

# The Specialist Committee on Procedures for Resistance, Propulsion and Propeller Open Water Tests

## Final Report and Recommendations to the 23rd ITTC

### 1. GENERAL

Gothenburg, Sweden, May 2001 (5)  
Vienna, Austria, November 2001 (4).

#### 1.1. Membership and Meetings

The committee appointed by the 22nd ITTC consisted of the following members:

- Mr. William G. Day (Chairman), Naval Surface Warfare Center, USA
- Dr. Anthony F. Molland (Secretary), University of Southampton, UK
- Dipl.-Ing. Richard Anzbock, Vienna Model Basin, Austria
- Mr. Lars T. Gustafsson, SSPA Sweden AB, Sweden
- Dr. Mustafa Insel, Istanbul Technical University, Turkey
- Mr. Mo-Qin He, China Ship Scientific Research Center, China
- Dr. Yukihiko Okamoto, NKK Corporation, Japan
- Dr. Sverre Steen, Marintek, Norway.

Mr. Mo-Qin He resigned from the Committee in May 2001 and was replaced by Mr. Han Ji, also of the China Ship Scientific Research Center.

Meetings of the Committee were held as follows:

Washington, USA, March 2000 (8)  
Shanghai, China, November 2000 (8)

The numbers in parenthesis indicate the number of members present noting that, for the Vienna meeting, three members had been unable to attend as a result of the tragic events in New York and Washington on the 11th September, 2001.

The committee has liaised with the Resistance and Propulsion Committees on areas of mutual interest.

#### 1.2. Recommendations of the 22nd ITTC

The recommendations for the work of the committee made by the 22nd ITTC were as follows:

Update the following procedures (including validation and uncertainty analysis) for conventional ships and high-speed ships such as planing and semi-planing monohull and multi-hull vessels:

- Ship Models  
ITTC Procedure 4.9-02-01-01  
Revision 00
- Resistance Test  
ITTC Procedure 4.9-03-02-01  
Revision 00
- Propulsion Test

- ITTC Procedure 4.9-03-03-01.1  
Revision 00
- Open Water Test  
ITTC Procedure 4.9-03-03-02.1  
Revision 00
- Resistance Test for HSMVs  
ITTC Procedure 4.9-03-03-05.1  
Revision 00

## 2. INTRODUCTION

The tasks of the Committee entailed updating the ITTC recommended standard tank test procedures, together with example applications of uncertainty analysis, as described in Section 1.

It should be noted that the Committee was concerned principally with recommended procedures for model testing and the analysis of the model test data and not with the extrapolation of model results to full scale. Exceptions to this are the need to estimate the model-ship skin friction for estimates of propulsion test loadings, and for the extrapolation of HSMV data, which need to be treated separately.

The approach adopted by the Committee was firstly to update and develop the existing versions of the test procedures and to establish drafts of the proposed recommended procedures. These draft procedures were then sent to selected test tanks representing a cross-section of the tank testing community, in order to invite comments and feedback on the proposals. The Committee was pleased to receive comments, suggestions and other relevant information from twenty-one test tanks and research establishments. These comments varied widely in subject matter, length and detail; where possible and appropriate, the comments and suggestions have been incorporated in the updated versions of the test procedures. There was, however, a diversity of opinion within the tank community over some matters and it was not always been possible to meet the suggestions and requirements of all the test tanks. These matters, together with appropriate discussion of decisions taken by the Committee over the detailed content of the various test procedures, are included in Section 3.

The final recommended procedures and examples of uncertainty analysis are included in the ITTC Quality Manual.

## 3. DEVELOPMENT OF THE TEST PROCEDURES

### 3.1. General

It was evident that, where possible, a reasonable level of commonality and consistency should be maintained between the various test procedures. These would include broad issues such as the layout of the procedures and symbols together with commonality of more detailed aspects of the test procedures. Symbols used are, where possible, those in the ITTC Symbols and Terminology List (2001). These matters and the updating and development of the test procedures are discussed in this and the next Sections. Firstly, topics which are effectively common across many of the procedures are discussed.

Overall Layout of Procedures. Discussions were held early in the process with the Resistance Committee and others regarding layout. These led to the following Section headings being adopted in order to provide commonality between the various test procedures:

1. Purpose of Procedure
2. Parameters
  - 2.1. Data reduction equations
  - 2.2. Definitions of variables
3. Description of procedure
  - 3.1. Model and installation
  - 3.2. Measurement systems (Block Diagram)
  - 3.3. Instrumentation
  - 3.4. Calibrations
  - 3.5. Test Procedure and Data Acquisition
  - 3.6. Data reduction and analysis
  - 3.7. Documentation
4. Validation
  - 4.1. Uncertainty analysis
  - 4.2. Benchmark tests
5. References

Model Size. The Committee refrained from recommending a minimum model size. Instead, it recommends that the model should generally be as large as possible for the size of test tank with respect to wall effects, shallow water, model mass and the maximum speed of the towing carriage. In the case of HSMVs, the geosim model tests reported in the Proceedings of the 19th ITTC, 1990, are referenced as providing guidance on the likely practical limiting features of model size.

Model Speed. The original draft of the procedure concerning the measurement of speed received much discussion from various test tanks. The problem arose as to whether the measurement was relative to water, with a correction for model movement and how that may be determined, or relative to ground. The final proposed procedure attempts to clarify the alternatives.

Range and Interval of Runs. There was a mixed reaction to the original proposal of the Committee to define the number of speeds and interval, together with closer spacing at higher speeds. Consequently the Committee decided to recommend an adequate number of points to define the curve and, in particular, to use a suitable number of speeds to define humps and hollows and any other rapidly changing features of the curve.

Waiting Times Between Runs. Following the reactions and comments of a number of tanks, the Committee was reluctant to specify a minimum time (such as a minimum of 10 minutes) between runs. It therefore recommends that sufficient time be allowed to achieve similar conditions for each of the runs and to obtain consistency in results. The Committee also notes that the waiting time will depend on the type and size of the model, model speed, the size of the test facility and its wave absorption equipment such as beaches.

Measurement Systems. In order to support the description and discussion of the measure-

ment systems, instrumentation and calibrations in the various test procedures, the various items were grouped to provide an overall summary as shown in Fig.1. This summarises the measurements taken during the various tank tests being considered. It is broadly arranged under items, measurement devices/instrumentation and recorded measurements. The measurements relevant to each particular test are included and described in the recommended test procedures.

Accuracy of Measuring Equipment. It was apparent from the early drafts of the procedures that the suggested measurement accuracies were not clearly defined nor (as defined) achievable by many tanks. This has now been clarified in that the recommended accuracies refer to the measuring equipment or instrumentation, noting that this does not necessarily imply that the recorded test measurements will be within the same tolerance.

Skin Friction Line. Skin friction coefficients are required in order to estimate the residual resistance coefficient in the case of the resistance test and for the model-ship skin friction correction to estimate loadings in the case of the propulsion test. The Committee recommends the continued use of the ITTC 1957 model-ship correlation line for these purposes.

Some test tanks have however proposed the inclusion in the procedures of additional friction lines, such as those due to Schoenherr or Prandtl-Schlichting. The Committee is aware that the ITTC 1957 line has shortcomings but, in the spirit of establishing consistency of methodology in test procedures and due to the current lack of a generally acceptable alternative, recommends the use of only the ITTC 1957 model-ship correlation line. The Committee would also point out that this recommendation is not meant to discourage continuing investigations into other friction lines in the spirit of advancing and improving the knowledge, understanding and estimation of the physical components of ship resistance.

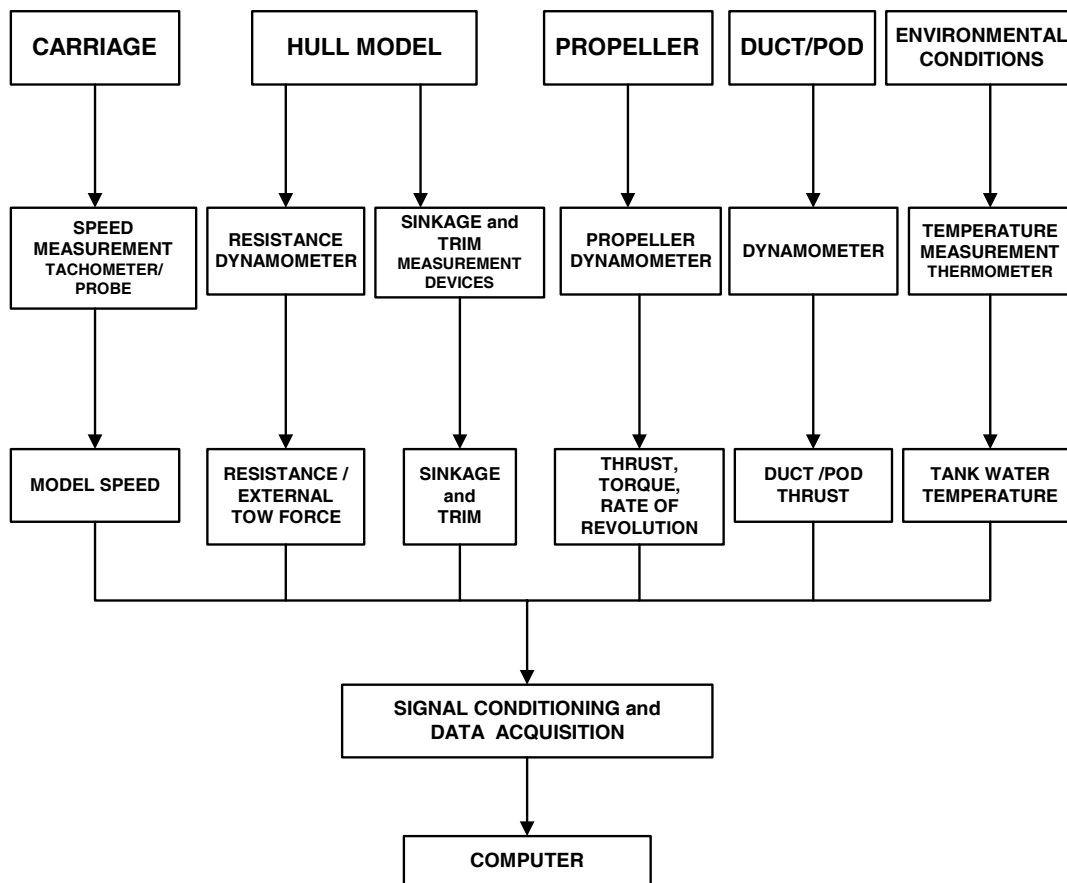


Figure 3.1 Measurement systems.

### 3.2. Model Manufacture

Station Spacing. A commonly used numbering system is described, but other methods are used and are acceptable.

Definition of Waterlines. This is moved from the Quality Manual, Procedure 7.5-01-01-02 Rev 00, to this procedure.

Manufacturing Tolerances. These remain at a maximum of 1mm on breadth and draught but a relative value of 0.05% length (with minimum 1mm) is used for length.

The tolerance on propeller diameter has been increased from 0.075 mm to 0.1 mm.

Turbulence Stimulation. This now includes reference to the application of turbulence stimulation on bulbous bows. Hama

strips are included as suitable turbulence stimulators for appendages.

Ballasting and Trimming. It is emphasised that the model should be loaded on displacement and not on draught.

### 3.3. Resistance Test

Model length. The procedure incorporates the use of Length on waterline ( $L_{WL}$ ), typically used in the calculation of Froude Number, and Length overall submerged ( $L_{OS}$ ), typically used in the calculation of Reynolds Number.

Test Conditions. The use of rudders, movable appendages and bilge keels in the naked and inclusive resistance tests has been clarified.

Installation. It is noted that the tow force should be in the line of the propeller shaft and at the LCB in order to avoid artificial trim effects, noting also that the tow force is measured in the horizontal plane.

Form Factors. The Committee notes that the assumptions in the recommended procedure for deriving form factors may not be valid for bulbous bows operating near the water surface, see for example Holtrop (2001). A comment to this effect has been added to the procedure.

Blockage Corrections. Those described in the existing resistance test procedure are retained and, at the suggestion of the test tanks in Japan, Tamura's method (Tamura, 1972) has been added.

The full recommended procedure for the Resistance Test is included in the ITTC Quality Manual as Procedure 7.5-02-02-01 Rev 01.

### 3.4. Propulsion Test

External Tow Force. The definition of the external tow force has been clarified, noting that the resistance force ( $F$ ) is the actual tow force (whether pre-calculated, imposed or measured) and  $F_D$  is defined as the frictional resistance scale effect correction.

Thrust. It is noted that thrust should be measured in the line of the propeller shaft(s).

Loading Methods. A brief description of the Mixed Loading Method has been added at the suggestion of the 22nd ITTC and some test tanks. This is seen as a commercially practical method, and is basically a combination of the load varying and constant loading methods.

Thrust and Torque Measurements. The Committee notes the response of some test tanks that alternative approaches to thrust and torque measurements may be preferred, espe-

cially for pods and azimuthing thrusters. This entails making the thrust and torque measurements inside the hub in such a manner that mechanical friction from seals and bearings is eliminated. The Committee felt, however, that it is not able at this stage to establish recommended procedures regarding the calibration and use of such devices.

The full recommended procedure for the Propulsion Test is included in the ITTC Quality Manual as Procedure 7.5-02-03-01.1 Rev 01.

### 3.5. Propeller Open Water Test

Ducted Propellers. The procedure for testing ducted propellers has been added.

Model. The fairings for a conventional pushing propeller are defined. It is noted that in the case of a pulling propeller the nose cone should be modelled accordingly.

The full recommended procedure for the Open Water test is included in the ITTC Quality Manual as Procedure 7.5-02-03-02.1 Rev 01.

### 3.6. Resistance Test for HSMVs

Much of the background to establishing this procedure and many of the considerations specific to HSMVs can be found in the Final Report and Recommendations of the Specialist Committee on Model Tests of HSMVs, Proceedings of 22nd ITTC, ITTC (1999h).

The full recommended procedure is included in the ITTC Quality Manual and the Committee would comment on the following particular topics.

Test Method. As part of the testing method for HSMVs, corrections may be required for artificial trim effects, such as when the model tow point does not coincide with



Extrapolation to Full Scale. Because of the special circumstances for many of the various types of HSMVs, summaries of the model to full scale extrapolation processes are included in the test procedure. These include recommended methods for semi-displacement and planing monohulls and multihulls, together with SWATHs, hydrofoils, SES and ACVs.

Form Factor and Model-Ship Correlation. It has been demonstrated, for example Couser et al. (1997), that fast craft with relatively fine hulls can exhibit significant form effects. It is however recognised that it can be difficult to obtain reliable form factors ( $1+k$ ) for high speed vessels due, for example, to the presence of a transom stern and to changes in wetted surface area with speed. For these reasons, the Committee recommends the continued use of  $(1+k) = 1.0$ . It does however also feel that further work should be carried out to improve the process. Alternative methods of deriving form factors for high speed craft are summarised and discussed in ITTC (1999h).

The Committee considered that it lacked adequate and suitable information to give guidance on model-ship correlation and that this should be left instead to the individual establishments to develop their own correlation methods. Such methods should be documented clearly in the test report.

Special Considerations. When testing HSMVs a number of items which may require special consideration can exist. Such special considerations are addressed in the recommended procedure, including the potential problems and possible practical solutions. The special considerations are: air drag, appendage effects, estimates of wetted area, spray resistance and blockage effects.

The full recommended procedure for the Resistance Test for HSMVs is included in the ITTC Quality Manual as Procedure 7.5-02-05-01 Rev 01.

## 4. UNCERTAINTY ANALYSIS

### 4.1. General

The approach used follows that proposed in the Quality Manual procedures 7.5-02-01-01 Rev 00, “Uncertainty Analysis in EFD, Uncertainty Assessment Methodology” and 7.5-02-01-02 Rev 00 “Uncertainty Analysis in EFD, Guidelines for Towing Tank Tests”.

The uncertainty example for the resistance test was established by the Resistance Committee of the 22nd ITTC, ITTC (1999g). This example remains broadly in its original form but has been revised with relatively small corrections, updates and additions. The changes have been discussed with the 23rd ITTC Resistance Committee.

Examples of uncertainty analysis for the propulsion test and the propeller open water test have been established and are described. The results of propulsion and open water tests carried out at SSPA, the Vienna Model Basin and the NKK Corporation tank were used in the development of these uncertainty examples.

Resources available to the Committee did not allow the update or development of an uncertainty example for the resistance tests of HSMVs. The Committee does however consider that, with many similarities to the resistance test methods, then for the interim and where necessary, reference may be made to the uncertainty example for the resistance test. Further possible sources of error arising in resistance tests on HSMVs are given in an early example of uncertainty analysis for HSMVs, reported in ITTC (1993).

### 4.2. Resistance Test: Uncertainty Analysis Example

A revision was made of the existing uncertainty example for the resistance test ITTC

(1999g). The example was extended to include error estimates for the residuary resistance coefficient and form factor. These are also outcomes of the resistance experiment, in addition to the total resistance coefficient, and are required inputs to the propulsion example.

The Uncertainty Analysis Example for Resistance Test is included in the ITTC Quality Manual as Procedure 7.5-02-02-02 Rev 01.

#### **4.3. Propulsion Test: Uncertainty Analysis Example**

In order to achieve commonality of presentation, the propulsion test uncertainty example was established following the layout of the resistance example. The propulsion example requires the results of both the resistance and propeller open water uncertainty analyses in order to obtain the overall uncertainty for the propulsive coefficients which are used to derive the ship power prediction. For the data reduction, only the ITTC 78 method was considered. The hull model was chosen to be the same as that used for the resistance example, and the propeller the same as the open water test uncertainty example, in order to achieve commonality and to reduce the size of the procedure.

The temperature effects on density and viscosity (fresh and salt water) were determined using the ITTC Quality Manual Recommended Procedure 7.5-02-01-03 Rev 00. Bias limits for the propulsion test measurements, e.g. propeller rate of revolution, thrust, torque and speed measurements, were established and bias limits for the propulsive factors were derived through data reduction equations.

Precision limits for multiple and single measurements were determined by repeat tests according to a recommended sequence of 5 sets of tests with 3 speed measurements in each set of tests.

By combining the bias limits with the precision limits for single and multiple tests, the uncertainties for the wake fraction, thrust deduction factor and relative rotative efficiency for single and multiple measurements could be determined.

It is noted that only the bias limit in propeller diameter is used to represent the error in propeller geometry. Many of the other error sources in propeller geometry are difficult to estimate, as discussed in Section 4.4, and are therefore not considered.

The Uncertainty Analysis Example for Propulsion Test is included in the Quality Manual as Procedure 7.5-02-03-01.2 Rev 00.

#### **4.4. Propeller Open Water Test: Uncertainty Analysis Example**

In order to achieve commonality of presentation, the open test uncertainty example was established following the layout of the resistance example.

The temperature effects on density were determined using the ITTC Quality Manual Recommended Procedure 7.5-02-01-03 Rev 00. Bias limits in open water test measurements, e.g. propeller rate of revolution, thrust and torque measurements, were established and bias limits for the thrust and torque coefficients were derived through data reduction equations.

Precision limits for multiple and single measurements were determined by repeat tests according to a recommended sequence of 5 sets of tests with 3 speed measurements in each set of tests.

By combining the bias limits with the precision limits for single and multiple tests, the uncertainties for the thrust and torque coefficients for single and multiple measurements could be determined.

The model is manufactured to be geometrically similar to the actual propeller geometry. Although efforts are made to produce an accurate propeller model, including the use of NC milling machines, errors in dimensions and offsets can occur leading, for example, to errors in diameter, chord length, pitch and blade section shape. The influence of these errors in dimensions and shape can strongly affect the flow characteristics around the propeller blades and hence the measured thrust and torque. These errors can only be estimated through systematic variations in propeller geometry and offsets. For example, the sensitivity of pitch setting can be estimated by performing multiple open water tests, where the pitch has been re-set between each set of tests. Errors arising from blade shape inaccuracies can only be estimated by performing multiple tests with different propeller models manufactured from the same surface description. It is thus seen that many of the errors in propeller geometry are difficult to estimate and are therefore not considered in this example. Therefore, in this example only the bias limit on propeller diameter is considered.

The Uncertainty Analysis Example for Open Water Test is included in the ITTC Quality Manual as Procedure 7.5-02-03-02.2 Rev 00.

## 5. GENERAL TECHNICAL CONCLUSIONS

The recommended procedures provide a framework for describing the various test methods, including the layout of contents, methodologies and reporting.

Whilst recommendations for good practice can be made for many aspects of the test procedures, several areas remain which do not lend themselves to the recommendation of a common standard across all test facilities. These currently include, for example, minimum model size and measurement of model speed.

The bias accuracies of instruments and measuring equipment quoted in the procedures are indicative. More work and discussion is required before levels acceptable to a wide range of test tanks will be achieved. A co-operative test programme on the bias and precision limits would contribute towards achieving better agreement between test tank results.

Novel methods of experimentation, such as alternative towing techniques for HSMVs, require further investigations and demonstration of satisfactory practical operation before they can be recommended as standard procedures.

In the case of HSMVs there remains a lack of reliable published information on spray resistance, form factors and model-ship correlation.

## 6. RECOMMENDATIONS TO THE CONFERENCE

Adopt the amended Procedure “Ship Models” 7.5-01-01-01 Rev 01.

(Note the Procedure “Spacing and Numbering of Displacement Stations and Waterlines” 7.5-01-01-02 Rev 00 has been included in the Procedure “Ship Models” 7.5-01-01-01 Rev 01).

Adopt the amended Procedure “Resistance Test” 7.5-02-02-01 Rev 01.

Adopt the amended Procedure “Propulsion Test” 7.5-02-03-01.1 Rev 01.

Adopt the amended Procedure “Open Water Test” 7.5-02-03-02.1 Rev 01.

Adopt the amended Procedure “Resistance Test for HSMVs” 7.5-02-05-01 Rev 01.

Adopt the amended Procedure “Uncertainty Analysis, Example for Resistance Test” 7.5-02-02-02 Rev 01.

Adopt the Procedure “Uncertainty Analysis, Example for Propulsion Test” 7.5-02-03-01.2 Rev 00.

Adopt the Procedure “Uncertainty Analysis, Example for Open Water Test” 7.5-02-03-02.2 Rev 00.

The above procedures are contained in the ITTC Quality Manual.

## 7. ACKNOWLEDGEMENTS

The committee wishes to acknowledge the cooperation and help of the many people and member organisations which supported its activity by commenting on the drafts of the proposed recommended procedures and for providing other relevant information.

## 8. REFERENCES

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# The Specialist Committee on Procedures for Resistance, Propulsion and POW Tests

Committee Chair: Mr. William G. Day (NSWC-CD)

Session Chair: Dr. Seung-Il Yang (KRISO)

## I. DISCUSSIONS

### I.1. Discussion on the Report of the 23rd ITTC Specialist Committee on Procedures for Resistance, Propulsion and POW Tests: Roughness and the ITTC correlation allowance – A new problem

By: Robert L. Townsin, United Kingdom

Although extrapolation problems may not be a central issue at ITTC 2002, it may be appropriate to draw attention to a recent anti-fouling coating development, which affects our understanding of hull roughness.

As Members may recall, at the 19th ITTC in Madrid, the (then) Powering Performance Committee put forward a standard for the model-to-ship correlation allowance. A part of that allowance takes account of the roughness of the hull outer bottom coating.

It is generally understood that the added drag of roughness on a surface, has to correlate, not only with roughness ‘height’ but also with ‘texture’. For example, over a wide range of typical hull paint surface roughness, the roughness function,  $\Delta u/u_\tau$  as determined from some 30 published tests in various laboratories, correlated reasonably with  $\log(hu/\nu)$  when  $h^2 = \alpha m_0 m_2$ , where  $m_n$  are spectral moments of the roughness profile, and  $\alpha$  is the bandwidth parameter (Townsin & Dey, 1990).

Whilst colleagues familiar with spectral representation of the seaway might have little difficulty with the above, it was a relief to find that those surfaces where the peak-to-trough roughness height,  $Rt(50)$ , was less than  $230 \mu\text{m}$ ,  $\Delta u/u_\tau$  correlated well enough when  $h = Rt(50)$ . This simplicity arose because the texture of anti-fouling paint roughness, at the time, correlated with its height. It will be noted that the values of  $Rt(50) < 230 \mu\text{m}$  cover the new ship and moderately rough range. The way was now open to correlate the roughness added resistance coefficient,  $\Delta C_F$ , with the average hull roughness,  $AHR$ , as measured by the BMT Hull Roughness Analyser, which records  $Rt(50)$ . The resulting hull roughness to added drag formulation is:

$$1000C_F = 44 [(AHR/L)^{1/3} - 10(Re)^{-1/3}] + 0.125$$

The recent development referred to earlier, is the production of low surface energy anti-fouling coatings, which are biocide free. In the industry, these are variously called non-stick or foul-release coatings. When in the dry, the coatings feel like rubber to the finger, whereas, underwater they are fish-slippy. Fouling species cannot readily attach and are washed off under fluid shear, although slime tends to remain.

Two problems arise when considering the roughness of these coatings and the consequent added drag. The first problem is that they have a different relationship between peak-to-valley height and texture when compared with conventional ablative anti-fouling, (which, nowadays, are copper-laden with booster biocides).

The curing of these new coatings results in relatively more spectral energy in the longer wavelengths, suggesting lower drag for the same roughness height when compared with conventional coatings. What little research has been undertaken into the roughness-to-drag relationship for these surfaces, tends to confirm this view (Candries et al., 2002). It follows that the formulation quoted above may not be adequate in respect to these coatings.

The second problem concerns the measurement of the roughness of low surface energy coatings. The current instrument, the Hull Roughness Analyser, has a stylus which judders when moved over these surfaces when dry, whereas, when the surface is wet, the drive wheel slips. In the laboratory, judicious wetting in the region of the stylus path, can produce a reliable result, but whole-ship surveys in dry dock or underwater, would not be reliable. It should not be difficult to modify the measuring instrument and this is in hand. Another valuable development would be to record the roughness digitally (Chuah et al., 1990).

Clearly, some extensive research is required to see if the peak-to-valley roughness height of these new surfaces can still be correlated with their added drag. Meanwhile, in the short term, comparisons can be made between the added drag of conventional ablative coatings and these new surfaces, for the same roughness height (Candries et al., 2002). Such comparisons should give an indication of the required (small) reduction in  $\Delta C_F$  in the above formula when foul-release coatings are being considered.

Finally, the persistence of slime on these new foul-release coatings, reminds us that we know little about the added drag of a slime film. We do know that slime develops shortly after undocking and that it can have a significant effect upon resistance; for example, the Lucy Ashton trials, 50 years ago, measured a 5% increase in frictional resistance due to slime alone, after only 40 days from out-docking, and similar augments due to slime have been measured since.

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### I.2. Discussion on the Report of the 23rd ITTC Socialist Committee on Procedures for Resistance, Propulsion and POW Tests: Use of measured or nominal $F_D$

By: Y. Kusaka, Mitui Akishima Laboratory, Japan

I would like to make comments on Propulsion test.

In the report, the thrust deduction factor is given as follows,

$$t = \frac{T + F_D - R_C}{T} \quad (1)$$

where:

$R_C$  is the resistance corrected for difference in temperature between resistance and propulsion tests,  $T$  is measured thrust,  $F_D$  is external tow force and defined as:

$$F_D = \frac{1}{2} \rho S V^2 [(1+k)(C_{FS} - C_{FM}) - \Delta C_f] \quad (2)$$

But at actual self-propulsion test, it is very difficult to propel the model at the perfect ship-point. From a practical view point, the thrust deduction factor may be discussed by using measured external tow force instead of calculated  $F_D$ .

In our practice of propulsion test analysis, the load factor defined below is employed in order to take the effect of difference between measured external tow force and calculated  $F_D$ .

$$1 + x = \frac{R_C - \Delta R}{R_C - F_D} \quad (3)$$

where  $\Delta R$  is measured external tow force.

The thrust deduction factor is analyzed on the basis of load factor.

If we introduce the measured external tow force instead of  $F_D$ , the expression of the uncertainty of thrust deduction fraction may have different form from that is presented in the report.

### **I.3. Discussion on the Report of the 23rd ITTC Socialist Committee on Procedures for Resistance, Propulsion and POW Tests: Reconsideration of the correlation of roughness and drag characteristics of surfaces coated with antifoulings**

By: M. Candries and M. Atlar, University of Newcastle-upon-Tyne, United Kingdom

This topic was last considered extensively by the Committee in 1990 (ITTC, 1990a, 1990b). The recommendations of the Powering Performance Committee were to include only a single roughness parameter to account for the effect of roughness on the correlation allowance for a moderately rough ship hull. Various experiments had shown that a single height parameter was sufficient since moderately rough ship hulls differ little in texture (Townsin, 1990; Townsin & Dey, 1990).

For the last 15 to 20 years, Tributyl-Tin Self-Polishing Co-Polymers (TAT-SPC), which can keep a ship free of fouling for 5 years by

means of a steady release of the TBT toxin, have dominated the antifouling market. However, due to environmental side-effects related with TBT, the International Maritime Organisation (IMO) has decided in October 2001 to prohibit the application of TBT-SPCs from 2003 and hence completely phase out their use by 2008. There are currently two alternatives on the market that can also offer 5 years of satisfactory antifouling performance. The first alternative, Tin-free SPC, operate by the same chemical principle but, instead of TBT, gradually leach copper-based toxins that are complemented by booster biocides. The second alternative, Foul(ing) Release coatings, act as a physical rather than a chemical defence against fouling. These coatings are silicone elastomers which have entirely different surface characteristics, notably their surface energy, so that firm attachment of fouling organisms is avoided and the release of the fouling organisms occurs at sufficiently high service speeds (> 15 knots).

This contribution summarises the findings of a research project carried out at the University of Newcastle-upon-Tyne to systematically compare the drag, boundary-layer and roughness characteristics of a Foul Release system and a Tin-free SPC system (Candries, 2001) and recommends the ITTC to reconsider the procedure adopted to correlate between roughness and drag.

Towing tank experiments have been carried out with two friction Planes of different size. Three series of measurements were carried out for each plane, uncoated, coated with Foul Release and coated with Tin-free SPC. It was found that the Foul Release system exhibits less drag than the Tin-free SPC system. The difference in frictional resistance varied between 2% and 23%, depending on the quality of application (Candries, 2001; Candries et al., 2001). Rotor experiments were also carried out to measure the difference in torque between coated and uncoated cylinders. The measurements indicated an average 3.6% difference in local frictional resistance coefficient between the Foul Release and Tin-free SPC (Candries et al., 2002a).

Table I.3.1 Overview of the drag characteristics of Foul Release and Tin-free SPC.

<b>Towing tank experiments</b>	$\Delta C_F$ (compared to reference, %)	$\Delta U^+$ (on average)	Average Roughness ( $\mu\text{m}$ )
<b>2.55 m long plate</b>	$2.0 \cdot 10^6 < Re < 4.2 \cdot 10^6$		
Sprayed Foul Release	3.9	0.20	44
Sprayed SPC	23.4	2.17	75
<b>6.3 m long plate</b>	$2.0 \cdot 10^7 < Re < 4.0 \cdot 10^7$		
Sprayed Foul Release	3.9	0.21	62
Sprayed SPC	23.4	0.62	39
<b>Rotor experiments</b>	$\Delta C_F$ (compared to reference, %)	$\Delta U^+$ (on average)	Average Roughness ( $\mu\text{m}$ )
<b>Cylinder</b>	$1.0 \cdot 10^6 < Re < 2.1 \cdot 10^6$		
Sprayed Foul Release	4.3	1.00	108
Rollered Foul Release	5.7	1.31	218
Sprayed SPC	8.0	1.80	54
<b>Water tunnel experiments</b>	$\Delta C_F$ (compared to reference, %)	$\Delta U^+$ (on average)	Average Roughness ( $\mu\text{m}$ )
<b>1m long vertical plate (Emerson Cavitation Tunnel)</b>	$8.5 \cdot 10^3 < Re_\delta < 3.4 \cdot 10^4$		
Sprayed Foul Release	10.9	1.25	51
Rollered Foul Release	13.1	1.54	60
Sprayed SPC	16	1.80	69
<b>1m long vertical plate (CEHIPAR Cavitation Tunnel)</b>	$1.6 \cdot 10^4 < Re_\delta < 4.6 \cdot 10^4$		
Sprayed Foul Release	14.6	1.68	50
Sprayed SPC	22.9	2.71	30

The friction of a surface in fluid flow is caused by the viscous effects and turbulence production in the boundary layer close to the surface. A study of the boundary-layer characteristics of the coatings was therefore carried out in two different water tunnels using Laser Doppler Velocimetry (LDV). The coatings were applied on 1 m long test sections that were fitted in a 2.1 m long flat plate set-up. An outer-layer wall similarity method and the Reynolds stress method were used to determine the friction velocity and both methods showed good agreement with each other. The experiments indicated that the friction velocity for the Foul Release surfaces is significantly lower than for Tin-free SPC surfaces. This implies that at the same streamwise Reynolds num-

ber the ratio of the inner layer to the outer layer is smaller for Foul Release surfaces. The inner layer is that part of the boundary layer where major turbulence production (and hence drag generation) occurs. The roughness functions of the different surfaces, determined from the measured velocity profiles as illustrated in Figure I.3.1, indicated that on average the Foul Release surfaces exhibit less drag than Tin-free SPC surfaces, which is in agreement with the findings from the towing tank and rotor experiments, as shown in Table I.3.1.

No significant differences between the different coatings were found in the turbulence intensities, although this may have been obscured by the experimental precision uncertainties.

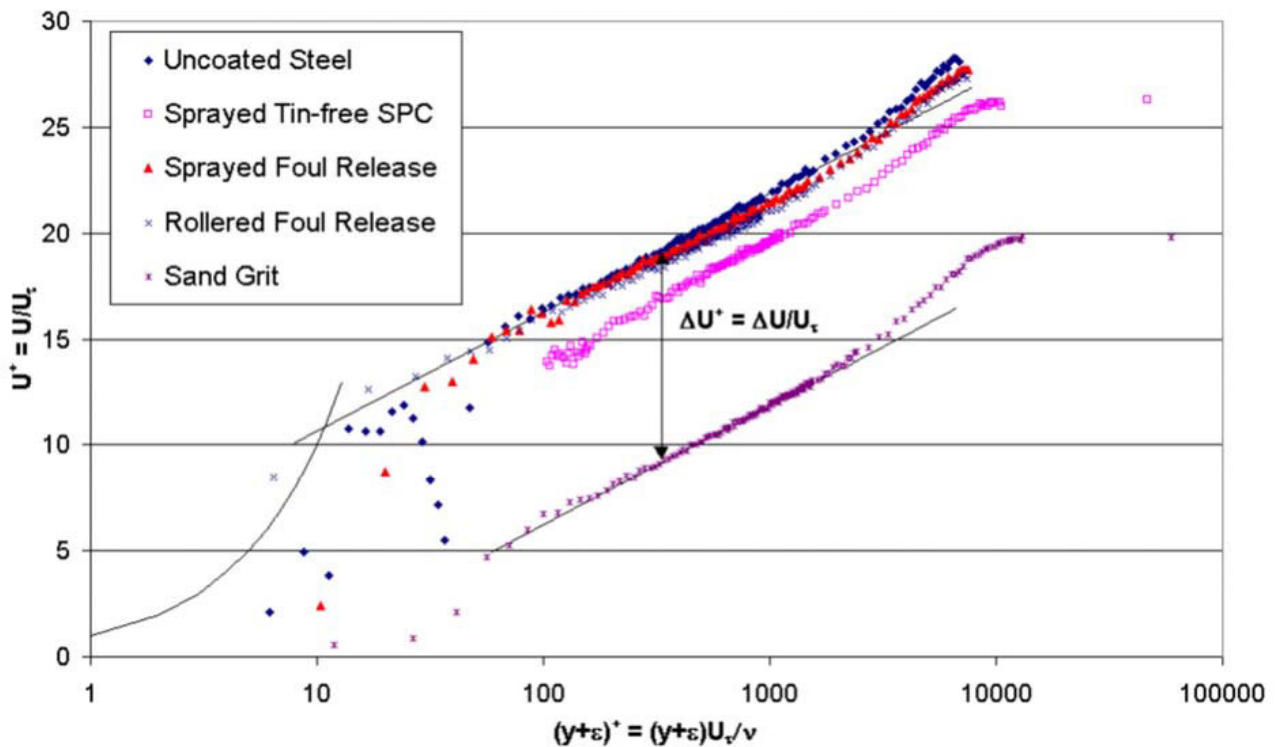


Figure I.3.1 Boundary-layer velocity profiles in inner co-ordinates (i.e. the distance from the surface,  $y+\epsilon$ , and the streamwise velocity component  $U$  have been scaled by the viscous length scale  $\nu/U_\tau$  and the friction velocity  $U_\tau$  respectively) at a free-stream velocity  $U_e = 5$  m/s and at a streamwise location  $x = 1.607$  m from the leading edge. A rolled and a sprayed Foul Release surface were tested to investigate the effect of application method. A surface covered with sand grit was tested in order to have a very rough comparison. The velocity loss or roughness function  $\Delta U^+$  indicates the difference in frictional resistance between a rough and a smooth surface. (Experimental precision uncertainty over the log-law region:  $U^+ : \pm 1.72\%$  for the uncoated steel surface,  $\pm 1.94\%$  for the rough surfaces;  $\Delta U^+ : \pm 14.74\%$ ).

Roughness measurements were carried out on the tested surfaces using a BMT Hull Roughness Analyser. This stylus instrument measured the extreme roughness amplitude over a 50 mm cut-off length at a sampling interval of 1.25 mm, Rt50. For a Foul Release surface, the average of this roughness parameter will not correlate with the measured drag. One of the towing tank experiments and the rotor experiments, for example, indicated that the average roughness was higher for the Foul Release surface than for the Tin-free SPC, whereas the measured drag was lower (cfr. Table I.3.1).

A detailed roughness analysis of sample plates, coated alongside the tested surfaces and representative of their surface characteristics, was carried out with an optical measurement system fitted with a 3 mW laser. The methodology which was developed to acquire the roughness parameters from six profiles of each sample, applies a moving average ‘boxcar method’ to filter the data. The upper bandwidth limit or cut-off length was set at 2.5 and 5 mm, the sampling interval at 50  $\mu\text{m}$ .

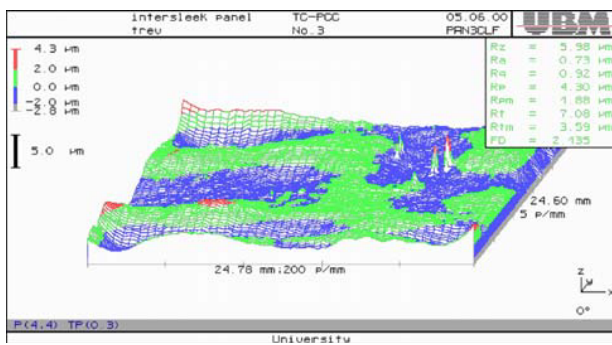


Figure I.3.2 Typical roughness measurement of a Foul Release surface.

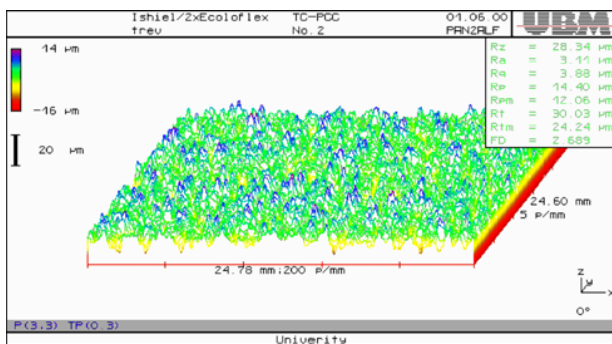


Figure I.3.3 Typical roughness measurement of a Tin-free SPC surface.

Figure I.3.2 and Figure I.3.3 show two typical measurements of a Foul Release and Tin-free SPC surface respectively. The detailed roughness analysis revealed that when the profiles are filtered, the amplitude parameters of the Foul Release surfaces are mostly but not always lower than those of the SPC surfaces. The main difference between the Foul Release and the Tin-free SPC systems lies in the characteristics. Whereas the Tin-free SPC surface displays a typical ‘closed texture’, the Foul Release surface exhibits a wavy, ‘open’ texture. This is particularly evident from parameters such as the mean absolute slope  $\Delta a$  and the Fractal Dimension  $FD$ . The spectra of the coated surfaces seem to follow a power law which is dependent on the Fractal Dimension and an implication of self-affine behaviour. A surface with an ‘open texture’ will have a lower Fractal Dimension than a surface with a closed texture (Candries, 2001). There is relatively little data available in literature on the influence of texture of irregular surfaces on drag, but Grigson (1982)

shows that open textures have a beneficial effect on drag.

It is thought that the rheology of the paint (which is significantly different for Foul Release systems than for Tin-free SPC systems as is clear from a parameter such as the viscosity) has a direct effect on its texture, whereas amplitudes depend significantly on the application quality. Correlation of the texture parameters with the amplitude parameters, however, shows that the two are inter-related so that bad application can be expected to have a knock-on effect on the texture parameters.

The roughness characteristics of both Tin-free and Foul Release surfaces correlate qualitatively with the drag differences given in Table I.3.1 when a texture parameter is included in the roughness characterisation. A semi-empirical approach was applied to correlate the roughness characteristics with the drag measurements of the surfaces tested here along with the surfaces included by Townsin & Dey (1990). The approach involved the selection of a characteristic roughness measure  $h$  which gives the best correlation assuming that the roughness function of the surfaces follows the Colebrook-White law. The characteristic measure which was found to give the best correlation for the present surfaces is  $h = Ra \cdot \Delta a / 2$  for an effective cut-off length, whereby  $Ra$  is the average amplitude (which strongly correlates with  $Rt$ ). The effective cut-off length increases with the degree of roughness and varied in the analysis between 2.5 mm for the Foul Release surfaces and 50 mm for a sand grit surface covered with paint (Candries, 2001).

The procedure presently adopted by the MC uses the formula suggested by Townsin et al. (1984) to predict the added resistance of new ships from roughness measurements:

$$10^3 \cdot \Delta C_F = 44[(h/L)^{1/3} - 10 \cdot Re^{-1/3}] + 0.125$$

where  $h$  is the Average Hull Roughness measured by the BMT Hull Roughness Ana-

lyser. Townsin & Dey (1990) showed that the roughness function  $\Delta U/U_\tau$  correlates well with Rt50 for new, moderately rough surfaces ( $Rt50 < 225 \mu\text{m}$ ) and that Rt50 was therefore adequate for quality control as well as for measuring the approximate power penalties due to roughness. Townsin and Dey argued that the reason why a single roughness parameter Rt50, could well predict the added resistance of a wide range of new ship surfaces, is that their texture is fairly similar, allowing for differences in method of application, paint rheology and the application environment. New ships have several coats of paint, the number and composition of which do not vary greatly.

The advent of Foul Release coatings, however, does not longer support his argument and in future a texture parameter will have to be included in the roughness characterisation if the added drag is to be predicted. This in turn requires the modification of the commercial version of the Hull Roughness Analyser. Roughness profiles are to be stored digitally. In order to calculate the spectral parameters and Fractal Dimension accurately by the acquisition of a sufficient number of data, a smaller sampling interval is also recommended.

In order to validate any prediction method, the acquisition of full-scale data is ultimately required and to the Authors' knowledge this has not yet been done for hulls coated with Foul Release coatings. Foul Release surfaces, however, quickly acquire a slime film, which unlike other fouling organisms does not release when the vessel is underway. The added drag of a slime film compared to a newly applied coating is likely to be significant, but limited (i.e. restricted to a few percent) (Candries et al., 2002b).

This research project is ongoing and water tunnel experiments are planned at the University of Newcastle-upon-Tyne to study the drag, boundary-layer and roughness characteristics of Foul Release surfaces which have been immersed in seawater for one year.

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**I.4. Discussion on the Report of the 23rd ITTC Socialist Committee on Procedures for Resistance, Propulsion and POW Tests: Human factor as Potential Uncertainty**

By: Ahmed Drradji-Aoua, NRC, IMD, Canada

Why include human factor "potential Uncertainties" into a bias Uncertainty?

The example of human factor that I am talking about is the "Installation of the model" in the tank. For instance, upon installation the heading may be  $\pm 1\%$ . Whilst another crew may install the heading within  $\pm 3\%$ . In this case the same model is being used and maybe in the same tank. However, the first crew introduced  $\pm 1\%$ , while the second crew introduced  $\pm 3\%$  of the heading angle.

I like your presentation, but I have dealt with Coleman and Steele (you used their equations) and I am not sure that human factor uncertainties should be included with bias. According to the theory, Bias error uncertainty is fixed for given system.

**I.5. Discussion on the Report of the 23rd ITTC Socialist Committee on Procedures for Resistance, Propulsion and POW Tests: Uncertainty Analysis of power prediction**

By: Jan Holtrop, MARIN, The Netherlands

My comments concern uncertainty analysis of power prediction:

1. We should not forget that we should aim at deriving the total uncertainty of the parameters our customers are interested in: the speed through the water and the rotation rate of the propeller.
2. We could also approach the problem of assessing bias errors by from the other end: the variation observed in model-to-ship correlation factors. By past Powering Performance Committees tentative figures were determined for model test accuracy extrapolation and the full-scale verification.

I like to convey my compliments to the Committee for the very nice report!

**I.6. Discussion on the Report of the 23rd ITTC Socialist Committee on Procedures for Resistance, Propulsion and POW Tests: Definition of residuary resistance**

By: L. Perez-Rojas, ETSIN, Universidad Politécnic de Mdrid, Spain

I would like to express my thanks to the Committee for the work done.

My question refers to terminology. You are referring to the residuary resistance including the form factor when in that case, to my knowledge, must be the wavemaking resistance. Have you checked that your definition of residuary resistance is consistent with ITTC terminology?

## II. COMMITTEE REPLIES

### II.1. Reply of the 23rd ITTC Specialist Committee on Procedures for Resistance, Propulsion and POW Tests to R.L. Townsin

The roughness allowance can have quite a large influence on the final prediction, but the knowledge of the roughness of the ships for which we make our prognoses is usually very limited. We should like to thank Dr. Townsin for bringing up this important topic. We agree that the roughness allowance of the new types of anti-foulings needs to be studied more closely. Within ITTC it will be up to the Powering Performance Prediction Specialist Committee of the next ITTC to look further into the implications of roughness and roughness allowance on the uncertainty of the final prediction of speed and RPM of ships.

### II.2. Reply of the 23rd ITTC Specialist Committee on Procedures for Resistance, Propulsion and POW Tests to Yuzo Kusaka

We would agree with Dr. Kusaka that it is difficult to propel the model at the nominal self-propulsion point. When performing a propulsion test at the balance point of nominal loading ( $F_D$ ), small deviations will occur.

The values used for the extrapolation of model test results are the thrust deduction ( $t$ ), wake ( $w_T$ ) and relative rotative efficiency ( $\eta_R$ ). If these values are assumed to be constant for small deviations in loading ( $F_D$ ), the measured thrust, torque and rate of revolutions can be corrected to the nominal  $F_D$ .

With the same assumption, there is no need for corrections to the thrust deduction ( $t$ ), wake ( $w_T$ ) and relative rotative efficiency ( $\eta_R$ ), and the corresponding uncertainties have been included in the ‘Uncertainty Analysis, Example for Propulsion Tests’, Procedure 7.5-02-03-01.2. If

propulsion Tests’, Procedure 7.5-02-03-01.2. If other assumptions are made, the uncertainty analysis has to be adapted according to the equipment used and procedures followed in each respective facility.

### II.3. Reply of the 23rd ITTC Specialist Committee on Procedures for Resistance, Propulsion and POW Tests to M. Candries and M. Atlar

The questions raised by the authors are very much the same as those raised by Dr. Townsin. Dr. Candries and Prof. Atlar present interesting results, and we would recommend that the Powering Performance Prediction Specialist Committee of the next ITTC should follow up the further outcomes of their ongoing research project.

### II.4. Reply of the 23rd ITTC Specialist Committee on Procedures for Resistance, Propulsion and POW Tests to Ahmed Derradji-Aouat

We would agree with Dr. Derradji-Aouat that the bias error is normally fixed for a given system, but we do not understand why he thinks we have included ‘human factors’ as bias limits. The ‘human factor’ referred to is the uncertainty associated with model alignment in the set up process in the towing tank. This error has been included as a precision error as we here are doing an end-to-end calibration with multiple set ups.

As described in ‘Uncertainty Analysis, Example for Resistance tests’, Procedure 7.5-02-02-02, the precision limits will be determined for  $C_T^{15deg}$  and for  $C_R$  by an end-to-end method where all the precision errors for speed, resistance and temperature/density/viscosity are included. The precision limits for a single run ( $S$ ) and for the mean value of multiple tests ( $M$ ) are determined. Regardless as to whether the precision limit is to be determined for single or multiple runs, the standard deviation must be determined from mul-



tiple tests in order to include random errors such as **model misalignment**, heel, trim etc.

### **II.5. Reply of the 23rd ITTC Specialist Committee on Procedures for Resistance, Propulsion and POW Tests to Jan Holtrop**

Mr. Holtrop makes a good point. The uncertainty of the final prediction is certainly what is of most interest to the typical client. However, the extrapolation and correlation procedures, and the uncertainty of these, were outside of the scope of our Committee. As we understand, these questions should be addressed by the Powering Performance Prediction Specialist Committee of the next ITTC. It should however be noted that the use of uncertainty analysis for the variables (and components of variables) themselves, rather than for the model-to-ship correlation factors, will give insight and knowledge about the magnitude of the uncertainty of the different variables. In this way we can constantly improve measuring accuracy and decrease the uncertainty in our predictions for full scale.

### **II.6. Reply of the 23rd ITTC Specialist Committee on Procedures for Resistance, Propulsion and POW Tests to Luis Perez-Rojas**

It is the view of the Committee that it is often common practice to name the resistance component remaining after viscous resistance has been subtracted from total resistance as the residual resistance. A more pedantic approach, if a form factor has been applied, is to describe the remaining component as wavemaking resistance  $C_W$ , as Prof. Perez-Rojas suggests. The ITTC Symbols and Terminology does not however define  $C_R$  or  $C_W$  in a way that answers the question by Prof. Peres-Rojas. The ITTC 1978 method, as presented in the ITTC Recommended Procedures, uses the term  $C_R$  even when a form factor is used. We would however suggest that the use of  $C_R$  and the term 'residual resistance' might be justified, since  $C_R$  is really a residual that we know includes various smaller components in addition to the wave resistance. The term wave resistance  $C_W$  can then be reserved for directly measured or calculated wave resistance.