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Resistance Test

1. PURPOSE OF PROCEDURE

The purpose of the procedure is to ensure consistency of methodology for towing tank tests and the acquisition of correct results for deep-water resistance, sinkage and trim.

The procedure addresses conventional displacement vessels only. Vessels with design speeds which correspond to Froude numbers greater than to 0.45, and/or vessels with speeds which are above $3.7\,\nabla^{1/6}$ (m/s), as well as dynamically supported vessels and vessels for which high trim angles are expected, are addressed by procedure 7.5-02-05-01.

The procedure addresses model scale only and does not consider extrapolation and full scale prediction.

2. PARAMETERS

2.1 Data Reduction Equations

Total Resistance Coefficient
$$C_{\mathrm{T}} = \frac{R_{\mathrm{T}}}{\frac{1}{2}\rho S V^2}$$

Residual Resistance Coefficient
$$C_{\mathrm{R}} = C_{\mathrm{TM}} - C_{\mathrm{FM}}(1+k)$$

Frictional Resistance Coefficient; ITTC 57 Model-Ship Correlation Line
$$C_{\mathrm{F}} = \frac{0.075}{(\log_{10} Re - 2)^2}$$

Froude Number
$$Fr = \frac{V}{\sqrt{gL}}$$

Depth Froude Number
$$Fr_h = \frac{V}{\sqrt{gh}}$$

Reynolds Number
$$Re = \frac{VL}{\nu}$$

Speed correction due to blockage
$$\frac{\Delta V}{V}$$

Blockage Parameter
$$m = \frac{A_{\mathrm{X}}}{A}$$

2.2 Definition of Variables

A_{X} Maximum sectional area of the model (for blockage correction) (m^2)

A Sectional area of the tank (m^2)

B Breadth (m)

C_{B} Block coefficient

g Gravity constant (m/s^2)

h Depth of water (m)

k Form factor

L Representative length [normally L_{WL} for Fr and L_{OS} for Re] (m)

L_{CB} Longitudinal centre of buoyancy

L_{OS} Length overall submerged (m)

L_{PP} Length between perpendiculars

L_{WL} Length on waterline (m)

R_{T} Total resistance (N)

S Wetted surface area (m^2)

V Speed (m/s)

∇ Moulded displacement volume of the model (m^3)

ρ Mass density of water (kg/m^3)

ν Kinematic viscosity (m^2/s)

Subscript $_M$ signifies model scale value

3. DESCRIPTION OF PROCEDURE

Resistance tests are conducted to provide data from which the resistance of the model hull at any desired speed may be determined. For this purpose, the model resistance and its speed through the water are simultaneously measured. The running attitude of the model - i.e. the sinkage fore and aft, or the running trim and sinkage - is usually also measured.

The resistance (or drag) is the horizontal component of the force opposing the steady forward motion of the model hull. The resistance is determined by measuring a towing force.

3.1 Model and Installation

3.1.1 Model

The model should be manufactured according to the ITTC Recommended Procedure 7.5-01-01-01, Ship Models with particular attention being paid to model manufacturing tolerances, surface finish, appendage manufacture, and the size and positioning of turbulence stimulation.

The model should generally be as large as possible for the size of the towing tank taking into consideration wall, blockage and finite depth effects (as discussed in section 3.6.3), as well as model mass and the maximum speed of the towing carriage.

3.1.2 Test condition

Models should be tested in one or both of the following conditions:

1. Model hull without any appendages (naked model). This test is intended to determine the resistance coefficients of the basic form. If any appendage is included as a part of the hull it should be clearly stated. Rudders should be present in the resistance test if they form a streamlined extension of a skeg, and might also be included in other cases.

2. Model hull with appendages. This test is intended to determine the increase in resistance coefficients due to the appendages. All fixed appendages, except those which are considered as propulsors, should be fitted to the model. Movable appendages or control surfaces should not be included in the standard inclusive resistance test. Bilge keels should not be fitted in the inclusive test if their resistance is expected to be small; their wetted area will however be included in the subsequent prediction procedure. A clear statement should be made of the appendages fitted for any specific test.

3.1.3 Installation

The model should be run at the correct calculated displacement. For model installation and trimming see ITTC Recommended Procedure 7.5-01-01-01, Ship Models.

The tow force should, where possible, be applied in the line of the propeller shaft and at the *LCB* in order to avoid artificial trim effects. Alternative approaches may be necessary for vessels with steeply-raked shafts or heavy running trim, and for those which have no defined shaft line.

The model should be attached to the measuring head of the resistance dynamometer by a connection which can transmit and measure only a horizontal tow force, even though raked

propeller shafts or heavy running trim would result in the line of action of the propeller thrust not being horizontal.

Guides may be fitted to prevent the model from yawing or swaying: these should not restrain the model in any other direction of movement, nor be able to impose any force or moment on the model which would cause it to roll or heel. The arrangement of any such guides that include sliding or rolling contacts should be such as to introduce the least possible friction forces. Guides may be used to restrain the model in heel in cases where transverse stability is low.

The model should be positioned such that it is in the centreline of the tank and parallel to the carriage rails. Transverse alignment errors at *FP* and *AP* should both be less than 0.05% L_{PP}.

If any instruments carried in the model are linked to the carriage by flexible cables, great care should be taken to ensure that the cables do not impose any force on the model: in practice the cables should therefore hang vertically from the carriage. Care should also be taken to balance any instruments that must have attachments to both the model and the carriage (e.g. mechanical trim recorders).

3.2 Measurement Systems

Fig. 1 shows a typical measurement system.

The following quantities are measured:

- Model speed
- Total resistance
- Sinkage fore and aft (or running trim and sinkage)

- Water temperature (for calculation of viscosity and density)

3.3 Instrumentation

The quoted bias accuracies are for indicative purposes only. Uncertainty analysis should be used to derive the actual requirements.

3.3.1 Resistance

The resistance dynamometer should measure the horizontal tow force to within 0.2% of the maximum capacity of the dynamometer or 0.05 N, whichever is the larger. This does not necessarily imply that the resistance itself is measured to within the same tolerance of its true value.

The range of the resistance dynamometer should be selected to be appropriate to the expected maximum resistance of the model.

3.3.2 Speed

Ideally the speed of the model through the water should be measured directly throughout the measuring run. Since this is in general impractical, one of the following two methods may be employed:

(i) the speed of the towing carriage relative to the ground should be measured. This may be measured using a trailing wheel with encoder or similar, direct from the carriage drive, using optical/proximity sensors with a counter/timer, or by another appropriate method.

(ii) the speed of the towing carriage relative to the water should be measured by a current meter far in front of the model. In this case

the current meter wake and waves should be minimised.

The speed of the model should be measured to within 0.1% of the maximum speed or to within 3 mm/sec, whichever is the larger.
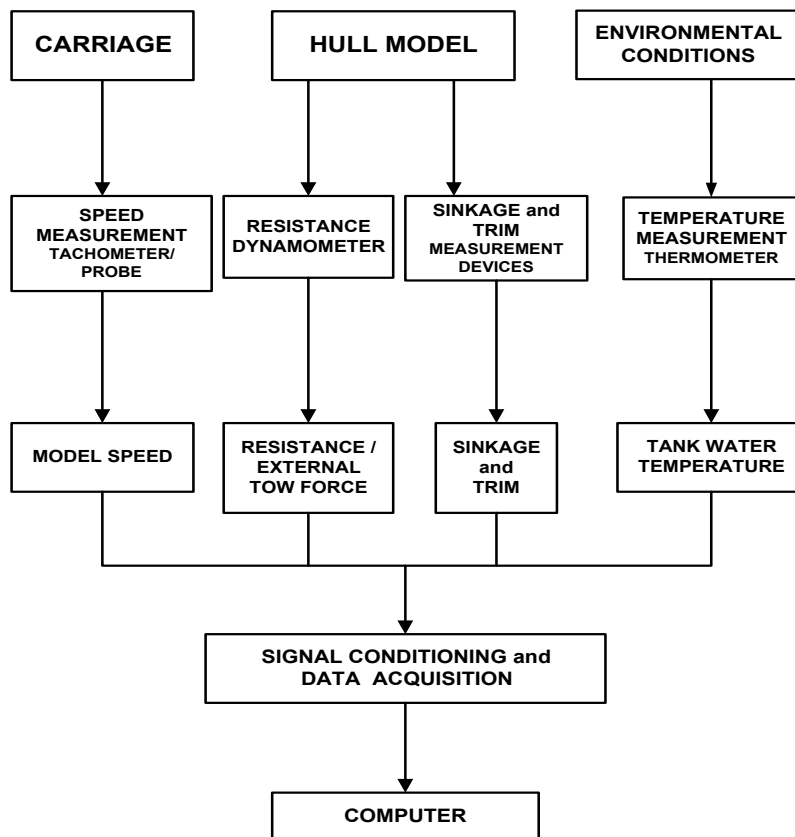

Figure1   Typical measurement system

3.3.3   Sinkage and Trim

Sinkage fore and aft may be measured with mechanical guides, potentiometers, encoders, LDVTs, optical tracking systems or with remote (laser or ultrasonic) distance meters. The running trim is calculated from the measured running sinkage fore and aft. The sinkage fore and aft should be measured to within 1.0 mm.

3.3.4   Temperature

The water temperature should be measured at a depth near half of the model draught using a thermometer.

3.4   Calibration

3.4.1   General remarks

All devices used for data acquisition should be calibrated regularly. For calibration, the measured quantities should be either substituted by calibrated weights and pulses or checked by other measuring devices which have already been calibrated. Calibration diagrams, where the measured quantities (output values) are plotted versus the calibration units (input units), may be useful to check the calibration itself as well as the linearity of the instruments. Calibration should generally be in accordance with ITTC Recommended Procedure 7.6-01-01.

The calibration of the resistance dynamometer and the sinkage and/or trim sensors should be checked immediately prior to the testing. The calibrations should preferably include as much of the measurement chain as possible (amplifier, filter, A/D converter). If the check indicates that the required accuracies cannot be met, the calibration should be renewed or the instrument replaced and the check repeated. Daily checking of a pulse counter for speed measurements is usually not required. Instead, the check on this device is covered by calibrations carried out at regular intervals.

Where the gravitational constant g is used in calculations, the value chosen should be appropriate to the location of the tank.

3.4.2   Resistance dynamometer

The calibration of the resistance dynamometer should be carried out by the use of calibrated weights as an input to the instrument.

3.4.3   Sinkage and trim transducers

The calibration of linear measuring devices should be performed with a calibrated ruler or other appropriately calibrated device such as a length bar, or Vernier height gauge.

3.4.4   Speed

The calibration of the carriage speed will depend mainly on how the carriage speed is measured. The carriage speed should be calibrated regularly and respective records should be stored.

Where possible the carriage speed measured with the primary speed measurement system should be checked with an alternative measurement system.

3.4.5   Thermometer

Thermometers should be calibrated according to common standards and/or following the advice of the manufacturer.

3.4.6   Signal conditioning and Data acquisition system

The various components of the signal conditioning and data acquisition system (e.g. amplifies, filters, A/D converters) should be checked and calibrated according to the manufacturers recommended schedule. Key features of the system, such as cut-off frequencies of filters employed, and resolution and sampling rate of A/D converters should be recorded.

3.5 Test Procedure and Data Acquisition

3.5.1 Method

Before each run begins zero readings of all instruments must be taken, over a period long enough to give a representative mean value.

The model is towed at speeds giving the same Froude numbers as for the full scale ship.

The model speed is selected and the model accelerated to that speed.

It is important to minimise "overshoot" of speed, since this will result in waves overtaking the model.

If the model has been held during initial acceleration, it is released as soon as the selected speed has been reached.

It is recommended that the data acquisition may either begin after a steady speed has been reached; or, alternatively, data acquisition may take place continuously from the time at which the zero readings are logged (in order to allow the entire speed profile to be determined).

The mean values are derived afterwards from a section of the time series during which the speed was steady. In some cases unsteady oscillations (related to unsteady wave resistance effects) may be observed in the measurements even when the model speed is constant. Where these oscillations have a significant magnitude, it is important to calculate the mean values of parameters of interest over an integer number of oscillation cycles; where possible, it is desirable to use at least five oscillations to find the mean. Note that the period of these oscillations in an unbounded fluid may be estimated as:

$$4\pi V / g$$

Maximum and minimum values together with mean and standard deviations should be stored for each run.

This process is repeated at other selected speeds covering the required range, avoiding continuous progression from one limit to the other. For example, runs at alternate speeds from the lowest speed to the highest followed by highest speed to the lowest filling in the gaps.

There should be sufficient waiting time between consecutive runs to achieve similar conditions for each of the runs and to obtain consistency in results. This waiting time will depend on the geometry of the test facility, the type and size of model and model speed. The waiting times should be recorded.

3.5.2 Range and Interval

The speed range should extend from at least 5% below the lowest speed at which reliable data is required to at least 5% above the highest speed required. This range should be covered by a suitable number of speeds. Low speeds may also be used for the derivation of form factors (see section 3.6.2). Care should be taken to ensure that there is sufficient number of speeds to define humps or hollows and other rapidly changing features of the curve.

3.5.3 Speed

The following aspects should be noted when measuring speed:

- Attention should be paid to residual currents in the towing tank near the surface, which are caused by previous tests. It is not

unusual to exclude the first run of the day if no active artificial circulating device is available. This has however not always shown to be necessary and can be tested with uncertainty analysis. For more information see Uncertainty Analysis, Example for Resistance test, provided in QM 7.5-02-02-02.

- It is essential that the speed of the model through the water should be constant throughout, and for a significant distance before, that part of the time series used for the calculation of the mean values of the parameters of interest.

- Steadiness of carriage speed is an essential element in achieving steady model speed, but is not necessarily sufficient since the rate of change of the initial acceleration and the moment and manner of release of the model may interact with the model-dynamometer system and cause it to oscillate.

- During the measuring run, the carriage speed should normally not vary by more than 0.1% of the mean speed or 3 mm/s, whichever is the larger. The cyclic characteristics of the carriage speed control system should be such as not to synchronise with the natural frequency of the model dynamometer system.

3.5.4 Measured Quantities

During each run the measured values of model speed and resistance (and when necessary sinkage and trim) should be recorded continuously.

The sampling rate for A/D converters should be chosen to give adequate definition of any oscillatory phenomena, and should avoid

frequencies (and harmonics) of noise sources such as electrical mains interference.

Water temperature should be measured at a depth near half of the model draught. If there is a non-homogeneous temperature in the tank it should be recorded. Temperature measurements should be recorded at the beginning and end of each test sequence or at least on a daily basis.

3.6 Data Reduction and Analysis

The speed, resistance, sinkage and trim and any other continuously recorded quantities of the test should be presented as mean values derived from an integration of the instantaneous measured values over the same measuring interval (chosen according to the guidelines in section 3.5.1 and 3.5.2), with the appropriately averaged zero measurements subtracted from the average values.

Total resistance and residuary resistance coefficients, together with Froude Number, are calculated for each speed using the data reduction equations given in Section 2.1.

3.6.1 Analysis of Model Scale Results

Resistance R_{TM} measured in the resistance tests is expressed in the non-dimensional form

$$C_{TM} = \frac{R_{TM}}{\frac{1}{2}\rho_M S_M V_M{}^2}$$

Model wetted surface area, to be used in the analysis, is calculated from the model body plan to the still waterline. The transom area is not included in the wetted surface area. The surface areas of the appendages are calculated separately and added to model surface area for appended resistance tests. The speed should, if

necessary, be corrected for blockage according to the equations given in Section 3.6.3. Values of water density and viscosity should be determined according to ITTC Recommended Procedure 7.5-02-01-03.

The residuary resistance of the ship is calculated from the model resistance tests assuming the form factor to be independent of scale and speed. The residuary resistance can therefore be calculated as:

$$C_R = C_{TM} - C_{FM}(1 + k)$$

where C_{FM} is derived from the ITTC – 1957 correlation line. If appendages are present and their resistance scaled separately the residual resistance can be calculated as:

$$C_R = C_{TM} - C_{AppM} - C_{FM}(1 + k)$$

C_{AppM} is the model appendage resistance coefficient and can be derived by calculation or from the difference in resistance by testing with and without appendages.

The form factor is determined from low speed tests as described in Section 3.6.2.

The C_R or C_T curve is the best basis for judging if a sufficient number of test points have been obtained in order to define humps and hollows. The resistance curve should be faired in order to facilitate reliable interpolation to obtain the resistance at the required speeds. The smoothing should be carried out with care in order not to remove humps and hollows. An acceptance criterion for the test might be derived based on the scatter in the C_R or C_T curve.

3.6.2   Form Factor

The recommended method for experimental evaluation of the form-factor is that proposed by Prohaska. If no separation is present, the total resistance can be written, to a first approximation, as

$$C_{TM}(Re, Fr) = (1 + k)C_{FM}(Re) + C_W(Fr)$$

If the wave-resistance component in a low speed region (say $0.1 < Fr < 0.2$) is assumed to be a function of Fr^4, the straight line plot of C_{TM}/C_{FM} versus Fr^4/C_{FM} will intersect the ordinate ($Fr = 0$) at $(1+k)$, enabling the form factor to be determined. In the case of a bulbous bow near the water surface these assumptions may not be valid and care should be taken in the interpretation of the results.

It should be noted that Prohaska's method should not be used for vessels with substantial transom sterns for which the transom runs wet at the speed range for the Prohaska test but runs dry at the design speed.

When using form factor methods for scaling the drag of appendages, the form factor increase due to fitting appendages should be determined from test results at higher speeds to avoid laminar flow.

$$\Delta k = d\left(C_{TM}(\text{appended}) - C_{TM}(\text{barehull})\right)/dC_{FM}$$

This procedure avoids the need for low speed testing to determine the form factor.

3.6.3   Blockage and Finite Depth Corrections

The dimensions of the towing tank should be reported with the test result documentation (see Section 3.7).

The dimensions should be large enough to avoid significant wall, blockage, and finite depth effects.

The importance of these effects depends upon a range of factors; key parameters include the blockage parameter, m, defined as the ratio of model cross section area, A_X, to tank cross section area, A, the Froude number, Fr, and the depth Froude Number Fr_h .

The following formulae are recommended for carrying out blockage corrections if they are necessary. For easy use and comparison the correctors are listed in their simplest form as given by the respective author, after neglecting second order terms or being simplified otherwise. Detailed information may be found in the original papers. The formulae are based on mean-flow theory:

1. Schuster

$$\frac{\Delta V}{V} = \frac{m}{1-m-Fr_h^2} + \left(1 - \frac{R_V}{R_T}\right)\frac{2}{3}Fr_h^{10}$$

where $m = A_X/A$, and R_V/R_T is the ratio of viscous to total resistance.

The second term is the finite depth influence on wave making resistance, converted to a speed correction where Fr_h^{10} is a good approximation of the hyperbolic function of the finite depth wave velocity within the range $0 < Fr_h < 0.7$.

2. Scott

$$\frac{\Delta V}{V} = K_1 \nabla A^{\frac{-3}{2}} + BL^2 K_2 A^{\frac{-3}{2}}$$

The first term is the empirically improved version of Scott's original formula with K_1 as a function of Re and the form-parameter

$C_B \nabla^{\frac{1}{3}}/L$ as shown in Fig. 2. The second term is a function of Fr and form from experiments deduced to extend the range of applicability up to $Fr = 0.38$. K_2 is given in analytical form

$$K_2 = 2.4(Fr - 0.22)^2 \quad \text{for } 0.22 < Fr < 0.38$$
$$K_2 = 0 \qquad \text{for } Fr < 0.22$$

The validity of the formula is confirmed for the range of model size 3.5 m $< L <$ 9 m, tanks of approximately 2:1 breadth to water depth ratio and speed range between 0.08 $< Fr <$ 0.4.

3. Tamura

$$\frac{\Delta V}{V} = 0.67.m.\left[\frac{L}{B}\right]^{\frac{3}{4}} \cdot \frac{1}{\left(1 - Fr_h^2\right)}$$
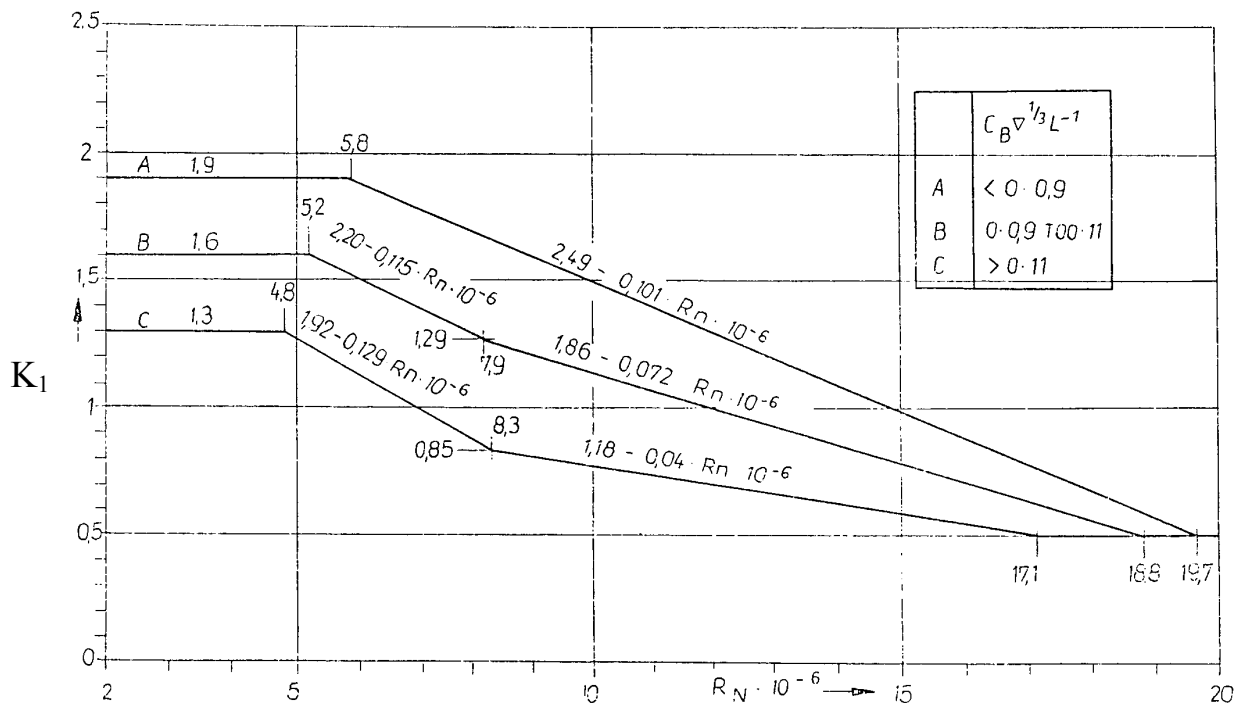
where $m = \dfrac{A_X}{A}$

Figure 2   Correction factor K_1 (Scott)

4. Discussion

It is generally preferable for a blockage correction to be expressed as a correction factor for speed, as this form of correction is well suited to resistance and propulsion tests.

The influences on wake blockage or pressure defect at the propeller are however unknown and are not separately considered.

Of the different correctors the Scott corrector tends to fit most of the data best but its theoretical base may not be universally accepted. It does however seem to be the best method available and may be recommended for general use with the following limitations:

Tanks of approximately 2:1 breadth to water depth ratio, model lengths between 3.5 m and 9.0 m and Froude number 0.08 to 0.4.

Based on the successful application of mean-flow theory in connection with finite depth wave theory, with no need for empirical adjustment and its easy employment, the Schuster corrector is also recommendable as a blockage correction formula with good overall qualities, up to say $Fr = 0.3$.

Another method commonly used is that due to Tamura which also includes finite depth effects.

All the previous comments are related to normal routine tank work. For blockage corrections in shallow water tanks essentially diverging from 2:1 breadth to water depth ratio, blockage ratios much larger than 0.03 and model tests at depth Froude numbers higher than 0.7, the proposal by Graff (1969) may be suggested as a useful guide.

3.7 Documentation

The results from the test should be collated in a report, which should contain at least the following information:

- Model specification:
    Identification (model number or similar)
    Loading condition
    Turbulence stimulation method
    Model scale
    Main dimensions and hydrostatics, included static wetted surface area (see recommendations of ITTC Standard Procedure 7.5-01-01, Ship Models)
    Towing Point location, Model condition

- Particulars of the towing tank, including length, breadth and water depth

- Test date

- Parametric data for the test:
    Water temperature
    Water density
    Kinematic viscosity of the water
    Form factor (even if $(1+k)=1.0$ is applicable, this should be stated)

- For each speed, the following data should be given as a minimum:
    Resistance of the model
    Sinkage fore and aft, or sinkage and trim

4. VALIDATION

4.1 Uncertainty Analysis

Uncertainty analysis should be performed in accordance with 'Uncertainty Analysis in EFD, Uncertainty Assessment Methodology' as described in QM 7.5-02-01-01 and 'Uncertainty Analysis in EFD. In addition to the above an example 'Uncertainty Analysis, Example for Resistance Test' is provided in QM 7.5-02-02-02.

4.2 Benchmark Tests

Benchmark data are described and collected in 'Benchmark Database for CFD, Validation for Resistance and Propulsion', ITTC QM 7.5-03-02-02

5. REFERENCES

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