformation, splitting and coalescence, and density and viscosity modification are among the many contributing factors that influence the result of drag reduction. Lately, Shen et al. (2005a) and Shen et al. (2005b) investigated the influence of bubble size on micro-bubble drag reduction. In their work, the compressed nitrogen was injected from a cross-stream slot into the wall turbulent layer of a high-speed water tunnel. The skin-friction drag measurements with and without gas injection showed that the drag reduction was independent of the bubble size and aqueous conditions. But it was strongly correlated to the injection rate and the pressure inside the channel. They suggested that the density modification is the primary mechanism for micro-bubble drag reduction.

To improve the drag reduction, Deutsch el al. (2005) investigated the drag reduction on a flat plate by combining micro-bubble and polymer solution injection in the Garfield Thomas Water Tunnel at the ARL/Penn State. Gas was injected upstream of the polymer for all of the combined injection cases considered. They found that the combined injection produced higher levels of drag reduction than expected based on the independent injection of micro-bubbles or polymer alone for a wide range of conditions.

To develop a method for transferring the model micro-bubble drag reduction performance to the full-scale performance, Latorre et al. (2003) later on presented a dimensional analysis and a detailed example for estimating the required micro-bubble gas flow for model and the full-scale ship along with the scale-up of the gas flow relation.

In addition to drag reduction using micro-bubbles, large air cavities or air films have been used for HSMV resistance reduction. Jang et al. (2005) investigated the resistance reduction of a small high-speed boat by covering the hull bottom surface with a large air cavity. The test results showed that a large air cavity formed beneath the bottom by an artificial air supply could be effective for drag reduction. The areas of air cavity and the required air flow rates affect the resistance reduction. In addition, they also found transversely grooved hull bottom surface could be useful to the drag reduction at a required air quantity. Three geosim models of a planning hull were also tested to investigate the effect of air lubrication on resistance reduction and scale effects. It was confirmed that the scale effects are not dominant at Fr=0.35 to 0.65. Through a trial of a small power boat in a lake, they found the maximum speed increase by the artificial air supply was bout 17%.

7.2 Accounting for drag reduction methods in the procedure for resistance tests with HSMV

Drag reduction methods might be divided in the following three categories:

- Reducing friction by intrinsic friction reduction
- Reducing wetted surface area by introducing an air or vapour barrier between the hull and the water.
- Conventional design optimisation methods

The last mentioned method is considered already covered by the procedure.

Drag reduction by reducing wetted surface area is also covered in the procedure, as long as we consider air cushions, hydrofoils, or stepped planing hulls. Also the skirt-less, shallow type air cushions seen in some recent designs can be addressed using the procedure as it currently is.

The problem arises when we consider what can be called intrinsic friction reduction methods, such as micro-bubble injection, special surface treatments (like “shark skin” etc.), or polymer injection. The literature survey reveals that there is very little literature regarding such drag reduction methods on HSMV, especially on experimental methods and extrapolation, and no literature on the effect of waves on the efficiency of the mentioned resistance reduction methods. Thus, it was decided that the committee is not able to address such drag reduction methods in the procedure. It could be mentioned that if one is able to predict the C_F in both model and full scale using such intrinsic friction reduction mechanisms, it should also be possible to use the current procedure for testing and extrapolation, using this modified C_F curve. The problem, which we couldn’t find treated in the literature, is to know the modification of C_F, especially in full scale.

7.3 Including the effect of added resistance in waves in the procedure for resistance test with HSMV

As part of our task related to the procedure for resistance tests of HSMV, the committee has made a new section for the procedure describing ways of doing measurements of added resistance in waves. Added resistance in waves is primarily of interest for estimating speed loss and added power, and that has some impact on the way the measurement and analysis is done.

Firstly, the towing method is discussed. Three different methods are described; the constant speed method, the partly free to surge method, and completely free to surge. To use the results in relation to a added power computation, the best approach is to keep the average speed constant, but let the model surge, typically by connecting the model to the carriage via a spring system. If the speed loss is wanted, the ideal approach is to apply a controlled towing force which mimics the thrust vs. speed characteristics of the propulsion system, and then adjust the speed of the carriage to follow the model.

By testing in regular waves of different length, one might calculate the full scale added power or speed loss using for instance the method outlined in ITTC Recommended Procedure 7.5-02-03-01.5. By testing in irregular waves, the added resistance in that particular sea state is found directly. Added power is then found by use of a propulsive efficiency. For small and moderate sea states, the propulsive efficiency might be taken as the value found in calm water, adjusted for propeller thrust loading effects. For higher sea states, propulsive efficiency had better be determined by self-propulsion tests in waves.

The scaling of the added resistance is discussed in the procedure. It is noted that although purely Froude scaling the added resistance is the common approach, the waves will lead to a change in frictional resistance due to a change of wetted surface area, and possibly due to an increase in C_F due to the boundary layer being disrupted by the wave motions. The problem of accounting for the increase in wetted surface is actually to measure the running wetted surface in waves. If an estimate of the increase of wetted surface can be obtained, this effect can be included in the scaling by means of adjusting the wetted surface, as explained in the procedure.

It should be noted that Froude scaling the added resistance will over-predict the full scale added resistance, so that neglecting the wetted surface increase can be considered a conservative approach.

7.4 Summary and discussion of procedure updates

The update of the ITTC recommended procedure 7.5-02-05-01 High Speed Marine Vehicle (HSMV) Resistance Test has been limited. The main change is adding a section on how to perform tests of added resistance in waves (see detailed discussion above). Other changes are:

- Using a nominal wetted surface for non-dimensionalisation of resistance coef ficients, instead of using the running wetted surface, as before. This means that the frictional resistance coefficient C_F has got a new term to account for running wetted surface: $C_F\, S_M / S_{0M}$, where S_{0M} is the nominal wetted surface and S_M is the running wetted surface. Instead of using the nominal wetted surface, one could use for instance B^2, where B is beam.
- A slightly more detailed treatment of the question of use of form factor for resistance extrapolation is given.

In addition, there have been several minor changes of formulations and words.

The use of form factor on HSMV was discussed in the committee. For many types of HSMV it is totally inappropriate to determine the form factor from model testing at low speeds. The difficulties in determining the form factor is probably the main reason not to use a form factor in the extrapolation. There seems to be no significant contributions in this field since the procedure was originally written, so it is not recommend to introduce a form factor for HSMV in the procedure. There is an exception for SWATH-ships, where separate form factors might be used for pontoon and struts. The exception is not unreasonable, since a SWATH is very different from the typical high speed vessels that are the main focus in the procedure.

It was discussed to introduce a roughness allowance also for HSMV, as this effect is undoubtedly present in the physical flow. However, the Townsin formula adopted for conventional ships is not suitable for the relatively short HSMV, as it uses k_s/L as parameter, so that it will give unrealistically high roughness allowances for small ships, even if we recommend a lower standard roughness (for instance k_s=75μm). A more suitable and still widely accepted formula was not available, so it was temporarily decided not to introduce a ΔC_F-term. This is something that should be looked into by later ITTCs.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The use of a “propulsion test only” type powering prediction method was not included in the recommended procedure for powering performance prediction, since there is not sufficient evidence to prove that such a method is significantly better than the existing procedure, based on the use of separate resistance, propulsion, and propeller open water tests. The use of uncertainty analysis as basis for choice of either “propulsion test only” or the conventional method was not recommended by the Specialist Committee on Uncertainty Analysis.

A possible scale effect on the form factor was investigated by the committee through analysis of several additional geosim model test series, based on a paper by Garcia-Gomez (2000). It was found that when using the ITTC’57 correlation line to determine the form factors, there seems to be a scale effect, and the results are well in line with the findings of Garcia-Gomez. It was also found that when using the Grigson friction line, the scale effect changed radically – towards a smaller scale effect. However, the full scale form factor predicted using the scale effect formula based on ITTC'57 agreed much better with the form factor that could be derived from the "Lucy Ashton" full scale towing tests than the full scale form factor predicted using the Grigson line.

It was found that the scale effect of form factor depends strongly on the selected friction line.

The Grigson friction line as well as other potential friction line formulations was considered as alternatives to the ITTC'57 correlation line for use with the updated powering performance prediction procedure. Although it was found that the form factor scale effect could be significantly reduced by changing the friction line, it was also found that the scatter in the predicted ship resistance coefficient was not reduced. The effect of changing the friction line was also found to have small influence on the average level of the predicted ship resistance. The effect on resistance was small compared to the typical scatter in the correlation factor. It was concluded that there is not enough evidence to justify a change of friction line.

The committee recommends changing the formulation for ΔC_F in the ITTC'78 method from the existing formulation, which includes a correlation allowance, to a formulation previously recommended by Townsin, which is only a roughness correction. A formula to add a correlation allowance that together with the new formula for ΔC_F will give predictions similar to the old formula for ΔC_F is given. It is noted that the roughness allowance is easily more important for the prediction than the choice of friction (or correlation) line. The committee recommends that a study of roughness allowance for both HSMV and conventional ships is to be included in the tasks of the next ITTC, especially in light of the recent quick developments in new paint systems.

The updated powering performance prediction procedure has had two alternative methods for appendage scaling added. The methods that have been included in the procedure reflect current practice, and require some empirical factors that aren't well known at the current time. The committee recommends to further study the scaling of appendage resistance, and that this study be coordinated with the problem of pod drag scaling.

The database of 120 ships has been further evaluated for use in model-full scale correlation studies. It was found that the database doesn't contain enough high quality complete datasets to enable a reasonable correlation study. The committee recommends to collect more high quality complete datasets in order to enable model-full scale correlation studies to be done by future committees.

Currently the HSMV Resistance procedure 7.5-02-05-01 applies a form factor k=0 due to the difficulty of determining the value of the form factor from low speed model tests. The committee recommends a further study of form factors for HSMV. A way forward in this question could be to use CFD methods to study the form factors of HSMV.

8.2 Recommendations to the conference

Adopt the updated procedure No. 7.5-02-03-01.4 Propulsion, Performance, 1978 ITTC Performance Prediction Method

Adopt the updated procedure No. 7.5-02-03-01.5 Propulsion, Performance, Predicting Powering Margins

Adopt the updated procedure No. 7.5-02-05-01 High Speed Marine Vehicles, Resistance Tests

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APPENDIX A: DATA SHEETS FOR DATABASE OF MODEL AND FULL SCALE TRIALS

Below, the data sheets used for collection of model and full scale trials data are shown. The type of input data is selected to match the ITTC recommended procedure 7.5-04-01-01.2 and the ISO 15016 standard for correction of full scale trials as closely as possible.

Model number:
Model scale
Length Lpp [m]
Breath B [m]
Draught FP T_{FP} [m]
Draught AP T_{AP} [m]
Length in waterline L_{WL} [m]
Breadth in waterline B_{WL} [m]
Displacement [m^3]
Wetted surface S [m^2]
Midship section coef C_M
Wind area A_X [m^2]
Block coefficient C_B
Type of turbulence stim.
Tested with rudder? (Yes/No)
Number of rudders
Rudder area [m^2]
Rudder aspect ratio [-]
Number of propulsors:
Propeller diameter Dp [m]
Type of prop. system:

Towing tank draught [m]
Towing tank beam [m]

Please enter all data in model scale, metric units

Please enter comments and further descriptions of the tests here:

In case of pod or azimuth, please fill out:

Wet surf.		For each unit
Flow length		For each unit

Propeller load variation tests:
If load variation tests have been performed, then please include the load variation runs in the table below.
If load variation tests with continous variation of propeller RPM has been conducted, the time series of the same measurement variables as listed below is needed. Please include them as separate files on ASCII or Excel format.

Please list appendages present during resistance test	Wet surf. [m^2]	Flow length [m]

Resistance test
Form factor 1+k:
Water temp:

V_m [m/s]	R_{Tm} [N]

Propulsion test
Note: It is the total thrust that shall be given!
Water temp:

		Propeller 1			Propeller 2		
V_m [m/s]	Tow f. F_D [N]	Tot. thr. T [N]	Torque Q [Nm]	Revs [Hz]	Tot. thr. T [N]	Torque Q [Nm]	Revs [Hz]

Figure A1 Resistance and propulsion test data for model

Open water tests for propellers applied in propulsion test (please add to the table if more than two tests were performed):

Propeller diameter (model):		mm					mm			
Propeller pitch ratio P/D:										
Prop. boss/diameter ratio										
Chord length at 0.7 d/D										
Max thickness at 0.7 d/D										
	Open water test					Open water test				
	Propeller pitch P/D:					Propeller pitch P/D:				
	Water temp:					Water temp:				
	V_m [m/s]	Tot. thr. T [N]	Prop.thr Tp [N]	Torque Q [Nm]	Revs [Hz]	V_m [m/s]	Tot. thr. T [N]	Prop.thr Tp [N]	Torque Q [Nm]	Revs [Hz]

Open water tests for propellers as on the full scale ship (please add to the table if more than two tests were performed):

Propeller diameter (model):		mm					mm			
Propeller pitch ratio P/D:										
Prop. boss/diameter ratio										
Chord length at 0.7 d/D										
Max thickness at 0.7 d/D										
	Open water test					Open water test				
	Propeller pitch P/D:					Propeller pitch P/D:				
	Water temp:					Water temp:				
	V_m [m/s]	Tot. thr. T [N]	Prop.thr Tp [N]	Torque Q [Nm]	Revs [Hz]	V_m [m/s]	Tot. thr. T [N]	Prop.thr Tp [N]	Torque Q [Nm]	Revs [Hz]

Figure A2 Propeller open water data for model propeller, and for the propeller on the full scale ship

Ship Data:
Ship name
Yard name
Yard build #
Length Lpp [m]
Breath B [m]
Rudder area A_R [m^2]
Rudder span b_R [m]
Propeller diameter D [m]
Propeller (design) pitch P [m]
Number of propellers
Transmission (mechanical) efficiency η_T
Relative rotative efficiency η_R

Condition dependant ship data:
Draught FP T_{FP} [m]
Draught AP T_{AP} [m]
Displacement [m^3]
Block coefficient C_B
Midship section coef C_M
Wind (frontal) area * A_{XV} [m^2]
Time since last hull and propeller cleaning
Estimated hull roughness μ [my]
Estimated propeller roughness μ_p[my]

Trial site data:
Area of trial
Water depth h [m]
Water temperature T_W [deg C]
Water density ρ [kg/m^3]
Air temperature [deg C]
Air density ρ [kg/m^3]

Directions:
All directions are supposed to be entered in degrees (for simplicity. The ISO uses radians).
Wind direction is supposed to be entered as relative direction, since that is usually what comes out of the ship instruments. Zero wind angle means head wind. Small positive values means the wind is coming from starboard direction.
Ship heading is supposed to be entered in absolute terms (relative to north, which is zero).
Wave heading is also supposed to be entered in absolute terms, since they might be a result of wave buoy or hindcasting.

Measured and observed data:

Run #									
Time of commencement									
Length of run [sec]									
Course direction [deg]									
Speed over ground V_G [m/s]									
Propeller freq. of revs. [Hz]									
Propeller shaft torque [Nm]									
Propeller shaft power [kW]	0	0	0	0	0	0	0	0	0
Propeller pitch									
Relative wind velocity [m/s]									
Relative wind direction [deg]									
Direction coefficient of wind resistance, K									
Significant wave height [m]									
Wave direction (zero is head seas) [deg]									
Mean wave period [sec]									
Significant wave height (swell) [m]									
Wave direction (swell) [deg]									
Mean wave period (swell) [sec]									
Ship drift angle [deg]									
Mean rudder angle [deg]									
Average rudder amplitude [deg]									

The average rudder amplitude is especially of interest in cases where the ship is controlled by auto-pilot.

Figure A3 Data sheet for entering data for the full scale trials.