ITTC Quality System Manual
Recommended Procedures and Guidelines

Guideline

Practical Guide for Uncertainty Analysis of Resistance Measurement in Routine Tests

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Disclaimer

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Practical Guide for Uncertainty Analysis of Resistance Measurement in Routine Tests

1. PURPOSE OF GUIDELINE

The purpose of the procedure is to provide a guideline for uncertainty analysis during a routine resistance test of a conventional displacement type mono-hull ship model in towing tank that follows the ITTC Procedure 7.5-02-02-01, “Resistance Test”. Uncertainties related to extrapolation and full scale prediction are not included in this procedure.

This procedure is recommended for use by well-experienced engineers in towing tank and can be regarded as a guide for simplified implementation of the ITTC guidelines 7.5-02-02-02, “General guidelines for Uncertainty Analysis in Resistance Tests” (2014). Such simplicity is based on the ITTC procedure 7.5-02-02-02.1, “Example for Uncertainty Analysis of Resistance Tests in Towing Tank” (2014).

2. UNCERTAINTY BUDGET BEFORE TEST

2.1 Estimate of Model Resistance

The estimation of ship model resistance is important for properly choosing the scale ratio of the model hull and the specification of the dynamometer. Such an estimation can be made on the basis of a database or even by CFD simulation. The useful range of the dynamometer should typically be at least 1.5 times the maximum resistance expected in a test series. Sometimes when there are few choices of dynamometers, selection of a proper range of calibration for the dynamometer is an alternative.

Special attention should be paid to the resistance at the lowest tow speed concerned, where the accuracy of the dynamometer (see later the *SEE* of fitting in calibration) will be one of the dominant sources of uncertainty in resistance measurement. If a measurement with high accuracy is desired for resistance at low speed, the accuracy, and hence appropriate selection of dynamometer range will be critical.

2.2 Budget of Uncertainty

The significant sources of uncertainty in the resistance tests of a conventional displacement-type monohull ship model can be analyzed as in Table 1, where the symbol u stands for the standard uncertainty and u' its relative value. The overall uncertainty of measurement is the expanded combined uncertainty U'_{P} (usually k_{P}=2 for 95% confidence level).

The five components of uncertainty listed in Table 1 can be preliminarily estimated on the basis of a database by experienced engineers. Usually, the uncertainties from the dynamometer and repeat tests are dominant while the other three sources can be negligible if the test process is well controlled as required by the ITTC recommended procedures concerned. According to Table 1, the overall uncertainty of a single measurement can be estimated as

$$U'_{\mathrm{P}}(R_{\mathrm{T}}) \approx k_{\mathrm{p}} \cdot \sqrt{(u'_2)^2 + (u'_A)^2} = \sqrt{\left(k_{\mathrm{p}} \cdot \frac{SEE}{R_{\mathrm{T}}}\right)^2 + \left(k_{\mathrm{p}} \cdot \frac{StDev}{R_{\mathrm{T}}}\right)^2} \quad (1)$$

Table1. Uncertainty components in resistance measurement

Components	Sources	Value of Uncertainty in Resistance
Wetted surface area	Displacement mass (Δ)	$u'_1(R_\mathrm{T}) \approx \frac{2}{3}u'(\Delta)$
Dynamometer	Calibration (*SEE*)	$u_2(R_\mathrm{T}) \approx SEE$
Viscosity (ν)	Water temperature	$u'_3(R_\mathrm{T}) \approx \frac{C_\mathrm{F}}{C_\mathrm{T}} \cdot \frac{0.87}{log_{10}Re - 2} \cdot u'(\nu)$
Speed (V)	Carriage/ Tachometer	$u'_4(R_\mathrm{T}) \approx 2u'(V)$
Repeat tests	Deviation for single test (*StDev*)	$u_A(R_\mathrm{T}) \approx StDev$
Combined standard uncertainty for single measurement		$u'_\mathrm{c}(R_\mathrm{T}) = \sqrt{{u'_1}^2 + {u'_2}^2 + {u'_3}^2 + {u'_4}^2 + {u'_\mathrm{A}}^2(R_\mathrm{T})}$
Expanded uncertainty for single measurement		$U'_\mathrm{P}(R_\mathrm{T}) = k_\mathrm{P} \times u'_\mathrm{C}(R_\mathrm{T})$
Repeat tests	Deviation for mean (*StDev*)	$u_A(\bar{R}_\mathrm{T}) \approx StDev/\sqrt{N}$
Combined standard uncertainty for mean of repeat tests		$u'_\mathrm{c}(\bar{R}_\mathrm{T}) = \sqrt{{u'_1}^2 + {u'_2}^2 + {u'_3}^2 + {u'_4}^2 + {u'_\mathrm{A}}^2(\bar{R}_\mathrm{T})}$
Expanded uncertainty for mean of repeat tests		$U'_\mathrm{P}(\bar{R}_\mathrm{T}) = k_\mathrm{P} \times u'_\mathrm{C}(\bar{R}_\mathrm{T})$

If the overall uncertainty is estimated within the desired limit, it can be sure that the choice of dynamometer is suitable. If the dynamometer component in Eq.1 is larger than the desired value, the user should either change the dynamometer to improve its accuracy (*SEE*) or enlarge the size of model hull to increase its resistance (R_T).

If the uncertainty component of a repeat test in Eq.1 is larger than the desired and nothing else is wrong, the first choice is to repeat tests *N* times to obtain the mean of repeat tests as a measurement and then the overall uncertainty of measurement is estimated as,

$$U'_\mathrm{P}(\bar{R}_\mathrm{T}) \approx k_\mathrm{p} \cdot \sqrt{\left(\frac{SEE}{R_\mathrm{T}}\right)^2 + \left(\frac{StDev/\sqrt{N}}{R_\mathrm{T}}\right)^2} \qquad (2)$$

However, if the repeat number *N* required is very large to achieve the desired accuracy of measurement, the dynamometer or the scale ratio of model hull should be changed.

3. PARTICULARS IN TEST PROCESS

3.1 Model Ballasting

The model with the instruments on board is ballasted to its displacement mass,

$$\Delta = \rho_\mathrm{water} \times \nabla \qquad (3)$$

where the density of tank water depends on its temperature that can be measured at the test date or the day before test. The accuracy of ballasting will be around 0.1% and then, the corresponding component of resistance uncertainty will be about 0.07%. This uncertainty component is usually considered negligible.

It should be noted that the geometry of the hull model is checked at a model workshop before ballasting. Usually, thermal deformation of the model hull due to the temperature difference of several degrees between the model workshop and towing tank water is assumed negligible. If the temperature difference is too large, the thermal deformation should be estimated and if necessary, the displacement volume used in Eq.3 should be corrected to the temperature of tank water.

3.2 Dynamometer Calibration

The dynamometer should be calibrated with masses before model tests according to the ITTC Procedure 7.5-01-03-01, “Uncertainty Analysis of Instrument calibration”. The loading force is related to mass by the following equation,

$$F = m\cdot g\cdot\left(1-\rho_{\text{air}}/\rho_{\text{weight}}\right) \approx m\cdot g \quad (N) \tag{4a}$$

or,

$$f \approx F/g = m \quad (kgf) \tag{4b}$$

where, g is the local acceleration of gravity. Calibration data are analyzed by the following linear curve fitting,

$$f_i = m_i = K_\text{g}\cdot V_i + O(\varepsilon) \tag{5}$$

where, V_i stands for the output voltage of DAS (Data Acquisition System). A proper OIML Class of weights should be used so that the uncertainty of weight itself can be assumed negligible. Thereafter, the standard uncertainty of calibration can be estimated as

$$SEE = \sqrt{\frac{1}{n-1}\sum_i^n\left(m_i - K_\text{g}\cdot V_i\right)^2}\ (kgf) \tag{6}$$

where, n is the number of loadings by weights.

3.3 Number of Repeat Tests

Based on the uncertainty estimate of dynamometer calibration, the choice of number of repeat tests can be re-assessed by Eq.2.

It is not necessary for routine tests to repeat the whole of test runs that includes all test points (towing speeds). It is recommended that only the tests at around the design speed or those for Energy Efficiency Design Index (EEDI) related speeds need be repeated in order to predict the powering performance with a desired accuracy, if there is no reliable database available for the towing tank.

However, if the form factor method (i.e., 1+k method) is used for data reduction, the number of test points within Fr=0.1~0.2 should be enough (say, around ten points) after outliers are eliminated. Repeat tests may be performed at very low speeds.

3.4 Sampling Interval of Time

Before formal tests, it is recommended to perform some preliminary tests in order to determine the proper interval of time for sampling, so that the standard deviation of the sampling time history can be assumed negligible in measurement of resistance. It is also recommended to filter the sampling signal by low-pass filter before data reduction.

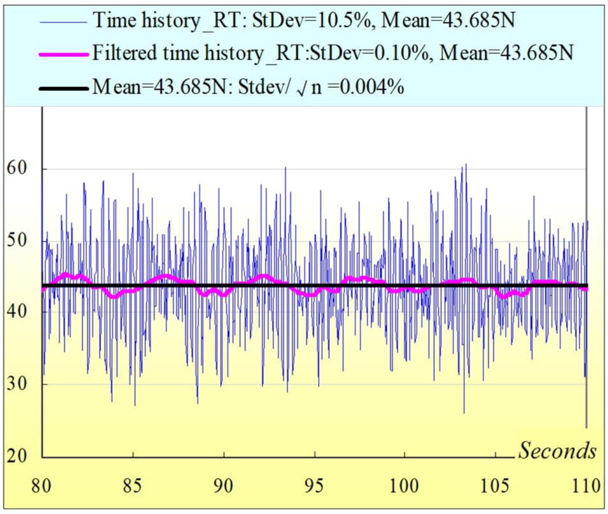

Figure 1. Example of time history of resistance measurement over 30s

In Fig.1 is given one example of time histories of resistance measurement for the large model of DTMB 5415 model provided by the Facility Bias World Campaign, ITTC(2011).

It is shown that in this example, the mean of 600 sampling data keeps the same before and after being filtered, but the standard deviation of filtered data is much smaller than that of unfiltered data, as in Tab.2.

Table 2. Analysis for an example of time history in resistance measurement

$R_T(N)$	Standard deviation of time history	Mean of time history (“Reading”)	Standard deviation of the mean
Before filtered	10.5%	43.685	0.43%
Low-pass Filtered	0.10%	43.685	0.004%

It can be concluded that, if the interval of time of sampling is properly selected, the uncertainty in the mean of sampling for resistance measurement is negligible, whether the sampling signal is filtered or not. Furthermore, the mean of one time history can be regarded as one “reading” and the uncertainty of repeat measurement is completely different from the standard deviation of the time history.

3.5 Water Temperature

In this guideline, since only the uncertainties related to the resistance measurement are analysed and those uncertainties in extrapolation are not considered, the uncertainties related to the form factor and residuary resistance coefficient determined by the resistance test are not covered and no data reduction is involved in the uncertainty analysis.

The temperature of tank water should be measured properly. Usually, the uncertainty of resistance measurement from temperature variation during tests is negligible. Otherwise, if the variation of resistance due to viscosity, as expressed by the following Eq.7, is not negligible, correction should be made before uncertainty analysis of resistance measurement.

$$\begin{cases} \frac{\delta R_\mathrm{T}}{R_\mathrm{T}} \approx \left[\frac{C_\mathrm{F}}{C_\mathrm{T}} \cdot \frac{0.87}{log_{10}Re-2}\right] \cdot \frac{\delta \nu}{\nu} \\ \hat{R}_\mathrm{T} = R_\mathrm{T} - \delta R_\mathrm{T} \end{cases} \tag{7}$$

3.6 Towing Speed

The accuracy of towing speed control is usually high enough that the resulted uncertainty in resistance measurement is negligible. Additionally, if variation of tow speed relative to the nominal speed is less than 0.05%, resistance measurement can be assumed at the nominal speed. Otherwise, correction should be made before uncertainty analysis of resistance measurement through the following.

3.7 Running Sinkage and Trim

Running sinkage and trim are of importance in resistance tests, not only for intra- and inter-laboratory comparison, but also for hull form optimization. However, there is no analytical or quantitative relationship between these two parameters and the resistance.

There is no special consideration in the uncertainty analysis of measurement of running and trim. Sometimes, the uncertainties of running sinkage and trim, beside that of resistance, may be amongst the other factors needed to determine the number of repeat tests for a particular site. It is worth noting that each site should have assessed the influence of the variation in height of the rails and their influence on the track of the model relative to the free surface (ITTC, 2014c).

4. UNCERTAINTY ANALYSIS

All the uncertainty components in resistance measurement can be evaluated in detail as in Table 2 and, if needed, uncertainties of running sinkage and trim can also be estimated by following the ITTC procedure 7.5-02-02-02.1, “Example for Uncertainty Analysis of Resistance Tests in Towing Tank” (2014).

Table 3a. Dominating uncertainties in resistance measurement (with repeat tests)

Source & Component		Uncertainty in resistance	Type
Dynamometer	Calibration (*SEE*)	$u_2(R_T)$	A
Repeatability	*N* repeat tests	$u_A(R_T)$	A
Combined	$u_C(\bar{R}_T) = \sqrt{u_2^2 + \left(u_A/\sqrt{N}\right)^2}$		
Expanded	$U_P(\bar{R}_T) = k_P \cdot u_C(\bar{R}_T)$ (k_p=2 for 95% confidence level)		

Table 3b. Dominant uncertainties in resistance measurement (without repeat tests)

Source & Component		Uncertainty in resistance	Type
Dynamometer	Calibration (*SEE*)	$u_2(R_T)$	A
Repeatability	*database*	$u_B(R_T)$	B
Combined	$u_C(R_T) = \sqrt{u_2^2 + u_B^2}$		
Expanded	$U_P(R_T) = k_P \cdot u_C(R_T)$ (k_p=2 for 95% confidence level)		

For conventional displacement-type monohull ship models, the dominant uncertainties only include those components from dynamometer calibration and repeatability of tests, as shown in Table 3.

5. UNCERTAINTY REPORT

After the uncertainty analysis is completed, the resistance measurement will be expressed by the total resistance coefficient,

$$\frac{R_T \pm U_p(R_T)}{\frac{1}{2}\rho S V^2} = \frac{R_T}{\frac{1}{2}\rho S V^2} \pm \frac{U_p(R_T)}{\frac{1}{2}\rho S V^2} \equiv C_T \pm U_p(C_T) \quad (8)$$

When the intra- and/or inter-laboratory comparison is performed, the coefficient will usually be converted to the nominal temperature of water 15 degrees with its corresponding uncertainty of the same value as that in Eq.8,

$$\hat{C}_T(15\text{deg}) = C_T(15\text{deg}) \pm U_p(C_T) \quad (9)$$

6. REFERENCES

ITTC, 2008, Model Manufacture Ship Models, ITTC Procedure 7.5-01-01-01.

ITTC, 2008, Uncertainty Analysis, Calibration Uncertainty, ITTC Procedure 7.5-01-03-01.

ITTC, 2011, Density and Viscosity of Water, ITTC Procedure 7.5-02-01-03.

ITTC, 2011, Resistance Test, ITTC Procedure 7.5-02-02-01.

ITTC, 2014a, General Guidelines for Uncertainty Analysis in Resistance Tests, ITTC Procedure 7.5-02-02-02.

ITTC, 2014b, Example for Uncertainty Analysis of Resistance Tests in Towing Tank, ITTC Procedure 7.5-02-02-02.1.

ITTC, 2014c, Resistance Committee Report, Proceedings of 27th International Towing Tank Conference.