The Specialist Committee on Uncertainty Analysis

Final Report and Recommendations

The 26th International Towing Tank Conference

Rio de Janeiro, Brazil

Aug. 28 – Sept. 3, 2011

Membership

- **Mr. Baoshan Wu**: China Ship Scientific Research Centre, CSSRC, Wuxi, Jiangsu, China.
- **Dr. Michael D. Woodward**: School of Marine Science & Technology, Newcastle University, Newcastle-upon-Tyne, UK.
- **Dr. Shigeru Nishio**: Kobe University, Faculty of Maritime Sciences, Dept. of Maritime Safety Management, Kobe, Japan.
- **Dr. Angelo Olivieri**: The Italian Ship Model Basin, INSEAN, Via di Vallerano, Roma, Italy.
- **Dr. Luis Pérez Rojas**: Universidad Politécnica De Madrid, Escuela Técnica Superior De Ingenieros Navales, Spain.
- **Mr. Martijn van Rijsbergen**: The Maritime Research Institute Netherlands, MARIN, The Netherlands.
- **Dr. Ahmed Derradji-Aouat**: National Research Council, NRC-IOT, Newfoundland & Labrador, Canada.
- **Dr. Joel T. Park** (ex officio): Naval Surface Warfare Center Carderock Division, Maryland, USA.

Meetings

The Uncertainty Analysis Committee (UAC) held three (3) meetings:

- Spain, Madrid University, January 2009.
- Italy, INSEAN, December 2009.
- Canada, NRC-IOT, June 2010.

Chairman notes:

1 - Meeting in Italy was planned to coincide with the time for the NAV conference 2009 in Italy.
2 - The meeting in Canada was joint with the ITTC 2-day workshop on Uncertainty Analysis.
3 - Many thanks to the host laboratories for the hospitality.
4 – Many thanks to all members of the UAC for the hard work.

Outline

- Terms of Reference (ToR) – Mandate.
- Recommended Procedures – Completed procedures.
- Uncertainty Analysis (UA) - ISO GUM (1995) guidelines.
- Water Properties (Equations and UA).
- UA in Multi Component Force Balances (Dynamometers).
- UA for CFD work.
- The 1978 - 3P task.
- UA for propulsion (Open Water).
- Reporting Experimental Uncertainties.
- The ITTC - UA Workshop in St. John's.
- General UA – Simple Best Practices.
- Conclusions

Terms of Reference (9 tasks were mandated)

- Tasks 1 and 2: Monitor new developments in verification & validation (V&V) methodology and Evaluate the state-of-the-art for Uncertainty Analysis.
- Tasks 3 and 4: Support (and work with) other ITTC committees to develop, revise, or harmonize UA procedures, as per ISO-GUM guideline.
- Task 5: Update ITTC recommended procedure 7.5-03-01-01 "Uncertainty Analysis in CFD.
- Task 6: Update ITTC Recommended Procedure 7.5-02-01-03, Density & Viscosity of Water.
- Task 7: Revise Proc. 7.5-02-03-01.2 & 7.5-02-03-02.2 "Propulsion and Open Water Tests".
- Task 8: Develop a Proc: "Uncertainty Analysis for the 1978 ITTC-3P Method".
- Task 9: Organize an ITTC UA workshop.

Recommendations

- Accept ITTC procedure 7.5-02-01-03, “Properties of Water”
- Accept procedures 7.5-02-03-01.2 “Uncertainty Analysis Example for Propulsion test” and 7.5-02-03-02.2 “Uncertainty Analysis Example for open water test” (**Note: the ITTC – AC asked the propulsion committee to merge the two procedures**)

Notes:
1 - A procedure for the 1978 3P method was not recommended (will be discussed in this presentation via examples)
2 - The state of art reviews, the ITTC UA workshop, and support to other committees were completed.

Experimental Uncertainty Analysis

- History of UA – Highlights.
- ISO-UA Fundamental Principles.

History of UA - Highlights

• 3000 BC:	Ancient Egypt (cubit), …..the Greeks (foot), …
• 1668	The tenth and the metric system.
• 1875	The meter convention (BIPM, CIPM, GCPM)
• 1977	CIPM call for UA.
• 1980	BIPM recommendation INC 1980.
• 1981	CGPM ratification OF INC-1980.
• 1993	JCGM produced ISO-GUM, revised in 1995 (**ISO-GUM 1995**)
• 1998-2008	ISO-GUM mirrors.

UA - Fundamental Five Principles

Principle # 1. Uncertainty grouped in 2 categories: Type A and Type B

•Type A - statistical methods to the results of measurements.

•Type B uncertainties are those evaluated by other means (not statistical).

Principle # 2. Type A defined by the estimated variance (DOF).

Principle # 3. Type B is an approximate variance (*existence assumed*).

Principle # 4. The combined uncertainty is the law of propagation of uncertainty.

Principle # 5. Expended uncertainty = Combined Uncertainty times a coverage factor.

Notes:

1 – Usually, in tow tank testing, the coverage factor is 2, for the 95% confidence level.

Water Properties

ITTC procedure 7.5-02-01-03.

Procedure was expanded to include:

- Fresh Water
- Sea Water

Notes:
1 – Properties are: density, absolute viscosity, kinematic viscosity, and vapour pressure

Freshwater Properties

- Properties are: density, absolute viscosity, kinematic viscosity, and vapour pressure.
- International Association for the Properties of Water and Steam (IAPWS).
- Computer code: Harvey, et al. (2008) from NIST/ASME.
- Uncertainty estimates for equations.
- Tables for properties & their sensitivity coefficients.

Uncertainty in Freshwater Equations

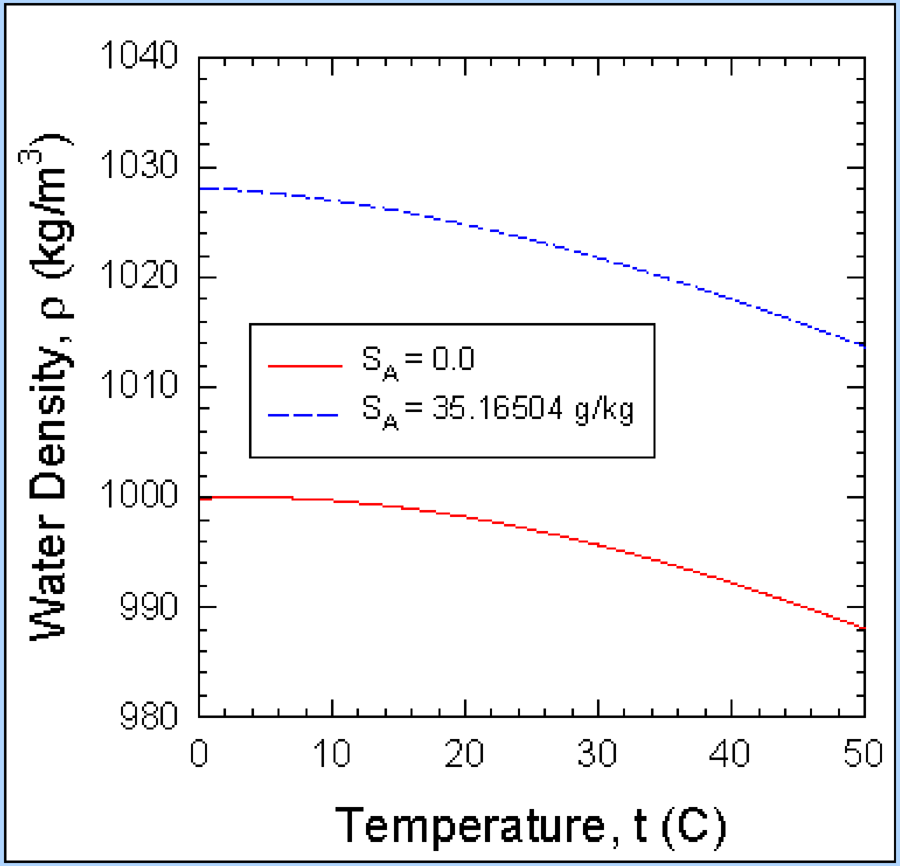
Property	Symbol	U_{95}	Units
Density	ρ	1	ppm
Viscosity	μ	1	%
Vapour Pressure	p_v	0.02	%

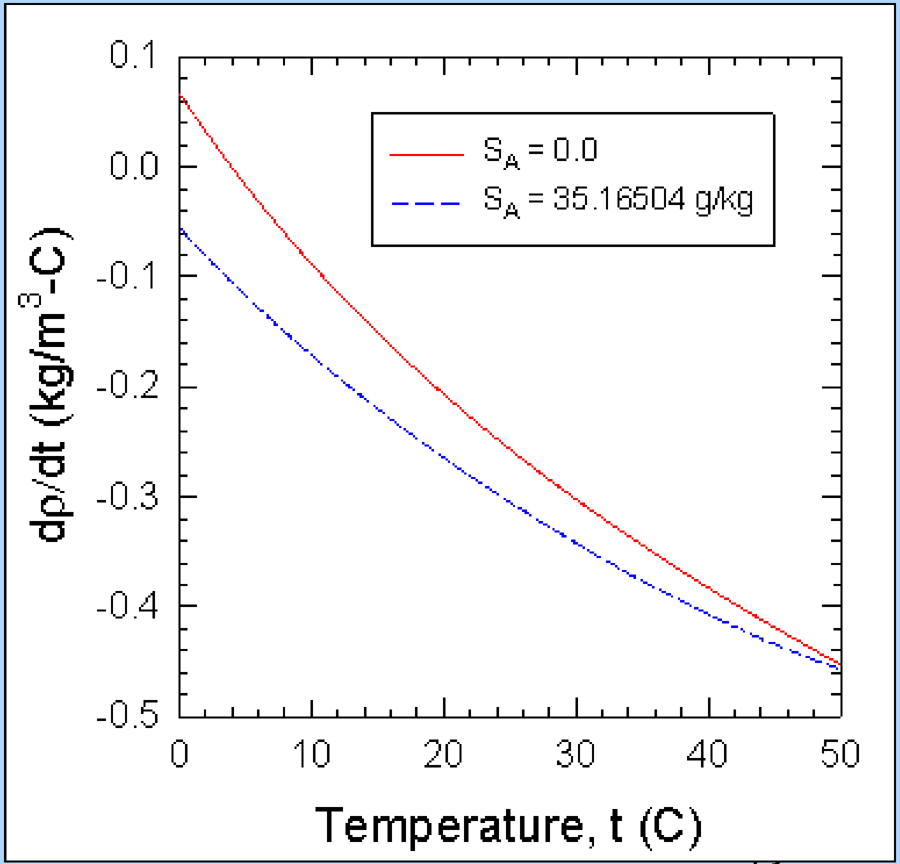
ppm: parts per million (0.0001 %)

Sensitivity Coefficients - Fresh Water

Temp t	Density ρ	$\partial\rho/\partial t$	Viscosity μ	$\partial\mu/\partial t$	$\nu = \mu/\rho$	$\partial\nu/\partial t$	Pressure p_v	$\partial p_v/\partial t$
(°C)	(kg/m^3)	(kg/m^3·°C)	(Pa·s)	(Pa·s/°C)	(m^2/s)	(m^2/s·°C)	(MPa)	(MPa/°C)
10	999.7025	-0.08791	0.001306	-3.760E-05	1.3063E-06	-3.749E-08	1.2282E-03	8.230E-05
11	999.6079	-0.10112	0.001269	-3.591E-05	1.2697E-06	-3.580E-08	1.3130E-03	8.728E-05
12	999.5004	-0.11399	0.001234	-3.433E-05	1.2347E-06	-3.420E-08	1.4028E-03	9.252E-05
13	999.3801	-0.12653	0.001200	-3.284E-05	1.2012E-06	-3.271E-08	1.4981E-03	9.802E-05
14	999.2474	-0.13877	0.001168	-3.144E-05	1.1692E-06	-3.130E-08	1.5990E-03	1.038E-04
15	999.1026	-0.15071	0.001138	-3.012E-05	1.1386E-06	-2.997E-08	1.7058E-03	1.099E-04
16	998.9461	-0.16237	0.001108	-2.887E-05	1.1093E-06	-2.872E-08	1.8188E-03	1.162E-04
17	998.7780	-0.17376	0.001080	-2.769E-05	1.0811E-06	-2.754E-08	1.9384E-03	1.229E-04
18	998.5986	-0.18489	0.001053	-2.658E-05	1.0542E-06	-2.642E-08	2.0647E-03	1.299E-04
19	998.4083	-0.19578	0.001027	-2.553E-05	1.0283E-06	-2.537E-08	2.1983E-03	1.372E-04
20	998.2072	-0.20644	0.001002	-2.453E-05	1.0034E-06	-2.437E-08	2.3393E-03	1.449E-04

Freshwater Density





Seawater Properties

- International Thermodynamic Properties of Seawater (TEOS-10).
- Computer codes: MATLAB & FORTRAN (GSW v3.0).
- Transport properties (Sharqawy et al., 2010).
- Uncertainty estimates for equations.
- Tables for sea water properties & sensitivity coefficients.

Uncertainty in Seawater Equations

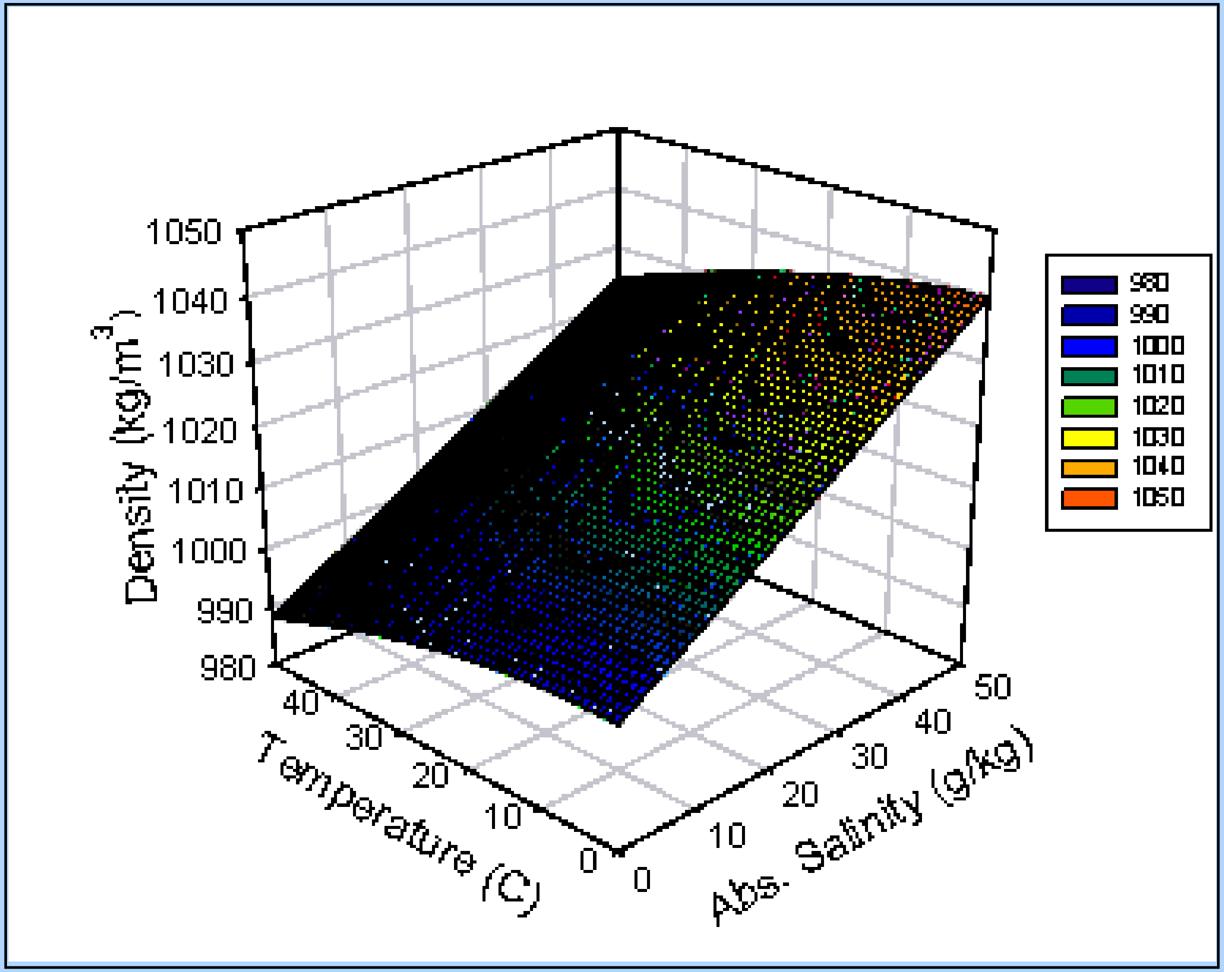
Property	Symbol	U_{95}	Units
Density	ρ	8	ppm
Viscosity	μ	1.5	%
Vapour Pressure	p_{v}	0.1	%

ppm: parts per million (0.0001 %)

Sensitivity Coefficients – Sea Water

Temp t (°C)	Density ρ (kg/m^3)	$\partial\rho/\partial t$ (kg/m$^3\cdot$°C)	Viscos μ (Pa·s)	$\partial\mu/\partial t$ (Pa·s/°C)	$\nu = \mu/\rho$ (m^2/s)	$\partial\nu/\partial t$ (m^2/s·°C)	Pressure p_v (MPa)	$\partial p_v/\partial t$ (MPa/°C)
1	1028.0941	-0.0680	0.001843	-6.186E-05	1.7926E-06	-6.005E-08	6.4363E-04	4.639E-05
2	1028.0197	-0.0810	0.001783	-5.862E-05	1.7341E-06	-5.689E-08	6.9153E-04	4.944E-05
3	1027.9327	-0.0930	0.001726	-5.561E-05	1.6787E-06	-5.395E-08	7.4256E-04	5.265E-05
4	1027.8336	-0.1050	0.001671	-5.282E-05	1.6262E-06	-5.122E-08	7.9689E-04	5.604E-05
5	1027.7225	-0.1170	0.001620	-5.021E-05	1.5762E-06	-4.867E-08	8.5471E-04	5.962E-05
6	1027.6000	-0.1280	0.001571	-4.777E-05	1.5288E-06	-4.630E-08	9.1620E-04	6.340E-05
7	1027.4662	-0.1390	0.001524	-4.549E-05	1.4836E-06	-4.408E-08	9.8157E-04	6.738E-05
8	1027.3214	-0.1500	0.001480	-4.337E-05	1.4406E-06	-4.200E-08	1.0510E-03	7.156E-05
9	1027.1659	-0.1605	0.001438	-4.137E-05	1.3995E-06	-4.006E-08	1.1248E-03	7.597E-05
10	1027.0000	-0.1710	0.001397	-3.950E-05	1.3604E-06	-3.823E-08	1.2030E-03	8.061E-05
11	1026.8238	-0.1815	0.001359	-3.774E-05	1.3230E-06	-3.652E-08	1.2861E-03	8.550E-05
12	1026.6376	-0.1915	0.001322	-3.609E-05	1.2873E-06	-3.492E-08	1.3741E-03	9.063E-05
13	1026.4416	-0.2010	0.001286	-3.454E-05	1.2532E-06	-3.341E-08	1.4674E-03	9.601E-05
14	1026.2360	-0.2105	0.001252	-3.308E-05	1.2205E-06	-3.198E-08	1.5662E-03	1.017E-04
15	1026.0210	-0.2195	0.001220	-3.170E-05	1.1892E-06	-3.064E-08	1.6709E-03	1.076E-04
16	1025.7967	-0.2290	0.001189	-3.040E-05	1.1592E-06	-2.938E-08	1.7816E-03	1.139E-04
17	1025.5633	-0.2380	0.001159	-2.918E-05	1.1304E-06	-2.819E-08	1.8987E-03	1.204E-04
18	1025.3210	-0.2470	0.001131	-2.801E-05	1.1028E-06	-2.706E-08	2.0225E-03	1.272E-04
19	1025.0700	-0.2555	0.001103	-2.692E-05	1.0763E-06	-2.599E-08	2.1533E-03	1.344E-04
20	1024.8103	-0.2640	0.001077	-2.588E-05	1.0508E-06	-2.498E-08	2.2914E-03	1.419E-04

Standard Saltwater Density



UA, What's New? State of the Art Review

- ISO GUM 1995 & VIM available on-line at BIPM.
- New supplements to ISO GUM.
  a) Monte Carlo methods
  b) Introduction to ISO GUM
  c) Five more in the near future
- New standard for CFD verification & validation, ASME (2009).
- Revised guide on SI units, NIST (2008).
- Application of ISO GUM to ITTC model test.

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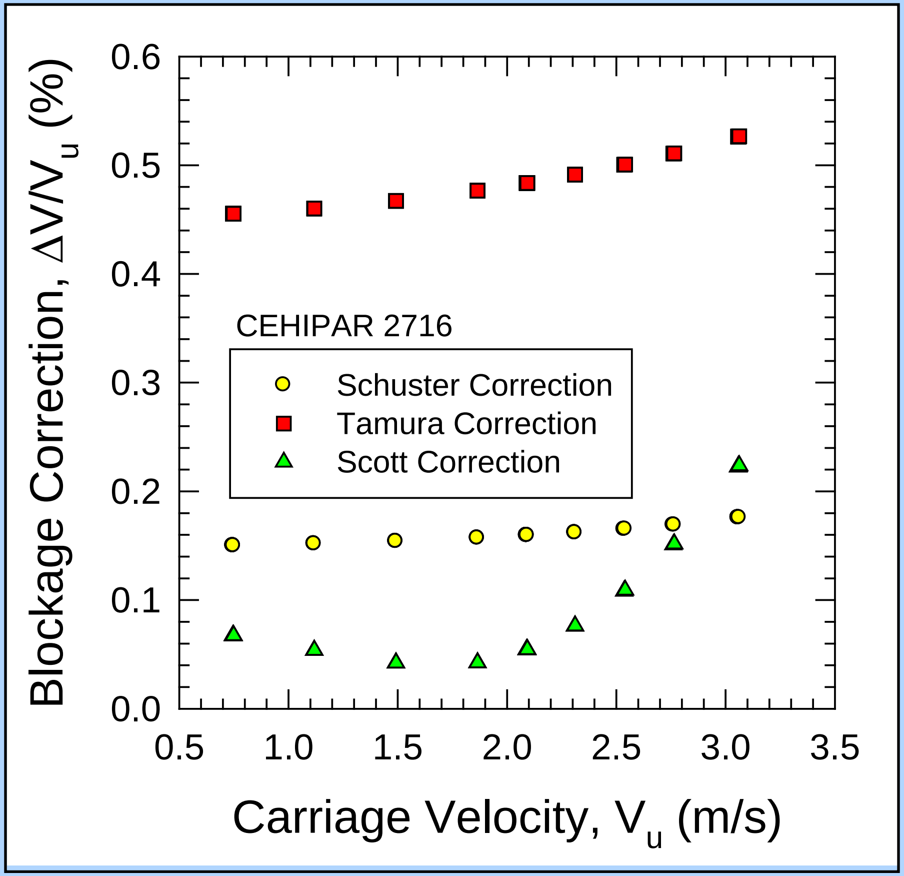
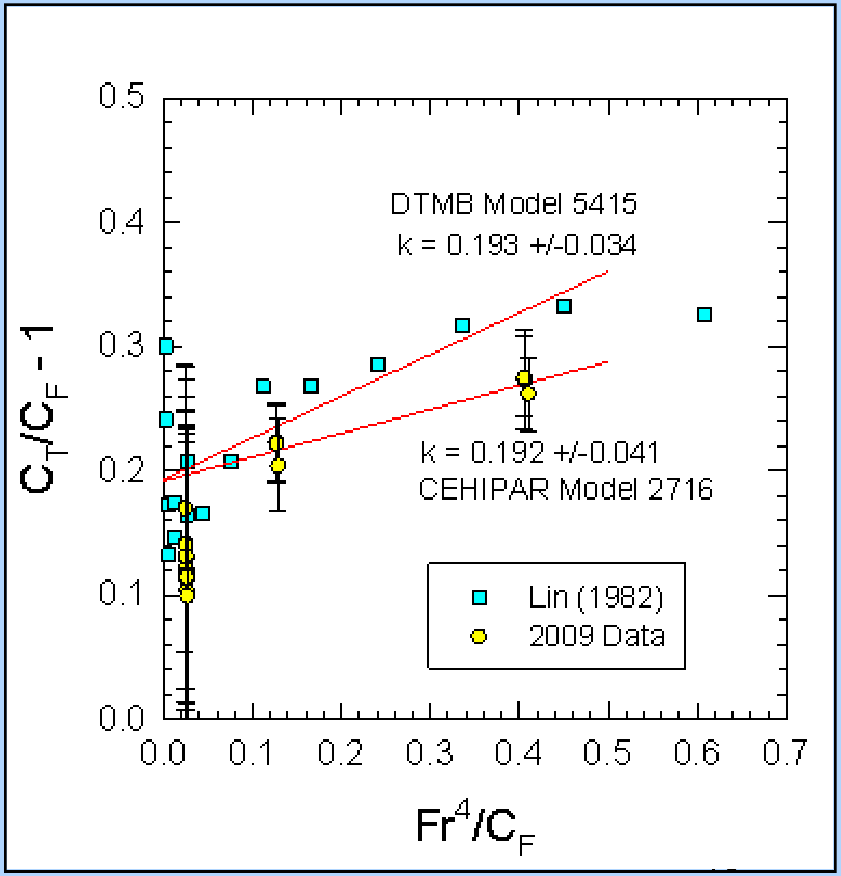
Example ITTC Model – ISO GUM

Blockage Correction & Form Factor

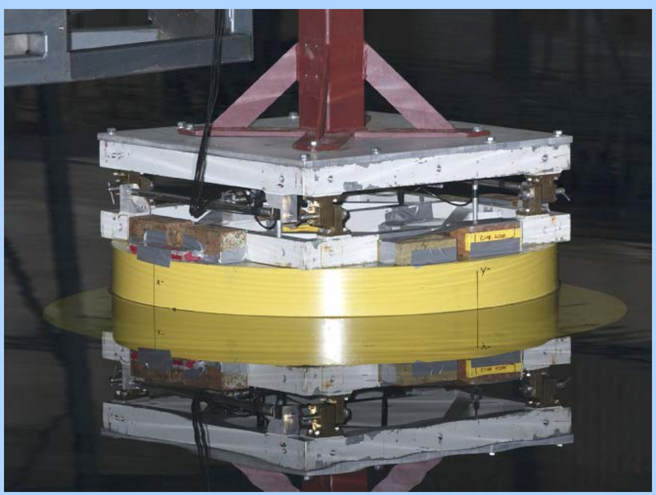


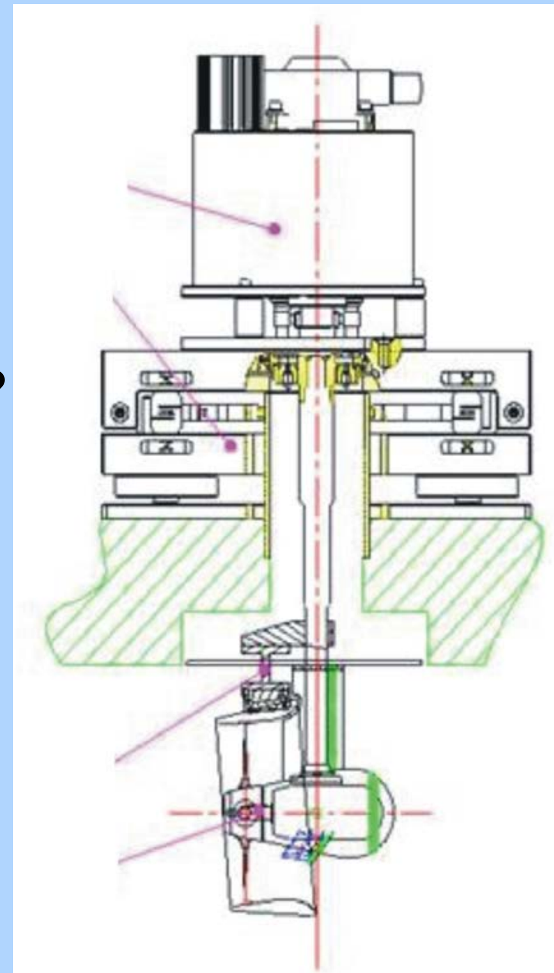


Multi-component force balances

Multi-component force balances are widely used

But what is the uncertainty?





Uncertainty Analysis

- Single component force transducers:
  - ISO 376: > 48 points at > 8 loadings in predefined scheme
  - ASTM E74: 30 points at 10 loadings, random loading
  - Valid for compression or tension
  - ITTC recommended procedure is based on ASTM E74

- Similar approach for thrust-torque transducer:
  - Compression and tension for two components
  - Extended ISO approach: 6*8*8*4 = 1536 points!
  - Not feasible!
  - Don’t think about UA for 6 components?

Calibration of multi-component force balances

- Mathematical model

$$F = BS$$

- F = force vector: Fx, Fy, Fz, Mx, My, Mz
- S = signal vector: S1 … S6 + quadratic & cross terms
- B = evaluation matrix (6x6 up to 6x96)
- B is determined by multiple linear regression on calibration data
- Residuals (difference between applied and predicted load) are calculated

Calibration of multi-component force balances

- Standard error of regression:

$$s_i = \left(\frac{\sum_{j=1}^{N} R_{ij}^2}{N - P} \right)^{\frac{1}{2}}$$

- R_{ij} = residual of i^{th} component and j^{th} loading
- N = number of points
- P = number of coefficients in mathematical model

UA for multi-component force balances

- **Sources of uncertainty**
  - Calibration system (weights, friction in pulleys, alignment, balance level etc.): Best Measurement Capability (BMC)
  - Balance design and manufacturing (bolted joints cause hysteresis effects)
  - Load table (time vs. quality, coverage of loading space)
  - Mathematical model (right type and number of terms)
  - Data reduction process (removal of outliers, overfitting, extrapolation errors)
- **Expanded uncertainty (k = 2) of force component F_i**

$$U_{F_i} = 2\left(s_i^2 + BMC_i^2\right)^{\frac{1}{2}}$$

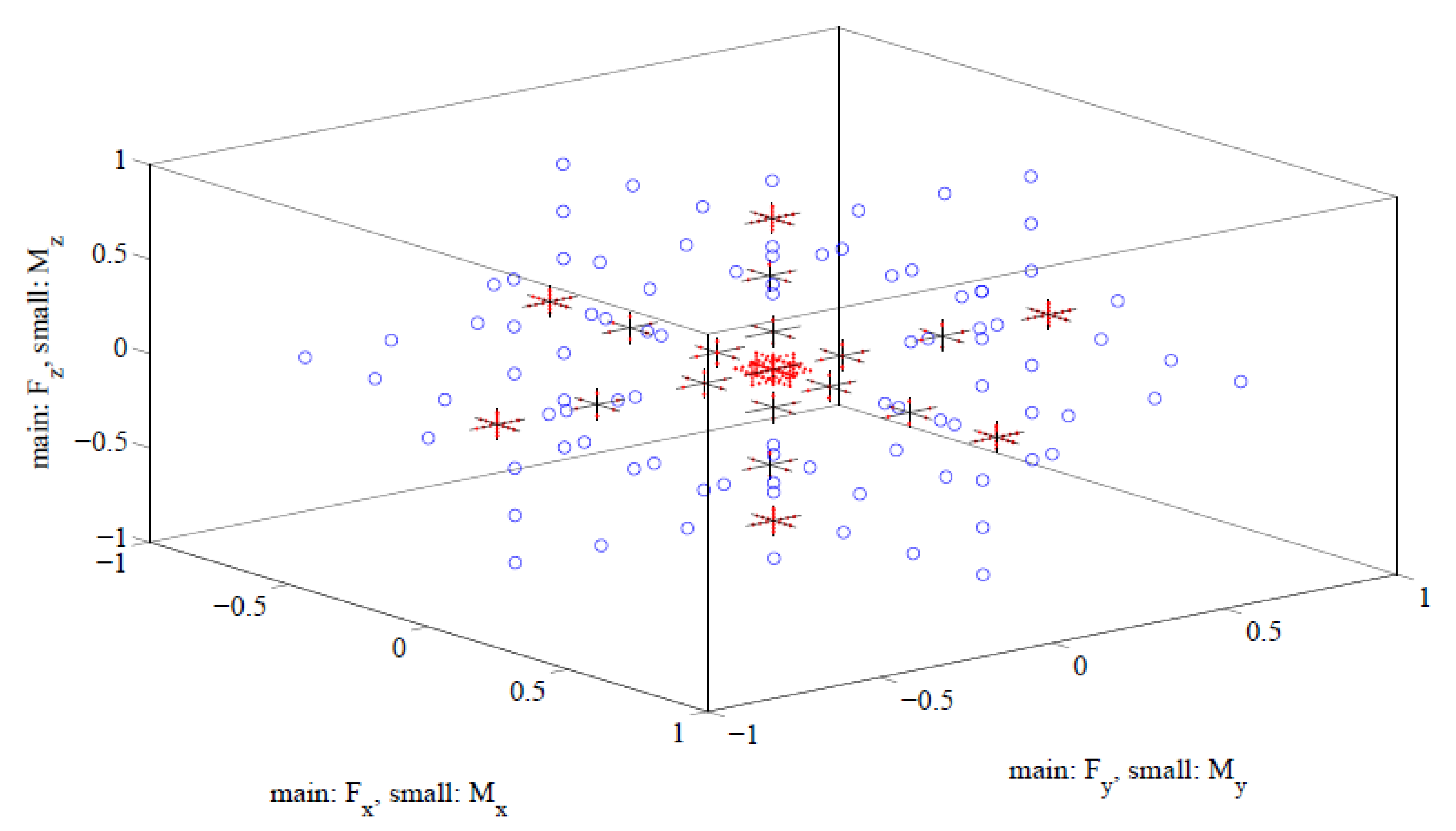
Effect of load table on uncertainty example from [1]

- One Factor At the Time (OFAT) table
  - Pure loads up to 100% of load range
  - Combined loads up to 75% of load range
  - 505 points in total

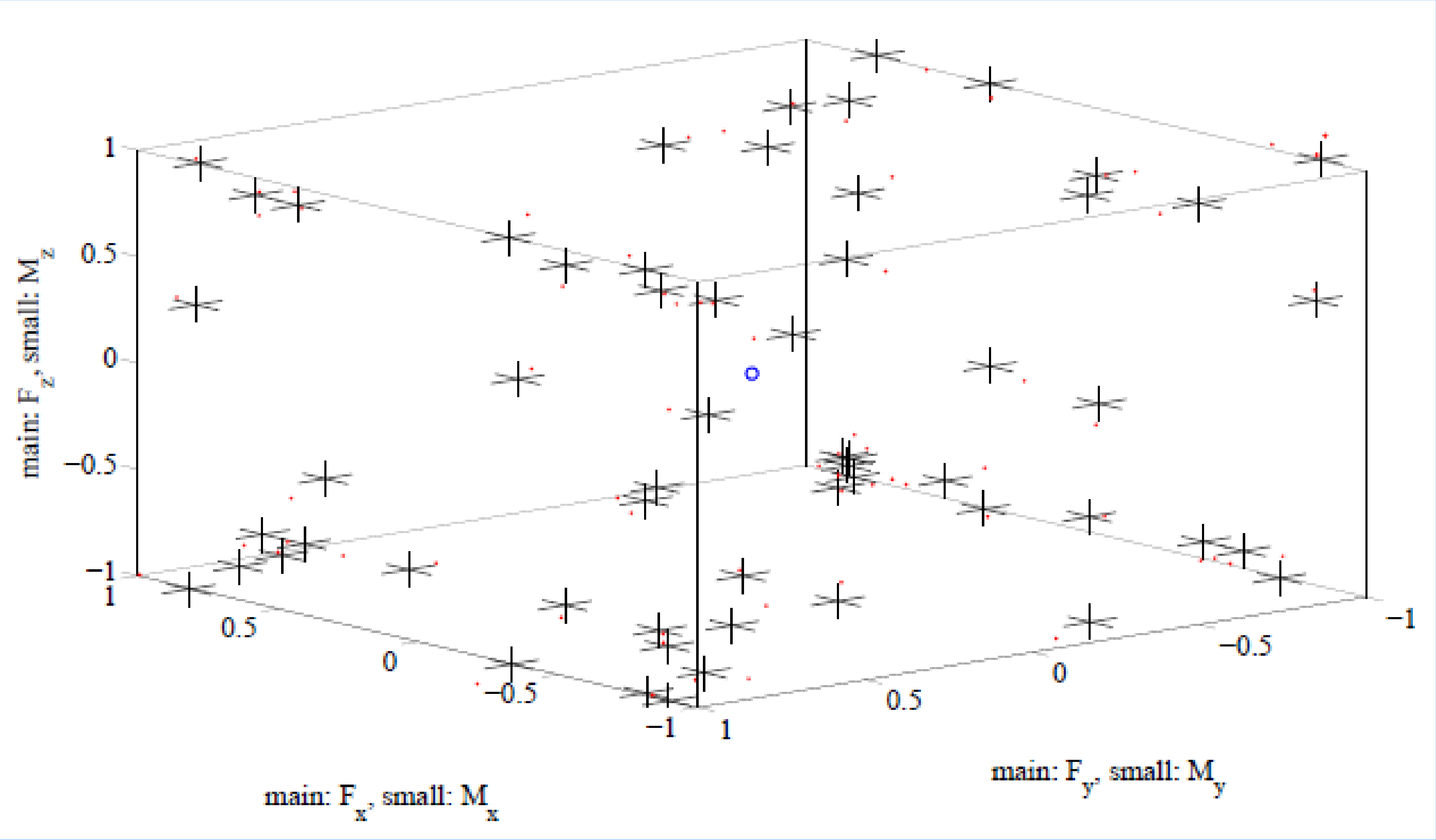
- Design Of Experiments (DOE) table
  - D-optimized twice (minimizes standard error and # points)
  - Only combined loads
  - 136 points in total

[1] Bergmann, R., Philipsen, I., 2010, An experimental comparison of different load tables for balance calibration, 7th International Symposium on Strain-Gauge Balances, Williamsburg, VA USA

OFAT table: forces and moments



DOE table: forces and moments



Effect of load table on uncertainty

- Both load tables are applied to internal balance
- Calibration machine at Qinetiq is used
- Evaluation matrix determined for each data set
- Back-calculated loads for own and other data set
- Comparison of normalized standard error in Fx

$10^3\ s_{Fx}/Fx_{FS}$	load table	
calibration model	OFAT	DOE
OFAT	0.31	1.37
DOE	0.85	0.90

- OFAT model best on own table, but worse on DOE table
- DOE model performs equally on both tables

UA Final results

- Normalized standard error = 0.9×10^{-3}
- Normalized BMC = 0.3×10^{-3}
- Expanded normalized uncertainty $U_{Fx} = 1.9 \times 10^{-3}$

Concluding remarks

- Visual inspection of 6D load table in 3D is useful to check coverage of load space
- DOE can be used to obtain a more stable regression model with less points
- Ideally, balance uncertainty should not be derived from the residuals of the data set used for the regression, but from a separately obtained data set

UA for the ITTC-1978 PPP Method (1)

- Validation of the ITTC-1978 Powering Performance Prediction Method.

INTERNATIONAL TOWING TANK CONFERENCE	ITTC – Recommended Procedures and Guidelines	7.5 – 02 03 – 01.4 Page 9 of 9	
	Performance, Propulsion 1978 ITTC Performance Prediction Method	Effective Date 2008	Revision 01

3. VALIDATION

3.1 Uncertainty Analysis

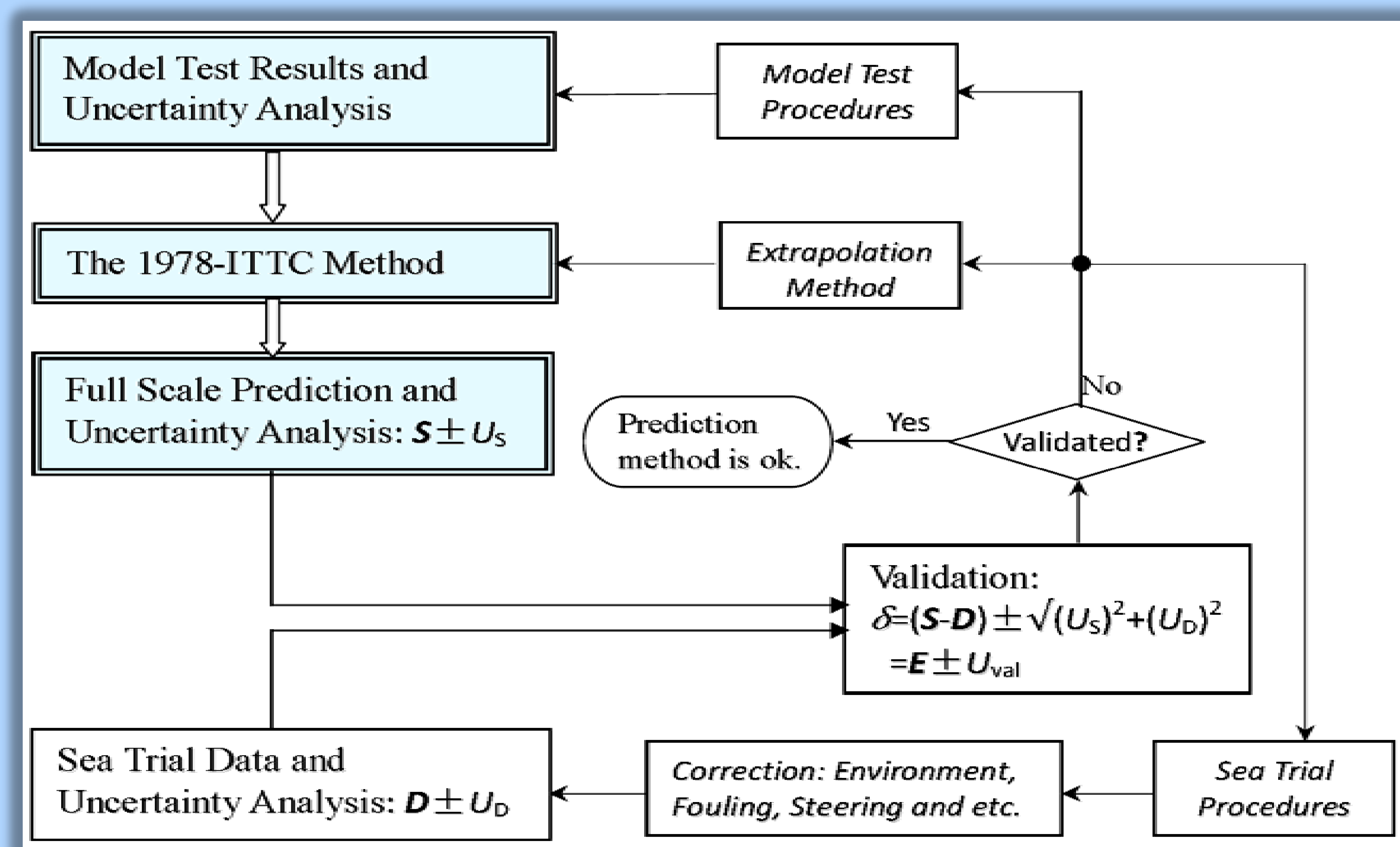
Not yet available

The main issues:

- Method of UA for the prediction is different from that of measurement
- The source of uncertainties from model-ship correlation not available

UA for the ITTC-1978 PPP Method (2)

Overview of the validation process



UA for the ITTC-1978 PPP Method (3)

A real example: 36,000DWT Bulk Carrier

Particulars of Ship Hull

Items	Symbol	Ship	Model
Length of waterline	L_{WL}	178.00m	6.5267m
Breadth, moulded	B	32.26m	1.1827m
Draft	T	10.00m	0.3667m
Displacement volume	∇	44212.0 m^3	2.1795 m^3
Waterline plane area coefficient	C_{WL}	0.9384	0.9384
Wetted surface	S	7762.0 m^2	10.4356 m^2

Particulars of Propeller

Items	Symbol	Model	Full scale
Diameter	D_P	0.1943m	5.30m
Developed Area Ratio	A_E/A_0	0.55	
Pitch Ratio	$(P/D_P)_{0.7R}$	0.64	
Number of Blades	Z	4	

UA for the ITTC-1978 PPP Method (4)

A real example: 36,000DWT Bulk Carrier

- Only the uncertainties of the powering performance prediction for the condition of the design draft and design speed (at 85%MCR) of the ship are evaluated.

Conditions:

calm and deep water
85%MCR= 6400kW
Transmission efficiency=0.985

Predictions:

Speed of ship at design draft (Mean Value with Uncertainty)
Revolution rate of propeller (Mean Value with Uncertainty)

- All model tests are carried out in the Deep Water Towing Tank at CSSRC.

UA for the ITTC-1978 PPP Method (5)

A real example: 36,000DWT Bulk Carrier

Simplifications:

- The Following uncertainty sources are not taken into consideration
  - Geometry uncertainties resulted from **model manufacturing**.
  - Uncertainties resulted from **installation** in model tests.
  - Uncertainties originated from **model-ship correlation**,
  - Uncertainties originated from all **full-scale corrections**.
  - Uncertainties related to extrapolation of **appendage resistance**.
  - Uncertainties related to **air resistance calculation**.
  - Uncertainties related to transmission efficiency of ship **shaft**
- The form factor is assumed to be zero

UA for the ITTC-1978 PPP Method (6)

A real example: 36,000DWT Bulk Carrier

Method of UA:

Input Parameters: Mean value+Deviation, such as $K_{Tm}+\delta(K_{Tm})$	⇒	The 1978-ITTC Method (e.g. using the routine software in Lab)	⇒	Output: $\boldsymbol{V_S}+\delta(V_S)$ $\boldsymbol{N_S}+\delta(N_S)$ at 85%MCR)

- All the standard deviations are really estimated with Type A or Type B method in the ISO-GUM (1995)
- Repeat tests are performed at the points around the design point that is estimated by resistance tests and open water tests

UA for the ITTC-1978 PPP Method (7)

A real example: 36,000DWT Bulk Carrier

Preparatory steps: estimate of design speed and design point of propeller

$$\hat{V}_S \approx 13.5kts \quad \text{and} \quad \hat{J}_0 \approx 0.40$$

- Repeat tests at the vicinity of the estimated design point to evaluate the measurement uncertainties of model tests

Repeat tests	Test points
Resistance test	$V_1 \approx \hat{V}_S - 1.0kts$ $V_2 \approx \hat{V}_S$ $V_3 \approx \hat{V}_S + 1.0kts$
Open water test	$J_1 \approx \hat{J}_0 - 0.05$ $J_2 \approx \hat{J}_0$ $J_3 \approx \hat{J}_0 + 0.05$
Self-propulsion test	$V_1 \approx \hat{V}_S - 1.0kts$ $V_2 \approx \hat{V}_S$ $V_3 \approx \hat{V}_S + 1.0kts$

UA for the ITTC-1978 PPP Method (8)

A real example: 36,000DWT Bulk Carrier

Repeat Tests

Uncertainty Sources	Standard Uncertainty		
	Components	$V_S\,(kts)$ =13.646	$N_S\,(rpm)$ =132.943
Resistance test	R_{Tm}: ±1.2%	$u_1(V_S)$=**0.029**	$u_1(N_S)$=**0.400**
Open water test	K_{Tm}: ±0.42%	$u_2(V_S)$=0.005	$u_2(N_S)$=0.066
	K_{Qm}: ±0.75%	$u_3\,(V_S)$=0.003	$u_3(N_S)$=0.091
Self-propulsion test at speed V_1	F_{D1}: ±4.1%	$u_4(V_S)$=0.000	$u_4(N_S)$=0.004
	T_{1m}: ±4.1%	$u_4(V_S)$=0.000	$u_4(N_S)$=0.000
	Q_{1m}: ±4.1%	$u_4(V_S)$=0.000	$u_4(N_S)$=0.000
Self-propulsion test at speed V_2	F_{D2}: ±3.1%	$u_4(V_S)$=**0.055**	$u_4(N_S)$=**0.360**
	T_{2m}: ±0.71%	$u_4(V_S)$=0.002	$u_4(N_S)$=0.011
	Q_{2m}: ±0.62%	$u_4(V_S)$=**0.018**	$u_4(N_S)$=**0.221**
Self-propulsion test at speed V_3	F_{D3}: ±3.6%	$u_4(V_S)$=**0.064**	$u_4(N_S)$=**0.481**
	T_{3m}: ±0.36%	$u_4(V_S)$=0.001	$u_4(N_S)$=0.005
	Q_{3m}: ±0.46%	$u_4(V_S)$=0.003	$u_4(N_S)$=0.035
(u_1~ u_{12}) Combined Standard Uncertainty		$u_C(V_S)$ = 0.091	$u_C(N_S)$ = 0.76
Expanded Combined Uncertainty		$U_C(V_S)$ = 0.18	$U_C(N_S)$ = 1.5

UA for the ITTC-1978 PPP Method (9)

A real example: 36,000DWT Bulk Carrier

Calibration

Uncertainty Sources	Components	Standard Uncertainty $V_S(kts)=13.646$	Standard Uncertainty $N_S(rpm)=132.943$
Load cell Calibration (±0.015kgf)	R_{Tm} ±0.39%	$u_{13}(V_S)=0.009$	$u_{13}(N_S)=$**0.130**
	F_{D1} ±1.2%	$u_{14}(V_S)=0.000$	$u_{14}(N_S)=0.001$
	F_{D2} ±0.96%	$u_{15}(V_S)=$**0.017**	$u_{15}(N_S)=$**0.111**
	F_{D3} ±0.91%	$u_{16}(V_S)=$**0.016**	$u_{16}(N_S)=$**0.122**
(±0.048kgf) Dynamometer Calibration (±0.0022kgf)	K_{Tm} ±0.60%	$u_{13}(V_S)=0.007$	$u_{13}(N_S)=0.009$
	T_{1m} ±0.09%	$u_{14}(V_S)=0.000$	$u_{14}(N_S)=0.000$
	T_{2m} ±0.08%	$u_{15}(V_S)=0.000$	$u_{15}(N_S)=0.001$
	T_{3m} ±0.06%	$u_{16}(V_S)=0.000$	$u_{16}(N_S)=0.001$
(±0.030kgf·cm) Dynamometer Calibration (±0.0081kgf·cm)	K_{Qm} ±0.17%	$u_{17}(V_S)=0.000$	$u_{13}(N_S)=0.018$
	Q_{1m} ±0.15%	$u_{18}(V_S)=0.000$	$u_{14}(N_S)=0.000$
	Q_{2m} ±0.14%	$u_{19}(V_S)=0.004$	$u_{15}(N_S)=0.050$
	Q_{3m} ±0.11%	$u_{20}(V_S)=0.001$	$u_{16}(N_S)=0.008$
(u_{13}~ u_{20}) Combined Standard Uncertainty		$u_C(V_S)=0.026$	$u_C(N_S)=0.22$
Expanded Combined Uncertainty		$U_C(V_S)=$ **0.052**	$U_C(N_S)=$ **0.43**

UA for the ITTC-1978 PPP Method (10)

A real example: 36,000DWT Bulk Carrier

Total Uncertainty

Uncertainty Sources	Standard Uncertainties	
	$V_S(kts)=13.646$	$N_S(rpm)=132.943$
Repeat model tests	$u(V_S)=0.091$	$u(N_S)=0.76$
Calibrations	$u(V_S)=0.026$	$u(N_S)=0.22$
Combined Uncertainty	$\mathbf{u_C(V_S)=0.095}$	$\mathbf{u_C(N_S)=0.79}$
Expanded Combined Uncertainty	$\mathbf{U_C(V_S)=0.19}$	$\mathbf{U_C(N_S)=1.6}$
Prediction	$V_S(kts)=\mathbf{13.65 \pm 0.19}$	$N_S(rpm)=\mathbf{132.9 \pm 1.6}$

Significant Uncertainty Sources:

The contribution of calibration uncertainty (bias uncertainty) is almost negligible with comparing to that of uncertainties (precision uncertainty) resulted from the repeat tests.

UA for the ITTC-1978 PPP Method (11)

A real example: 36,000DWT Bulk Carrier

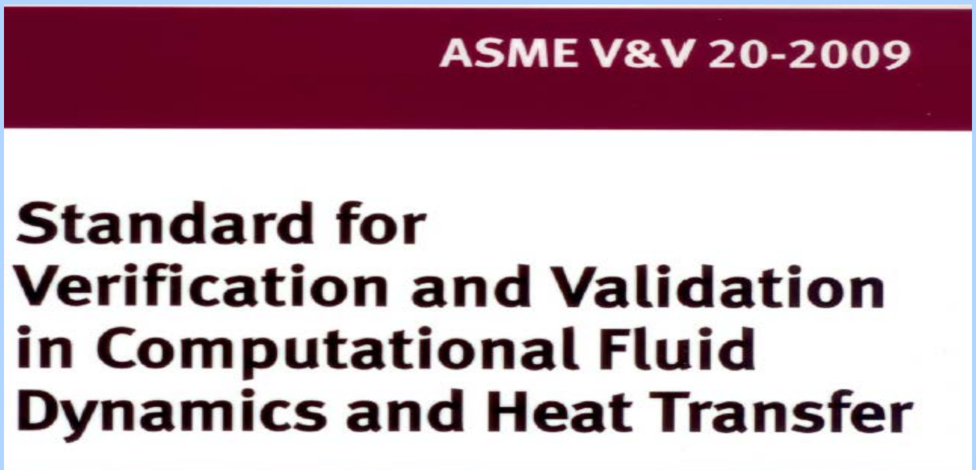
Conclusive Remarks

- The uncertainties from model tests can be evaluated with the method suggested in the example. *The uncertainty of level of confidence 95% for the ship speed prediction is 0.19kts, while the uncertainty for the propeller revolution is 1.6rpm*
- The significant uncertainties unavailable will result from the model-ship correlation.

25th ITTC Powering Performance Prediction (2008) found that the database of 120 ships doesn't contain enough high quality complete datasets to enable a reasonable correlation study.

Uncertainty Analysis for CFD (1)

Important Advance in UA for CFD



The Objective is the specification of a verification and validation that the degree of accuracy inferred from the comparison of solution and data for a specified at a variable at a specified validation point

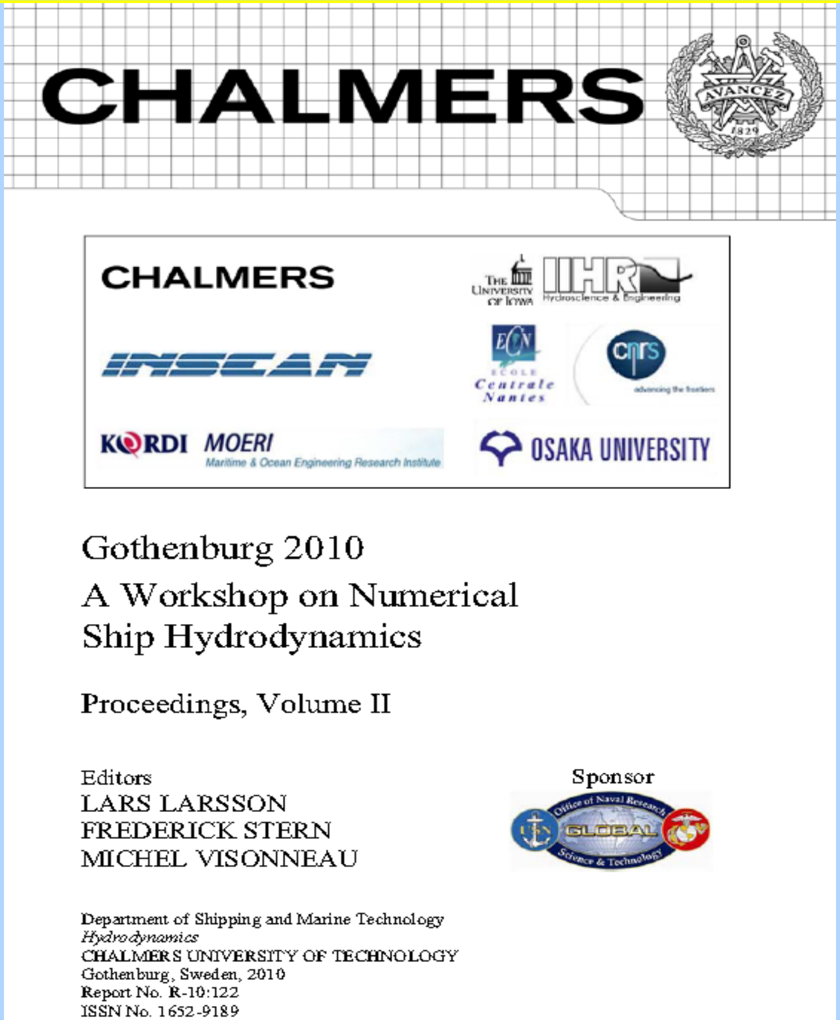
Uncertainty Analysis for CFD (2)

Important Advance in UA for CFD

Three hulls of different types were used and 18 test cases using these hulls were specified.

33 groups carried out computations for one or more cases and reported the results to the organizers who compiled the results.

- Most of groups who had performed V&V and presented uncertainty results complied with the ITTC-2008 approach for UA of CFD.



Uncertainty Analysis for CFD (3)

Concluding remarks based on review

ITTC Recommended Procedure 7.5-03-01-01 (Revision 02), 2008

Uncertainty Analysis in CFD, Verification and Validation Methodology and Procedures

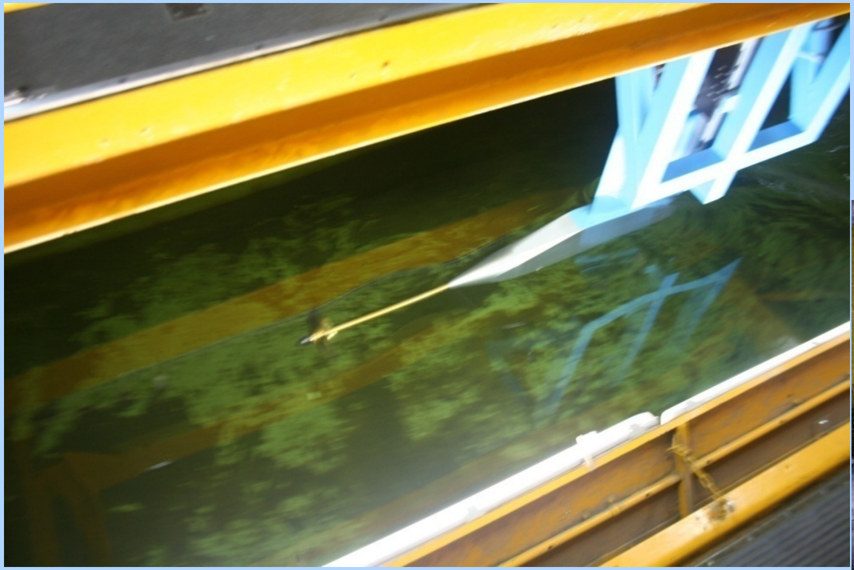
- The ITTC procedure is very detailed for estimating the uncertainty in a simulation result. It is intended for practical use and presented in an easily-implemented way.
- Basically, the ITTC recommended approach is consistent with the ASME V&V20
- It is recommended to keep ***Procedure 7.5-03-01-01*** relatively stable other than updating frequently.

  A sufficient number of documented V&V solutions for practical applications will be necessary for ***programmatic levels of uncertainty to be established****, which will provide targets for reductions in numerical and experimental uncertainties (****Larsson, et al, 2003****)*

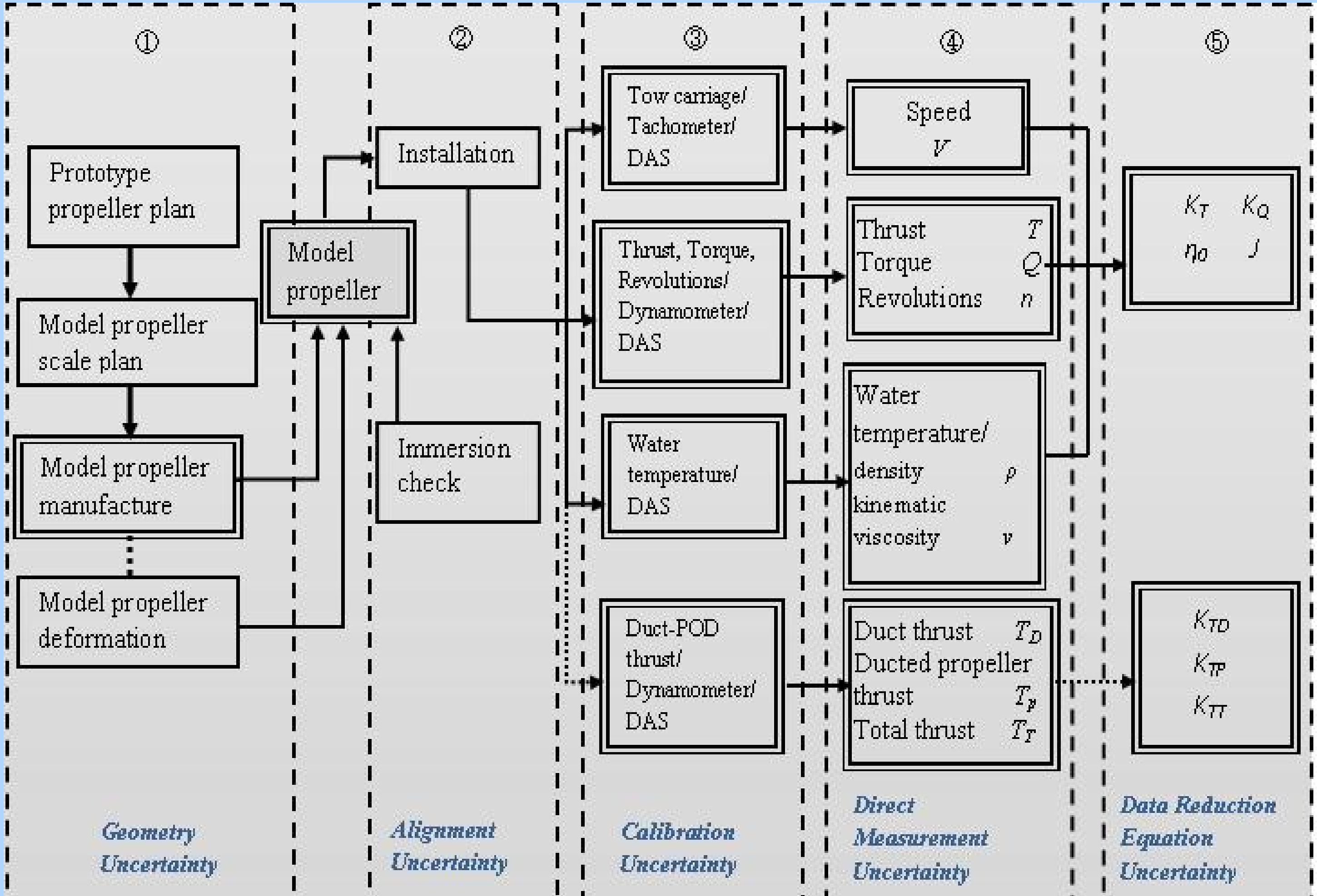
➢ V&V is more empirical than mathematical

  *The various approaches to error estimation and quantification of uncertainty in CFD have their relative merits. (****Roache, 1997****)*

Open water & propulsion Procedures



Open water Procedure



Open water Procedure

Data reduction equations:

$$K_T = \frac{T}{\rho \cdot n^2 \cdot D^4}$$

$$K_Q = \frac{Q}{\rho \cdot n^2 \cdot D^5}$$

$$J = \frac{V_A}{nD}$$

$$\eta_0 = \frac{J K_T}{2\pi K_Q}$$

Open water Procedure

Uncertainty Analysis for propellers coefficients:

$$\left(u_{K_T}/K_T\right)^2=\left(u_T/T\right)^2+\left[\left(u_t\cdot\partial\rho/\partial t\right)/\rho\right]^2+\left(2u_n/n\right)^2+\left(4u_D/D\right)^2$$

$$\left(u_{K_Q}/K_Q\right)^2=\left(u_Q/Q\right)^2+\left[\left(u_t\cdot\partial\rho/\partial t\right)/\rho\right]^2+\left(2u_n/n\right)^2+\left(5u_D/D\right)^2$$

$$\left(u_J/J\right)=\left(u_{V_A}/V_A\right)^2+\left(u_n/n\right)^2+\left(u_D/D\right)^2$$

$$\left(u_{\eta_0}/\eta_0\right)=\left(u_J/J\right)^2+\left(u_{K_T}/K_T\right)^2+\left(u_{K_Q}/K_Q\right)^2$$

Uncertainty Analysis for propellers coefficients (example)

$$\boxed{\left(u_{K_T}/K_T\right)^2 = \left(u_T/T\right)^2 + \left[\left(u_t \cdot \partial\rho/\partial t\right)/\rho\right]^2 + \left(2u_n/n\right)^2 + \left(4u_D/D\right)^2}$$

$$u_T = \sqrt{u_A^2 + u_B^2}$$

$$u_B = u(F) = \sqrt{u_1^2(F) + u_2^2(F)}$$

$$u_A = s_T/\sqrt{n}$$

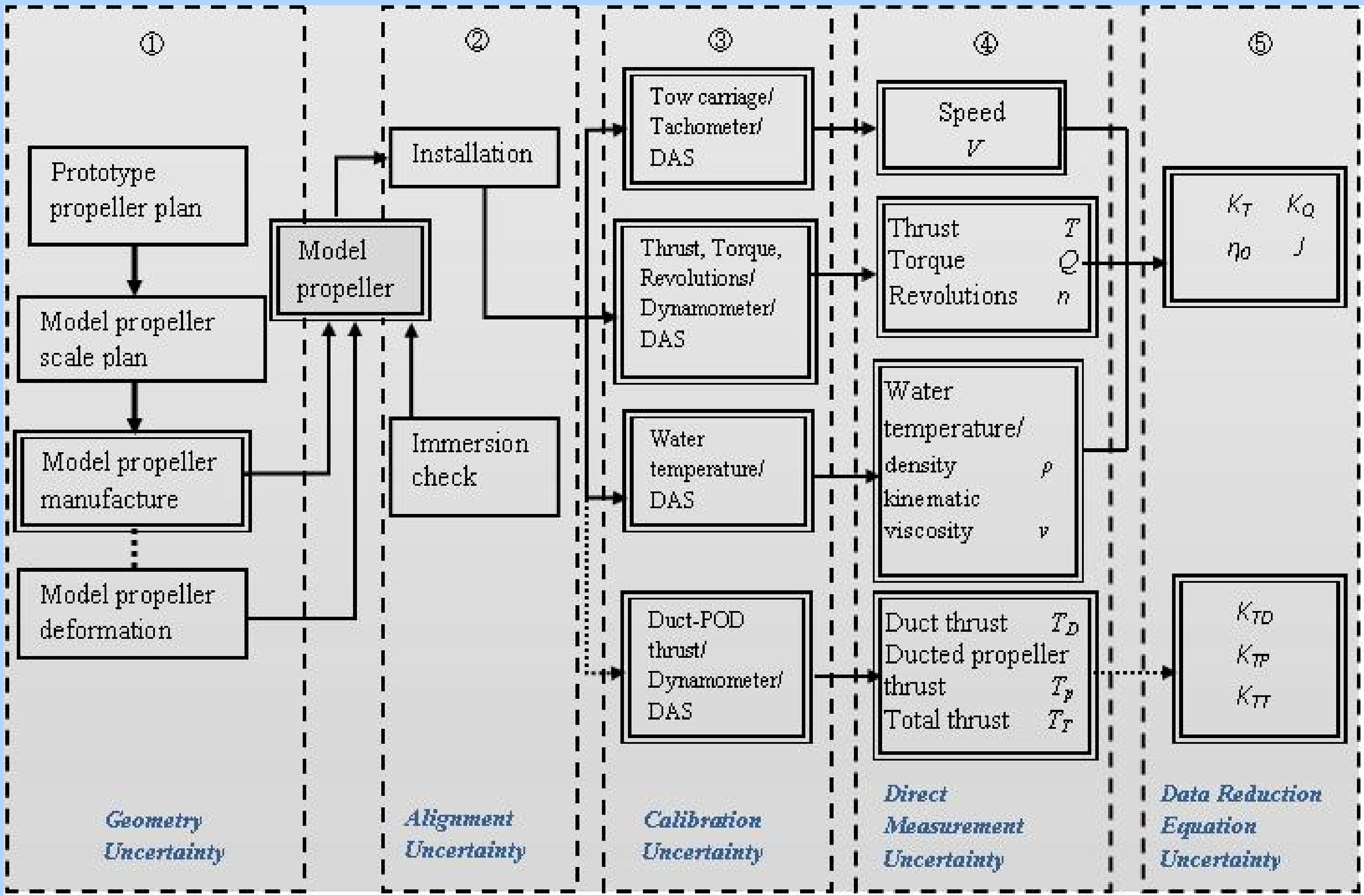
$$u_2(F) = SEE = \sqrt{SS_R/(n-2)}$$

$$u_1(F)/F = \sqrt{\left(u_m/m\right)^2 + \left(u_g/g\right)^2}$$

Open water Procedure

$$u_m = \sum_{i=1}^{n} u_i$$

Open water Procedure



Propulsion Procedure

Data reduction equations:

$$K_T = \frac{T}{\rho \cdot n^2 \cdot D^4}$$

$$K_Q = \frac{Q}{\rho \cdot n^2 \cdot D^5}$$

$$w_T = 1 - \frac{J_T D n}{V}$$

$$\eta_R = \frac{K_{QT}}{K_Q}$$

$$t = \frac{T + F_D + R_C}{T}$$

Uncertainty Analysis for propulsion coefficients

Propulsion Procedure

$$(u_{w_T}/w_T)^2 = (u_{J_T}/J_T)^2 + (u_D/D)^2 + \\ + (u_n/n)^2 + (u_V/V)^2$$

$$(u_{\eta_R}/\eta_R)^2 = (u_{K_{QT}}/K_{QT})^2 + (u_{K_Q}/K_Q)^2$$

$$(u_t/t) = (u_T/T)^2 + (u_{F_D}/F_D)^2 + (u_{R_C}/R_C)^2$$

$$(u_F/F)^2 = (u_{1+k}/(1+k))^2 + (u_{C_{FC}}/C_{FC})^2 \\ + (u_{C_R}/C_R)^2$$

$$(u_{R_C}/R_C) = (u_{R_T}/R_T)^2 + (u_F/F)^2$$

$$(u_{F_D}/F_D)^2 = \left[\left(u_t \cdot \partial\rho/\partial t\right)/\rho\right]^2 + (u_S/S)^2 + \\ (2u_V/V)^2 + (u_{1+k}/(1+k))^2 + (u_{C_{FC}}/C_{FC})^2$$

The 2010 ITTC UAC workshop

GENERAL INFORMATION

The City of St. John's is very warm and welcoming. In a typical June month, icebergs and whales/birds watching are just some of many attractions St. John's offers. From the business perspective, St. John's is the home of several Ocean Technology laboratories and the Ocean Technology Cluster called "Oceansadvance" that is made up of over 60 companies and interacts with a larger number of oil and gas companies and marine related industries.

Contact Information
For info on the UA workshop/training, please contact:
Ahmed.Derradji-Aouat@nrc-cnrc.gc.ca

Workshop Document repository Contact Information:
http://researchers.iot.nrc.ca/~derradji/ITTC/

Relevant Information
Information for NRC-IOT (Host laboratory):
http://www.nrc-cnrc.gc.ca/eng/ibp/iot.html

Information for Canada-National Metrology Institute:
http://www.nrc-cnrc.gc.ca/inms-ienm/index.html

Information for the city of St. John's, Newfoundland:
http://www.stjohns.ca/index.jsp

Information for Canada Ocean Technology Cluster:
www.Oceansadvance.net

LIAISONS WITH OTHER ITTC COMMITTEES

In order to further facilitate communications between the UAC and other ITTC committees, the UAC designated at least one of its members to be the permanent contact point with another committee, as shown below. This includes all necessary communications; not only communications concerning the 2010 UA workshop.

	Committee/Group	UA - Member
ITTC General Committees	Resistance	A.O., L.P.R, W.B.
	Propulsion	W.B.
	Manoeuvring	M.W., M.R.,W.B.
	Seakeeping	A.D., W.B.
	Ocean Engineering	W.B, M.W.
ITTC Specialist Committees	CFD in Marine Hydrodynamics	S.N., M.R., A.O.
	Scaling of Wake Fields	L.P.R.
	Surface Treatment	M.W.
	High-Speed Craft	S.N.
	Stability in Waves	A.O.
	Vortex Induced Vibration	A.D., A.O.
	Detailed Flow Measurement	W.B.
ITTC Group	Quality Systems Group	A.D.

A.O. (Angelo Olivieri, Italy),
W.B. (Wu Baoshan, China),
S.N. (Shigeru Nishio, Japan),
M.R. (Martijn van Rijsbergen, The Netherlands),
L.P.R. (Luis Pérez Rojas, Spain),
M.W. (Michael Woodward, UK) and
A.D. (Ahmed Derradji-Aouat, Canada)

The 2010 ITTC Workshop on Uncertainty Analysis

June 8 and 9, 2010

NRC-IOT,
St. John's, Newfoundland, Canada

ITTC

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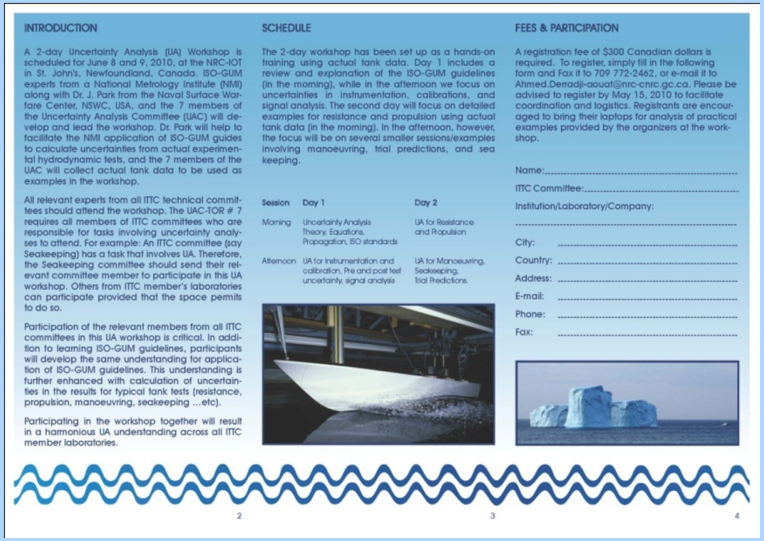

INTRODUCTION

A 2-day Uncertainty Analysis (UA) Workshop is scheduled for June 8 and 9, 2010, at the NRC-IOT in St. John's, Newfoundland, Canada. ISO-GUM experts from a National Metrology Institute (NMI) along with Dr. J. Park from the Naval Surface Warfare Center, NSWC, USA, and the 7 members of the Uncertainty Analysis Committee (UAC) will develop and lead the workshop. Dr. Park will help to facilitate the NMI application of ISO-GUM guides to calculate uncertainties from actual experimental hydrodynamic tests, and the 7 members of the UAC will collect actual tank data to be used as examples in the workshop.

All relevant experts from all ITTC technical committees should attend the workshop. The UAC-TOR # 7 requires all members of ITTC committees who are responsible for tasks involving uncertainty analyses to attend. For example: An ITTC committee (say Seakeeping) has a task that involves UA. Therefore, the Seakeeping committee should send their relevant committee member to participate in this UA workshop. Others from ITTC member's laboratories can participate provided that the space permits to do so.

Participation of the relevant members from all ITTC committees in this UA workshop is critical. In addition to learning ISO-GUM guidelines, participants will develop the same understanding for application of ISO-GUM guidelines. This understanding is further enhanced with calculation of uncertainties in the results for typical tank tests (resistance, propulsion, manoeuvring, seakeeping ...etc).

Participating in the workshop together will result in a harmonious UA understanding across all ITTC member laboratories.

SCHEDULE

The 2-day workshop has been set up as a hands-on training using actual tank data. Day 1 includes a review and explanation of the ISO-GUM guidelines (in the morning), while in the afternoon we focus on uncertainties in instrumentation, calibrations, and signal analysis. The second day will focus on detailed examples for resistance and propulsion using actual tank data (in the morning). In the afternoon, however, the focus will be on several smaller sessions/examples involving manoeuvring, trial predictions, and sea keeping.

Session	Day 1	Day 2
Morning	Uncertainty Analysis Theory, Equations, Propagation, ISO standards	UA for Resistance and Propulsion
Afternoon	UA for Instrumentation and calibration, Pre and post test uncertainty, signal analysis	UA for Manoeuvring, Seakeeping, Trial Predictions.

FEES & PARTICIPATION

A registration fee of $300 Canadian dollars is required. To register, simply fill in the following form and Fax it to 709 772-2462, or e-mail it to Ahmed.Derradji-aouat@nrc-cnrc.gc.ca. Please be advised to register by May 15, 2010 to facilitate coordination and logistics. Registrants are encouraged to bring their laptops for analysis of practical examples provided by the organizers at the workshop.

Name: ....

ITTC Committee: ....

Institution/Laboratory/Company:

....

City: ....

Country: ....

Address: ....

E-mail: ....

Phone: ....

Fax: ....

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June 8 and 9, 2010, St. John’s, NL, Canada (NRC-IOT)

25 Participants

2 CDs Proceedings

Dr. Joel Park and Dr. Rob Douglass (Instructors/Facilitators)

Questions ?