The Resistance Committee

Final Report

RC members & meetings

- Chairman: Emilio F. **Campana**, *INSEAN, Italy*
- Secretary: Joseph **Gorski**, *Carderock Div,Naval Surface Warfare Center, USA*
  - Ho-Hwan **Chun**, *Pusan National University, Korea*
  - A. H. (Sandy) **Day**, *Universities of Glasgow and Strathclyde, UK*
  - De-Bo **Huang**, *Harbin Engineering University, China*
  - Gregor **MacFarlane**, *Australian Maritime College, Australia*
  - Tommi **Mikkola**, *Helsinki University of Technology, Finland*
  - Yusuke **Tahara**, *Osaka Prefecture University, Japan*
  - Jesus **Valle**, *Canal de Experiencias Hidrodinamicas de El Pardo (CEHIPAR), Spain*

I. 6 ~ 7 February 2006, Launceston, Australia

II. 16 ~ 17 September 2006, Rome, Italy

III. 3 ~ 4 May 2007, Valencia, Spain

IV. 11 ~ 12 December 2007, Washington, USA

Structure of the RC report

1. Introduction
2. Review of Procedures - Questionnaire
3. Trends in Experimental Fluid Dynamics
4. Scaling and Extrapolation Methods
5. Trends in Computational Fluid Dynamics
6. Validation of Prediction Techniques
7. Worldwide Comparative Tests on the Facilities Bias
8. Design and optimization
9. Far-Field Waves and Wash
10. Airwakes

2. Review of Procedures

The Resistance Committee (RC) was charged with reviewing procedures 7.5-01-01-01 and 7.5-02-02-01 to 7.5-02-02-06.

- **ship model manufacture**,
- **resistance tests**,
- **uncertainty analysis of measurement of**
  - *resistance,*
  - *speed,*
  - *sinkage/trim,*
  - *wave profile.*

RC was asked to determine if changes are required in light of current practice, and to identify requirements for new procedures

Questionnaire: Resistance Test Procedure

In some parts of the procedures, improvements could be made in wording and notation; however **some areas also offered the potential for technical improvements**

The RC prepared a questionnaire on issues considered by the RC to offer potential for improvement. This addressed three areas:

- Turbulence Stimulation and Scaling;
- Speed Measurement,
- Model Installation.

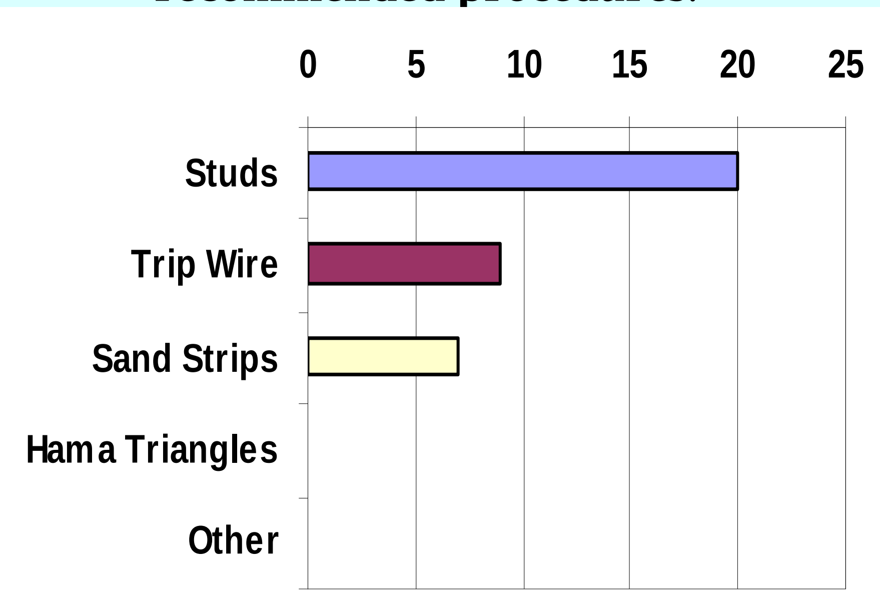
The questionnaire was circulated by e-mail to all ITTC facilities.

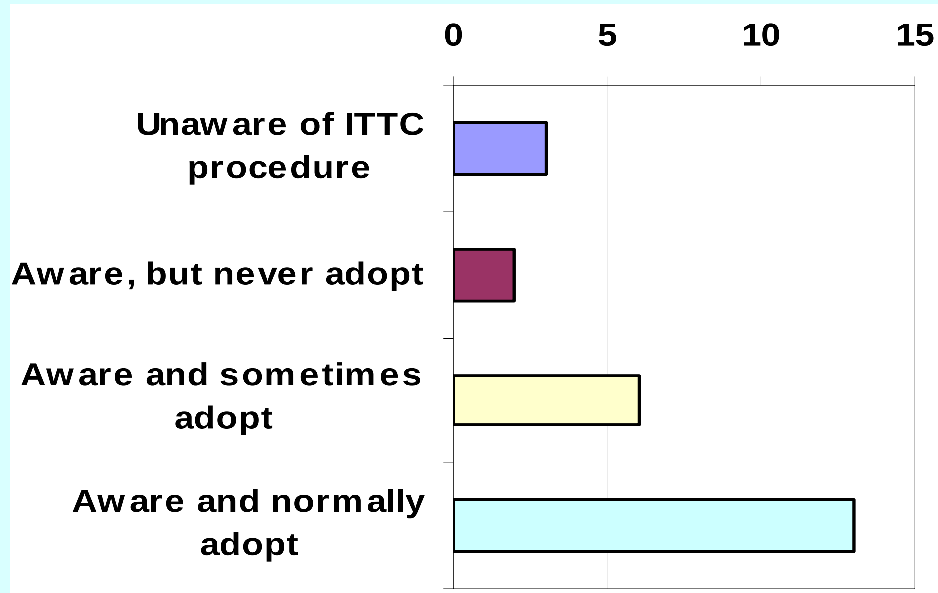
25 facilities replied to the questionnaire; 11 from Europe, 11 from Asia and Australia and 3 from the Americas.

The results of the questionnaire were used to inform the proposed changes to the procedures

Turbulence Stimulation

Members were asked **what approach** they adopted, and **whether they followed recommended procedures**.



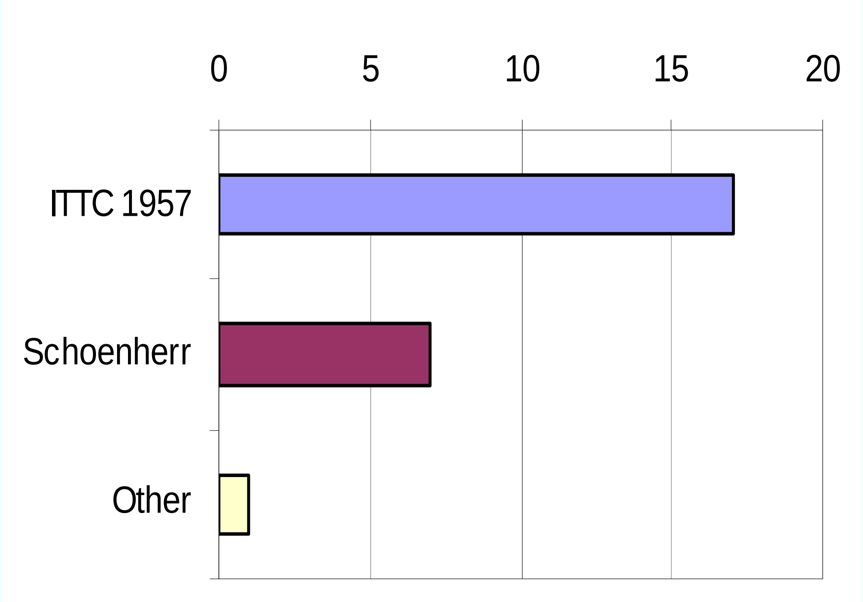


Issues raised by members include:

- turbulence stimulation on **bulbous bows**, on vessels with **large dynamic trim,** on **appendages**;
- special procedures required for **yachts**

Scaling

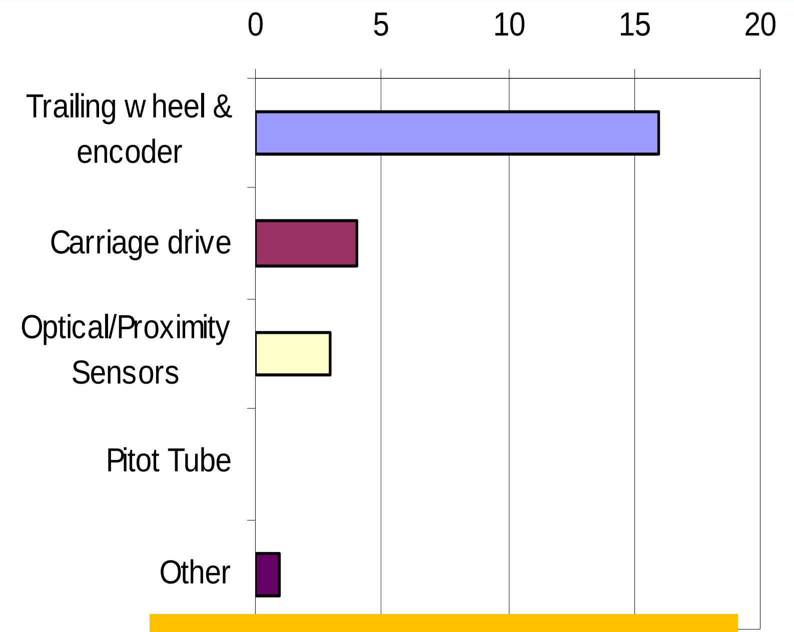
Members were asked **which correlation line** they adopted



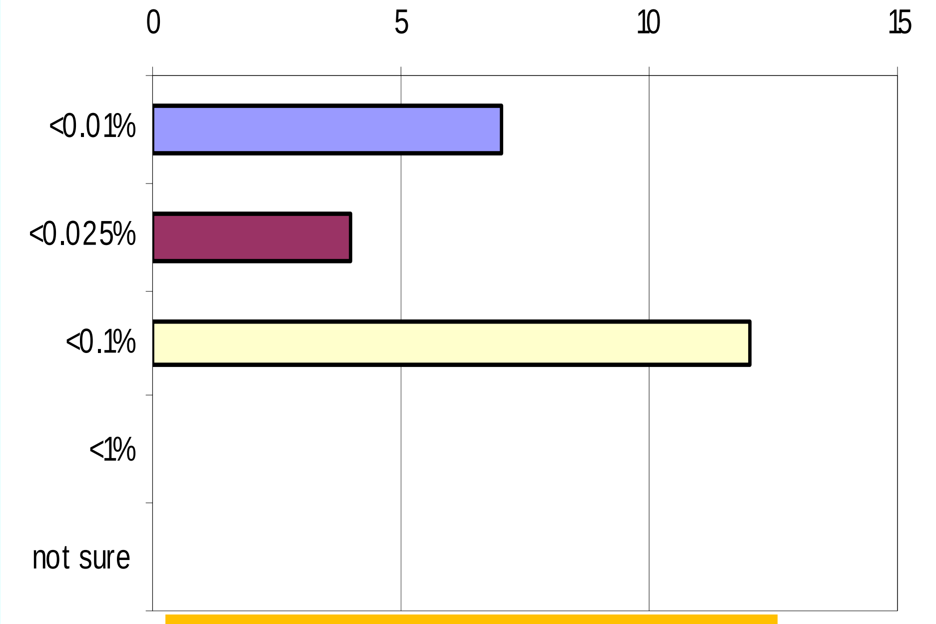
Japanese Members predominantly use the Schoenherr line; other members predominantly use the ITTC 1957 line

Speed Measurement

Key questions included **which instrumentation** members adopted, and **what accuracy** they expected. Results are shown below:



Primary speed measurement



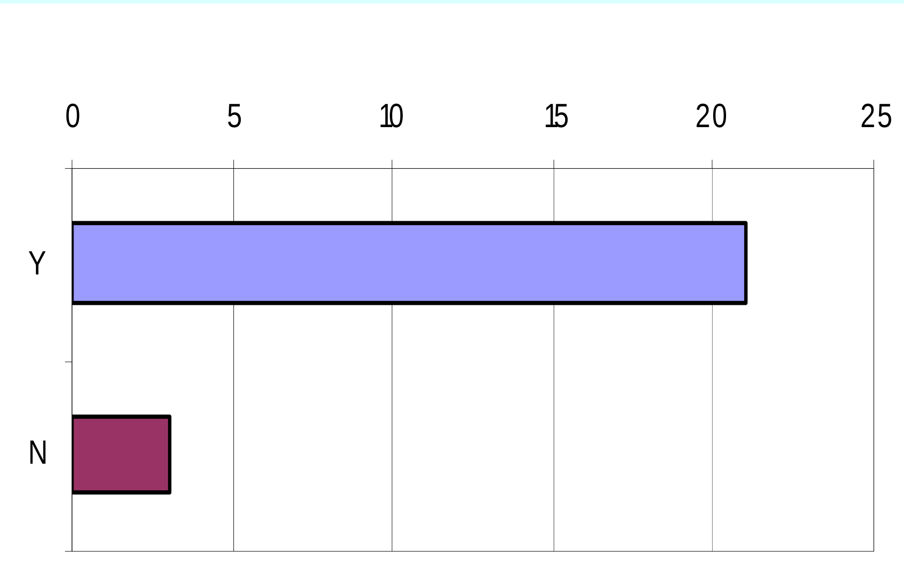
Speed measurement accuracy

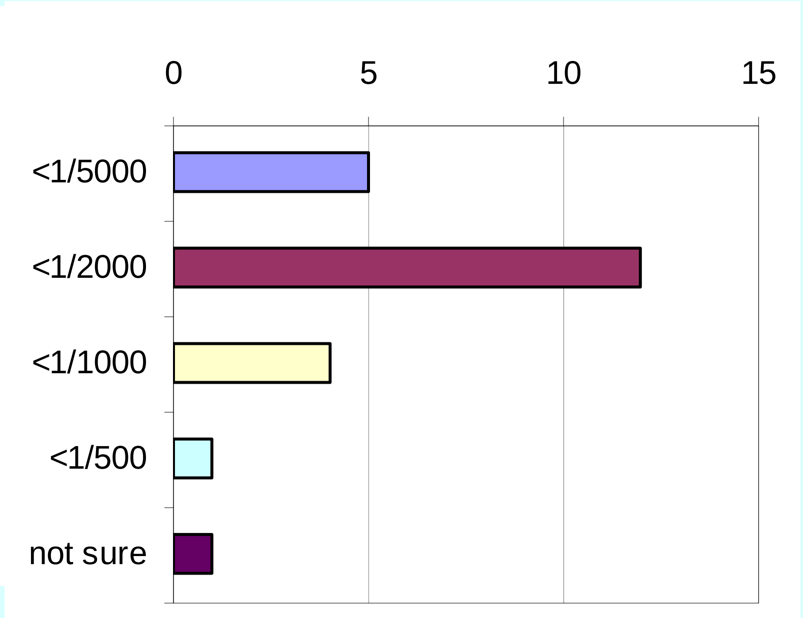
Frequency of speed calibration was reported to vary between **daily calibration** and **calibration over several years**; typical values indication calibration once or twice per year.

All facilities indicated accuracy better then current standard (0.1%)

Model Installation

Members were asked a series of questions, including **whether they followed ITTC** procedure related to the towing attachment, how they handled challenging hull forms and **what accuracy of alignment** they expected.





Some members indicated that there are fundamental inconsistencies with the current procedure for ships with non-horizontal shafts

It is suggested that towing at the waterline with a horizontal force may provide a useful alternative reference condition in challenging cases

Changes to procedures

7.5-01-01-01: Model Manufacture: Ship models

There were few revisions of substance proposed. A number of minor changes were suggested:

- A number of modifications and additions to detailed specifications of parameters such as **error tolerances** were suggested.
- A few minor recommendations were added for completeness in line with common practice
- Some **clarifications** were made (in particular with regard to ballasting procedure) to reduce scope for **errors of interpretation**
- Typographical errors were corrected.

Changes to procedures

7.5-02-02-01: Testing and Extrapolation Methods: Resistance

A number of revisions were proposed. These address:

- Clarification of **range of vessel types**
- Additional recommendations regarding **model installation and alignment**
- Clarifications and additions to **lists of "typical" instruments** used for various measurement tasks
- Record-keeping of **signal conditioning and data acquisition** configuration
- Practice related to **zeroing** of instruments
- Practice related to **averaging oscillatory variation of wave resistance**
- Choice of **sampling rates** for data acquisition systems
- Use of Prohaska test for vessels with transom sterns

New Facilities

As part of the questionnaire, members were asked what major new facilities they had commissioned during the period between the 24th and 25th ITTC.
Three replies were received:

Australian Maritime College: A **new cavitation tunnel** is being commissioned during 2008. The tunnel is of the vertical plane, closed recirculating type. The working section maximum velocity is 12m/s, and the maximum and minimum absolute pressures are 400kPa, 4kPa. The cavitation number range is from 0.07 to 5.5

CEHIPAR have installed a **numerically-controlled five-axis milling machine** with capacity to produce models up to 10950 mm long, 2500 mm wide and 1200 mm high using a range of materials including aluminium, bronze, wood, paraffin wax, PVC, polystyrenes, polyurethanes

Universities of Glasgow and Strathclyde A **new four-paddle absorbing wavemaker** was installed which can generate periodic waves from 0.2Hz -2Hz. Periodic waves over 600mm in height can be generated; single breaking waves can be generated up to around 1000mm in height.

3. Trends in Experimental Fluid Dynamics

- Review for new techniques and trends in EFD
    - New and advanced techniques in hydrodynamic experiments
    - Wake and pressure measurements
    - Wave breaking and wave profile measurements
    - Full scale tests
    - Drag reduction

New and Advanced Techniques in Hydrodynamic Experiments

New developments in hydrodynamic experiments and measurement techniques in towing tanks, water channels and wind tunnels

EFD progress is closely related with the improvements of **optical techniques** such as:

- Particle Image Velocimetry (PIV),
- Particle Tracking Velocimetry (PTV),
- Laser Doppler Velocimetry (LDV),
- Laser Induced Fluorescence (LIF)

and other techniques such as Acoustic Doppler Velocimetry (ADV)

Wake and Pressure

- Wake and turbulent flow measurement behind a structure using PIV (Paik et al., 2007 and Wosnik & Arndt, 2006)

- Application of the **stereoscopic PIV** system to investigate flow structures behind cylinder (Perrin et al., 2007) and of a prototype waterjet model (Jung et al., 2006)

- **Pressure Sensitive Paint (PSP)** in wind tunnel
  - Dynamic and static surface pressure on a square cylinder measured by PSP (McGraw et al., 2006)
  - Evaluation four PSP formulation in slow speeds wind tunnel (Lee and Kang, 2006)

Wave Breaking and Wave Profile Measurement

- Bow waves were measured by laser imaging technique (Karion et al., 2004)
- Model and Full scale reconstruction of the near and far field wave pattern of a given hull, obtained by a combination of various instruments (Rice et al., 2004)
- PIV technique was employed to measure the velocity field near the floating structure and to understand the eddy making damping and turbulent properties (Jung et al., 2005 and Jung et al., 2006)
- Flow field under the plunging wave breaking was obtained by LDV and PIV (Stern et al., 2006)
- Some limitations of PIV and PTV (*light saturation on bubbles*) can be overcome by the combination with LIF

Full Scale Tests

- Full scale measurement of spray droplets from a breaking bow wave was carried out by using a high speed digital video camera (Sur and Chevalier, 2004)
- Velocity measurement in wave field was performed at full scale using ship-mounted LDV during sea trials (Starke et al., 2006)
- Free surface and bubble dynamics around a ship were measured by integrating 11 measurement systems and instruments (Fu et al., 2006)
- LIDAR (LIght Detection And Ranging) was employed to obtain the full scale wave field around Sea Fighter (Terrill and Taylor, 2007)

Drag Reduction

- Microbubble Injection

  Visualization of the interaction b/w the flow and microbubbles using PIV combined with Shadow Image Technique (Kitagawa et al. 2005)

- Polymer Injection

  DR by polymer injection (Baik et al., 2005, and Jovanović et al., 2006) and with combined injection of gas and polymer (Deutsch et al., 2006)

- Compliant Coating

  Collaborative effort of USA, Russia and UK for undersea application (Bandyopadhyay et al., 2005)

- Active Control

4. Scaling and Extrapolation Method

The 25th ITTC RC conducted an analytical study on friction lines

- Overview of Methods
- Comparison of the Results

Friction Lines used in TT activity

The speed-power prediction is one of the most important functions of towing-tank facilities.

During the extrapolation to ship-scale resistance (for power estimation) friction line plays a major role.

Empirical equations for frictional resistance, such as Schoenherr’s formula (Schoenherr, 1932) and the ITTC’57 correlation line, are used.

•Recent reliable measurements of friction resistance for a flat plate indicate that Schoenherr’s formula overestimates the local frictional coefficient by 2-3% even in the range of model scale Reynolds number.

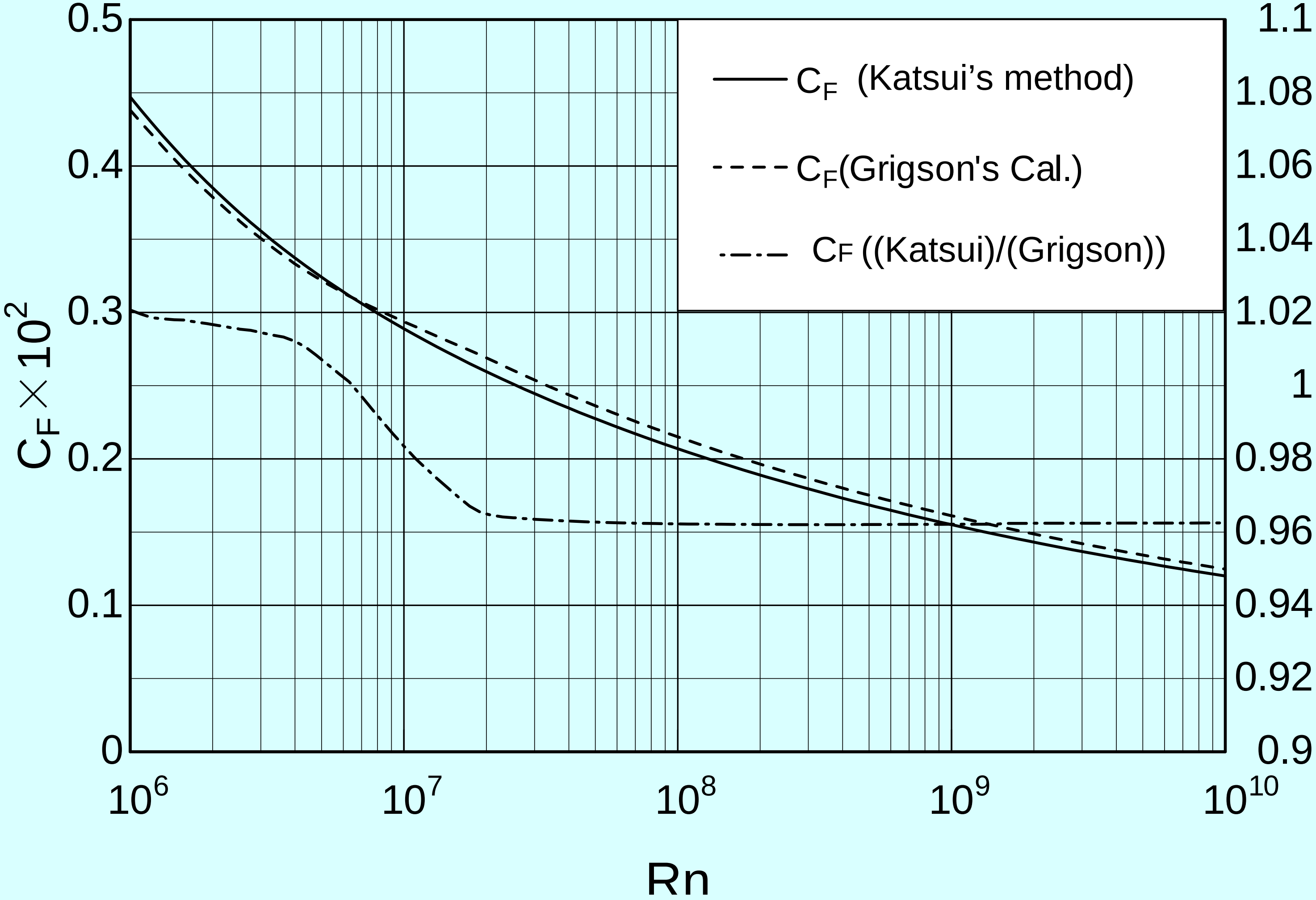
•Grigson (1993) and Katsui et al. (2005) proposed methods to predict friction resistance for model- through ship-scale Reynolds numbers, by solving the momentum integral equation.

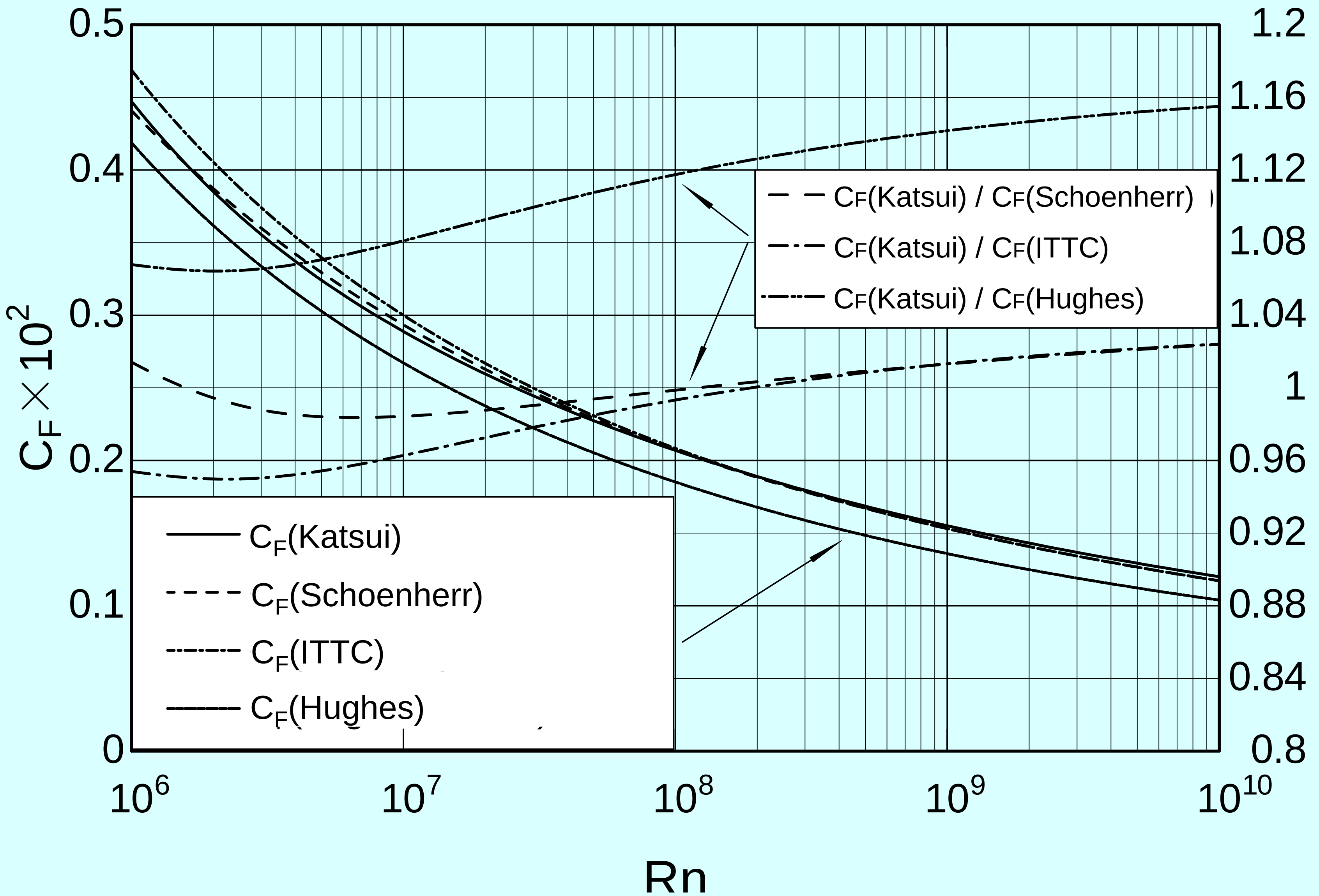
- Both methods are based on the solution of the momentum integral equations and Coles' wall-wake law.

- Major differences between Katsui et al. (2005) and Grigson (1993) :
  - Recent experimental results (Osaka et al., 1993) are considered;
  - More exact form of the differential equations is solved;
  - Definition of the wake parameter;
  - The derivative of the wake parameter is included in the calculation.

Flat plate frictional resistance coefficient

As compared to Grigson's values, CF values are about:
+2% for *Rn*=10^6, –2% for *Rn*=10^7, and –4% for *Rn*=10^9.





0.5
0.4
0.3
0.2
0.1
0
1.2
1.16
1.12
1.08
1.04
1
0.96
0.92
0.88
0.84
0.8
$C_F \times 10^2$
10^6
10^7
10^8
10^9
10^{10}
Rn
CF(Katsui) / CF(Schoenherr)
CF(Katsui) / CF(ITTC)
CF(Katsui) / CF(Hughes)
C_F(Katsui)
C_F(Schoenherr)
C_F(ITTC)
C_F(Hughes)

Summary

- The 25th ITTC RC conducted an analytical study on friction lines, starting to analyse the possible recommendation for a new formula.

$$C_F = \frac{0.0066577}{\left(\log Re - 4.3762\right)^{0.042612 \cdot \log Rn + 0.56725}}$$

- Katsui et al. , 2005 suggest that this formula might be useful for verification of CFD results at ship-scale Reynolds numbers.

- Further discussions about scientific as well as practical aspects are obviously necessary before proposing a new friction line

5. Trends in Computational Fluid Dynamics

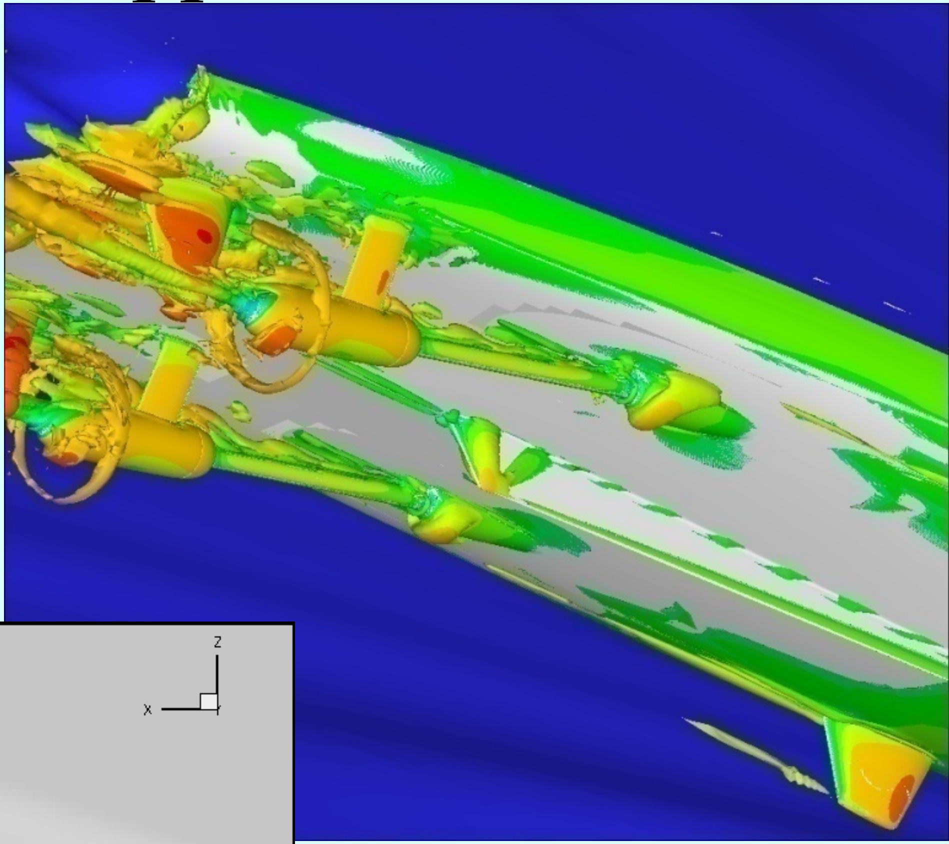
- Practical Applications of CFD
- Progress in Viscous Flow Calculation Methods
- New Applications

Practical Applications of CFD

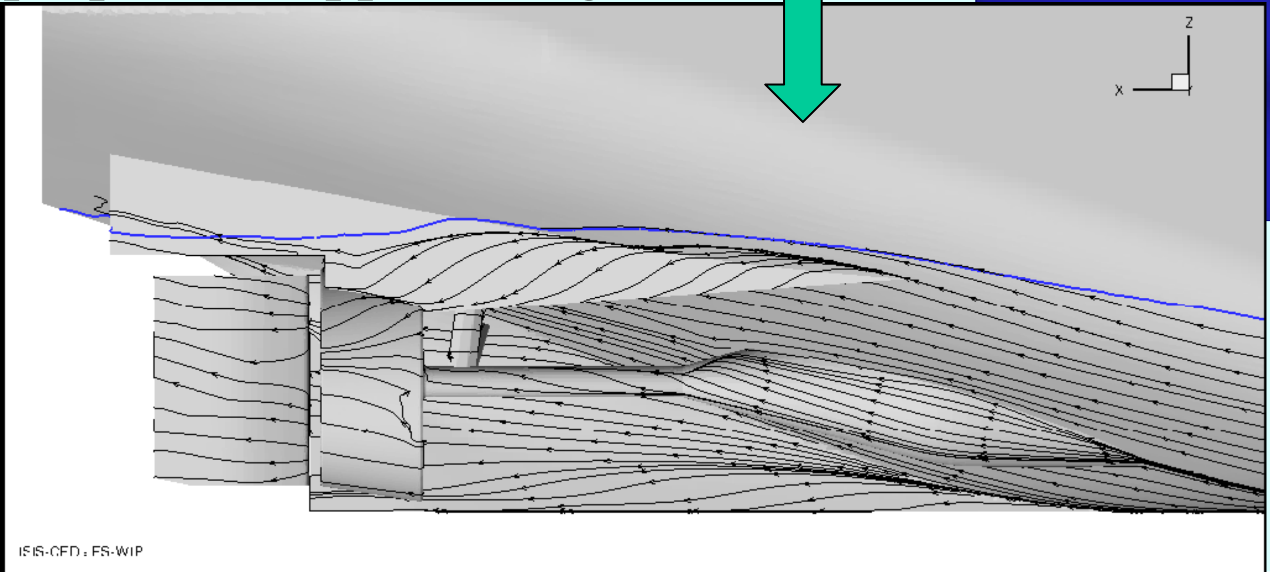
- Inviscid methods still heavily used
  - New Neumann-Michell consistent linear potential flow model proposed by *Noblesse and Yang (2006)* for slender mono- and multihulls
- RANS model scale calculations
  - Large amount of literature for many hull forms: *e.g. Athena blind test case (Wilson et al., 2006)*
  - Increasingly sophisticated with actual geometry: appendages, bilge keels, shafts, struts, propulsors
- RANS full-scale calculations
  - Use of wall functions, surface roughness can be included
  - Becoming nearly as routine for realistic configurations as model scale predictions
  - Limited experimental data for comparison (*EFFORT UE program*)
- More groups able to directly predict sinkage and trim

RANS Practical Applications

Miller et al. (2006)
Athena model scale prediction



Visonneau et al. (2006)
Limiting wall streamlines of propelled hopper-dredger at full scale

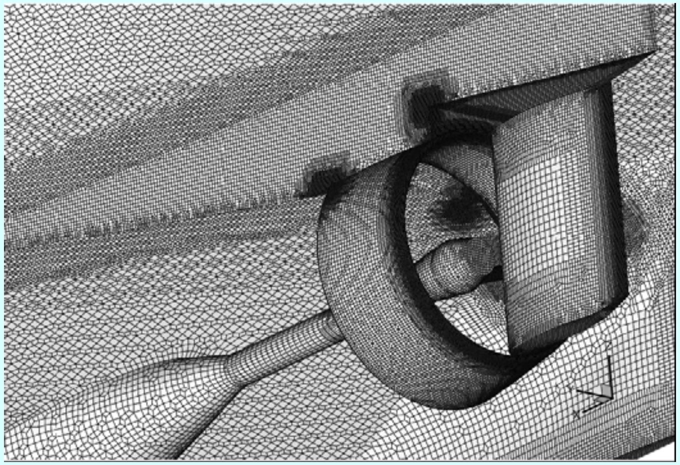


Progress in Viscous Methods

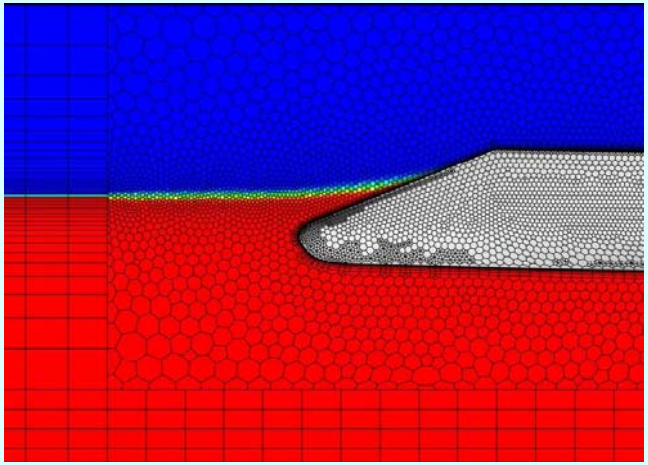
- Continuous evolution of grids and gridding techniques
  - Structured grids most heavily used
    - Good for bare hulls and some complicated geometries
    - Oversets being used more often for complicated geometries
  - Unstructured grids
    - Hexahedral, tetrahedral, and polyhedral
    - Tetrahedral and polyhedral need prism layers for boundary layer accuracy
  - Cartesian being used with **immersed boundary** methods
    - Gridding is trivial (as for Panel codes)
    - Boundary layer prediction still problematic

Gridding

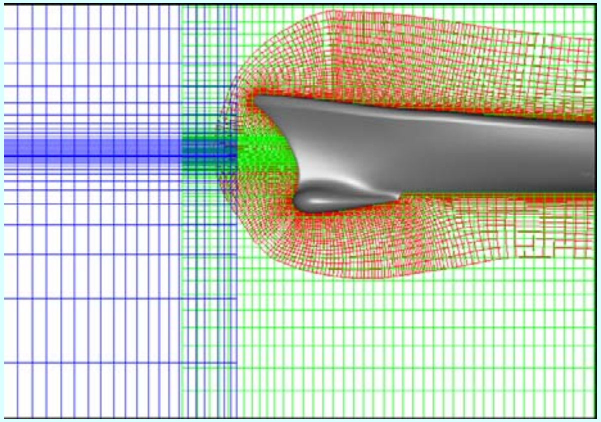
Visonneau et al. (2006) Stern region of hopper-dredger

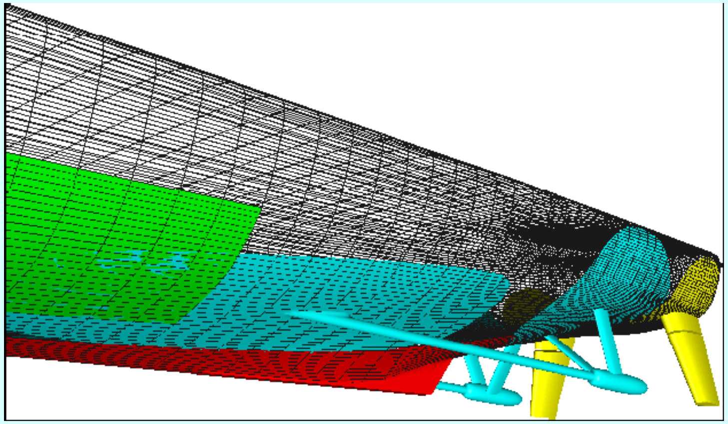


Maki et al. (2007) Trimaran polyhedral grid



Noack (2007) Overset grids for combatant





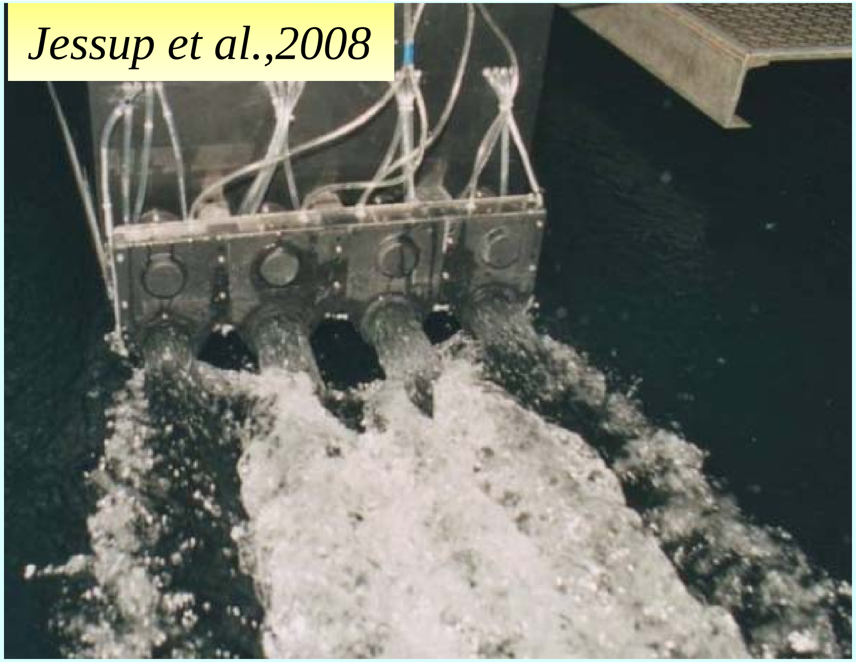
Progress in Viscous Methods

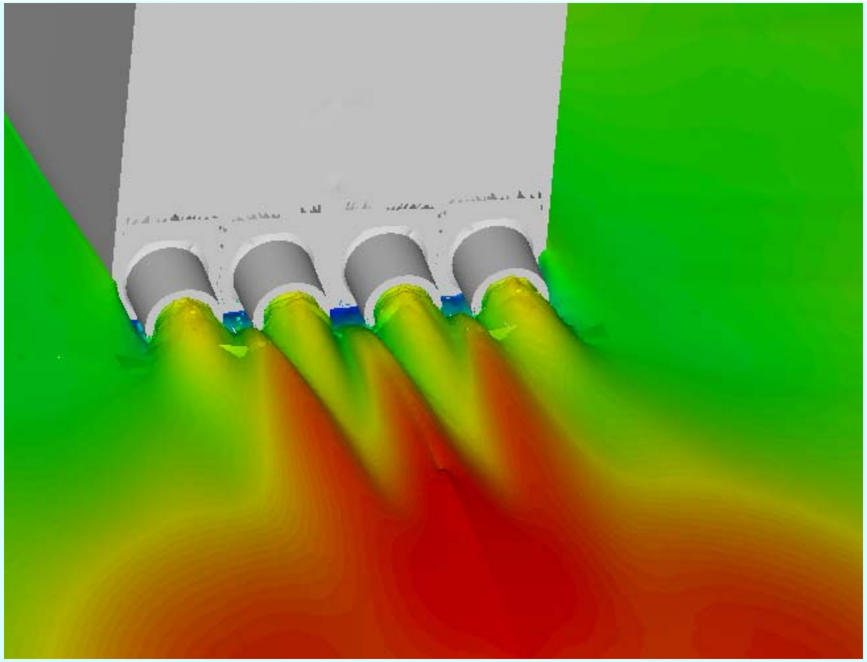
- Free surface treatment
  - Capturing methods have become routine (Volume of Fluid and Level Set (*one-phase and two-phases*)) and used by the majority of groups
  - Can numerically handle very complex free surface
- Turbulence modeling
  - Largely one- and two-equations models in practice
  - Reynolds stress models by some groups for flow details
  - Large Eddy Simulations (LES) and Detached Eddy Simulation (DES) seeing more use, but still limited

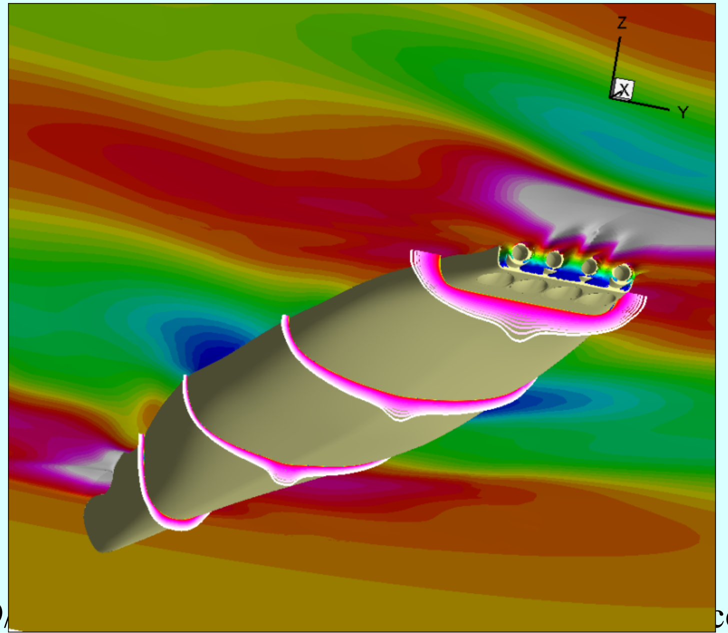
New Applications

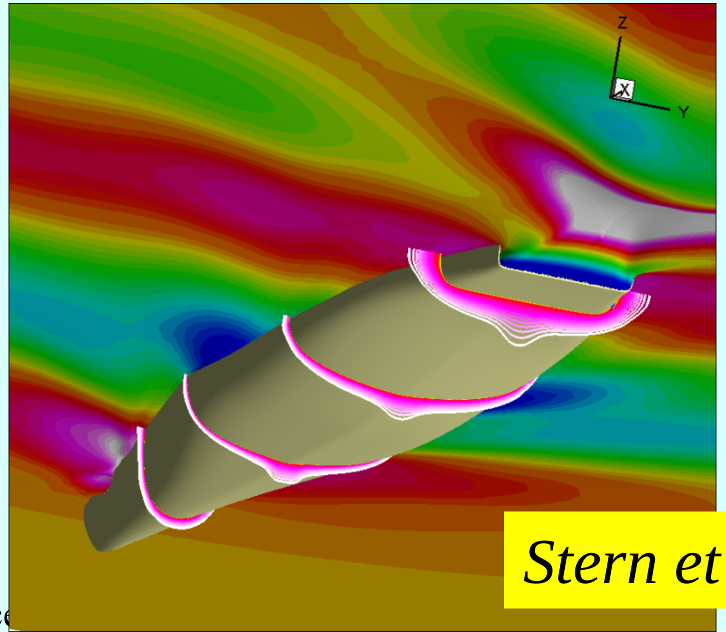
- Propulsor/Hull Interaction
  - Actuator disk models
  - Lifting surface/panel methods
  - Full rotating propeller
- Drag Reduction
  - Microbubble and polymer effects modeled
  - Mostly restricted to simple flows and modeling issues
- High Speed Vessels
  - High Froude number
  - Catamarans, trimarans, slender monohulls

Jessup et al.,2008









Stern et al.2008

Summary

- **CFD tends to unify most of the ITTC fields of interest:** resistance, seakeeping, manoeuvring of fully appended ships
- Increasingly more useful to many groups
  - Many good codes with many groups able to use the codes
  - Inroads to the design process being made
  - RANS having a larger role for viscous flow study
  - Realistic geometries at model <u>and full scale</u>
  - Expected to have larger role in the future with increasing experience and computer power
- Still not the confidence in CFD that many have with experiments.

6. Validation of prediction techniques

- The report reviews recent activities in the field of Verification and Validation (V&V) considered to be of significance for the members of ITTC.

- Different aspects of V&V have been summarised in a number of papers, including issues related to achieving consensus on V&V (*Oberkampf et al., 2004, Roy, 2005, Stern et al., 2006*)

V&V studies

- Still very few systematic V&V studies in the field
- The ITTC recommended procedure has been used for the V&V of resistance and velocities, propeller thrust and torque as well as roll decay (*Visonneau et al., 2006, Stern et al. 2006a, Di Mascio et al. 2007*, *Kim et al., 2006*)
- *Toxopeus (2006)* has used an alternative least squares based Grid Convergence Index for V&V of drift forces
- *Werner (2006)* has compared the performance of three different uncertainty estimation methods, including the ITTC recommended procedure, using an analytical BL-solution
- An extension of V&V, **quantitative code certification**, has been studied by *Stern et al. (2006c)* using the Gothenburg 2000 data

Iterative convergence

- Most studies deal with grid and temporal convergence
- However, some studies published on **the influence of incomplete iterative convergence (**often negligible compared to other sources *Wilson et al., 2006, Di Mascio et al., 2007*). Procedure developed for quantitative estimation of iterative error (*Eca and Hoekstra, 2006*)

Method of Manufactured Solutions (MMS)

- MMS has become an established tool for code verification with some exhaustive examples (*Roy, 2005, Salari and Knupp, 2000*)
- Problems with the setting up of manufactured solutions in some cases, due to the existence of damping and blending functions (*Eca and Hoekstra, 2006*)

Issues in V&V

Despite the established research still several issues related to V&V

- Problems in reaching the asymptotic range, oscillatory convergence, unrealistic order of convergence, monotonic divergence, issues with complex geometries (*Hino, 2005, Celik et al., 2005, Eca and Hoekstra, 2006, Visonneau et al. 2006, Starke et al. 2006*)
- Issues and necessary conditions to reach grid convergence with focus on unequal refinement in different coordinate directions (*Salas, 2006*)
- Severe grid dependency of the pressure resistance (*Visonneau et al., 2006, Raven et al. 2006*)

7. Worldwide Comparative Tests on the Facilities Bias

Determine, through a **great number of tests**, a faithful **reference value** to determine **uncertainties** to be used in tests according ITTC document:

"Testing and Extrapolation Methods, General Uncertainty Analysis in EFD, Guidelines for Resistance Towing Tank Tests"

	24th ITTC	→	25th ITTC
Number of Institutions:	20	→	**35**
Number of countries:	15	→	**19**

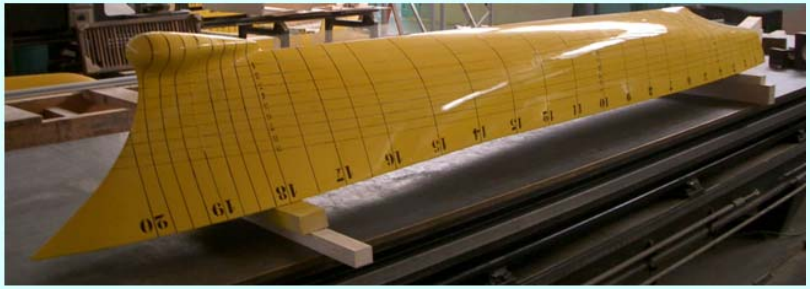
There are two models travelling around the world:

✓ 5.720 m length geosim

- Wood model
- Scale 24.824
- Length = 5.720 m.
- Calm water draught = 0.248 m
- Displacement in fresh water: 549 kg

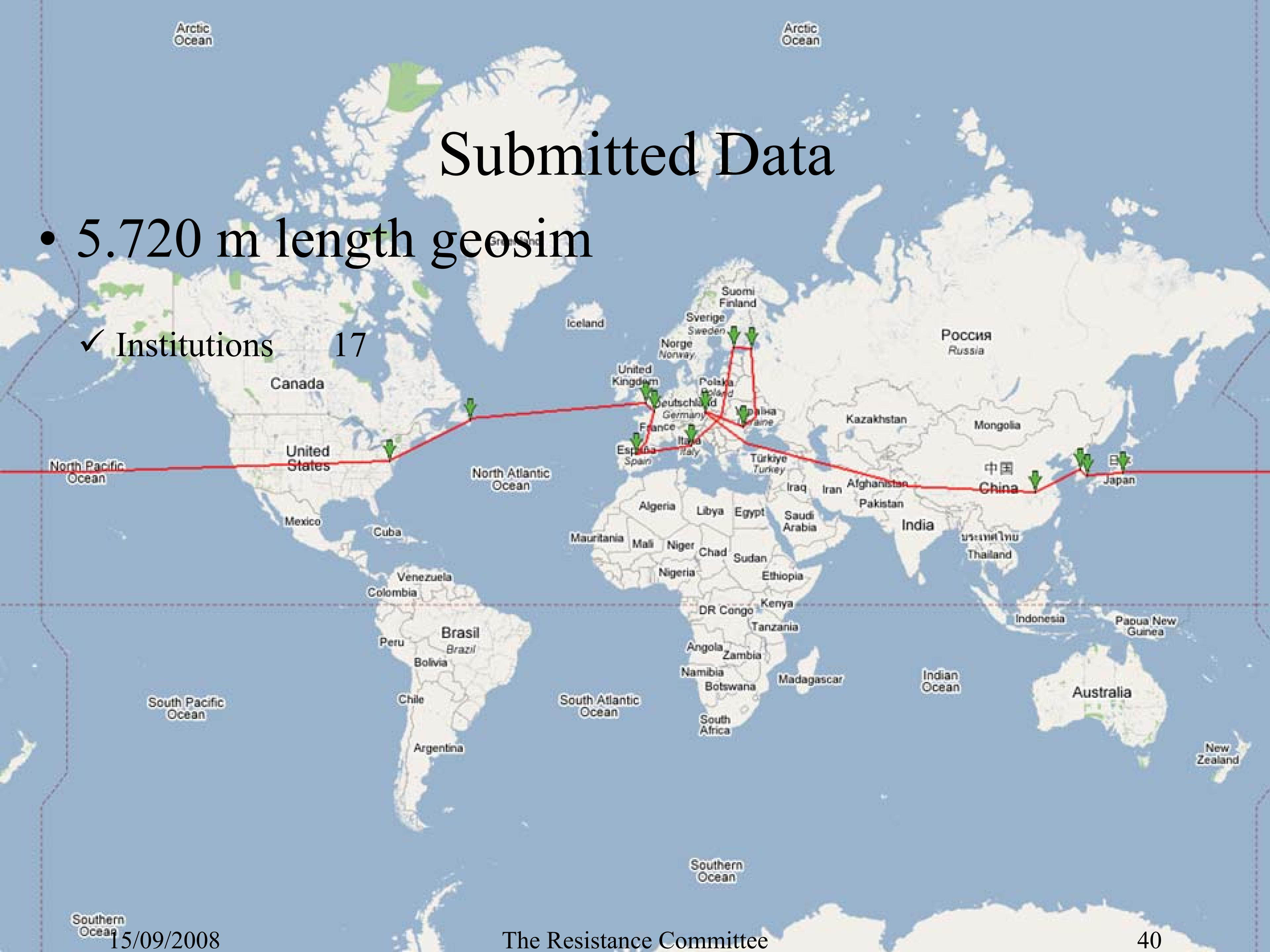
✓ 3.048 m length geosim

- Wood model
- Scale 46.600
- Length = 3.048 m.
- Calm water draught = 0.132 m
- Displacement in fresh water: 83 kg



Submitted Data

- 5.720 m length geosim
  - ✓ Institutions 17



Submitted Data

- 5.720 m length geosim

✓ Institutions 17

✓ **Tested 11**

✓ **Submitted 4**

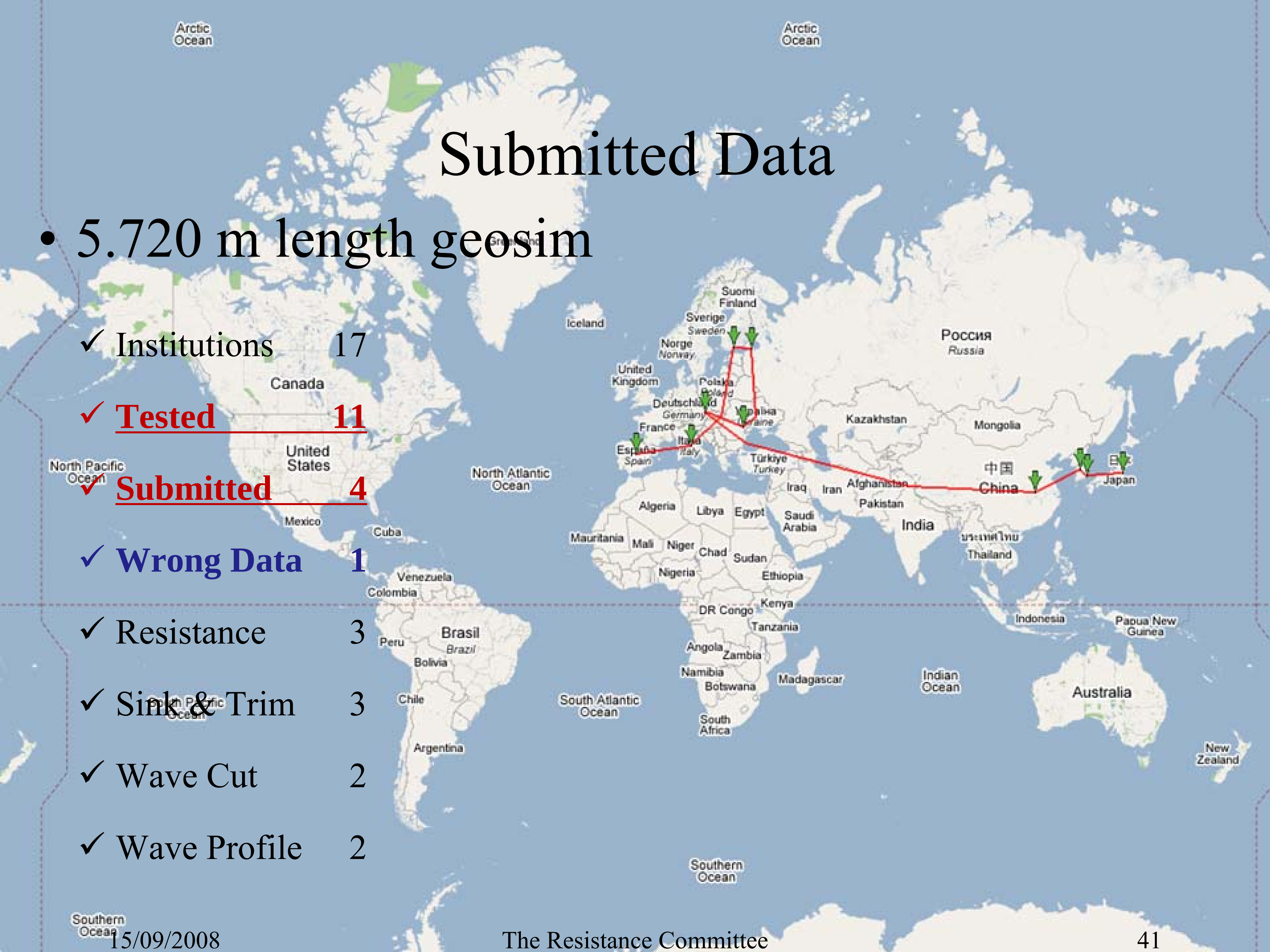
✓ **Wrong Data 1**

✓ Resistance 3

✓ Sink & Trim 3

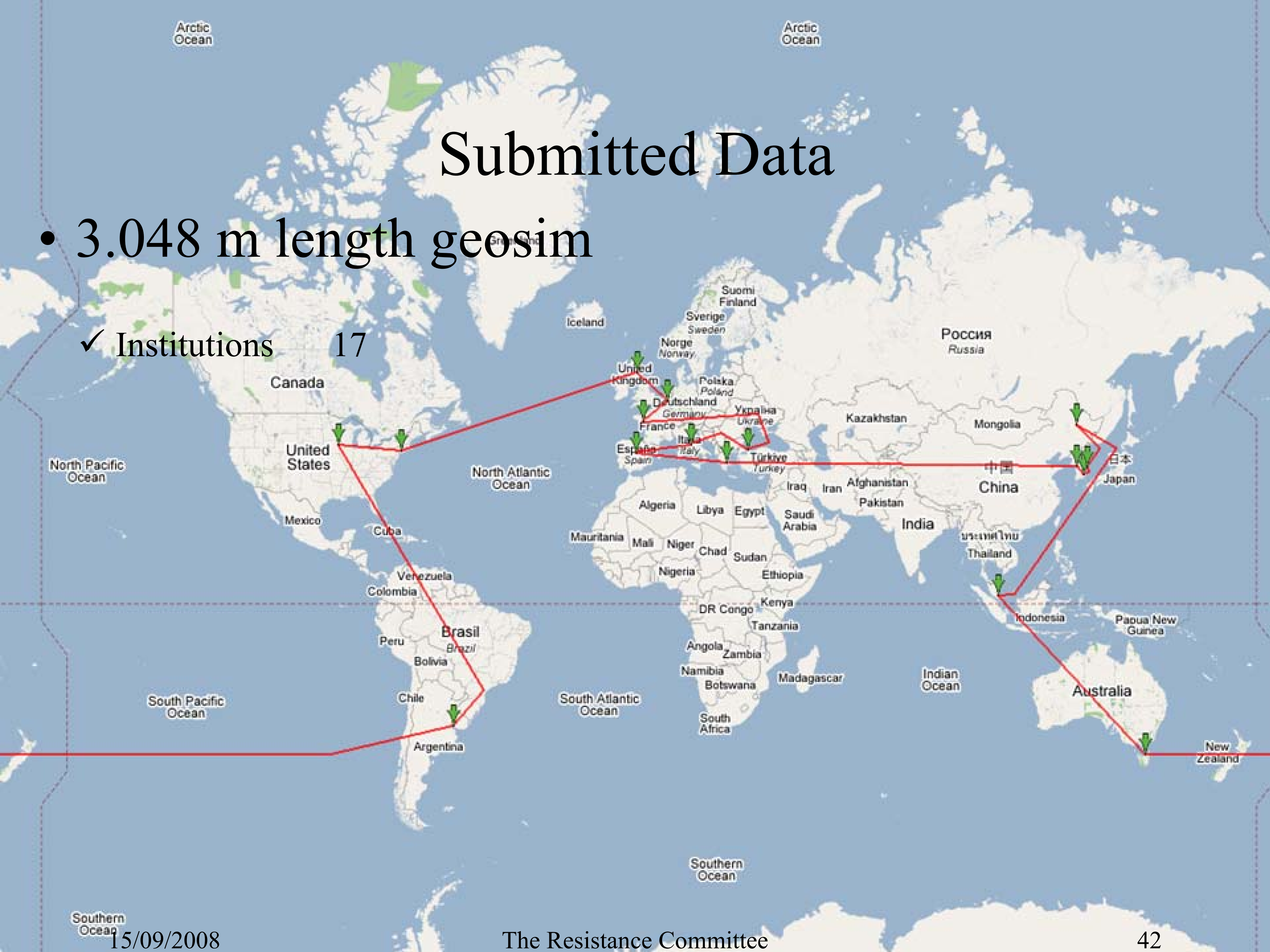
✓ Wave Cut 2

✓ Wave Profile 2



Submitted Data

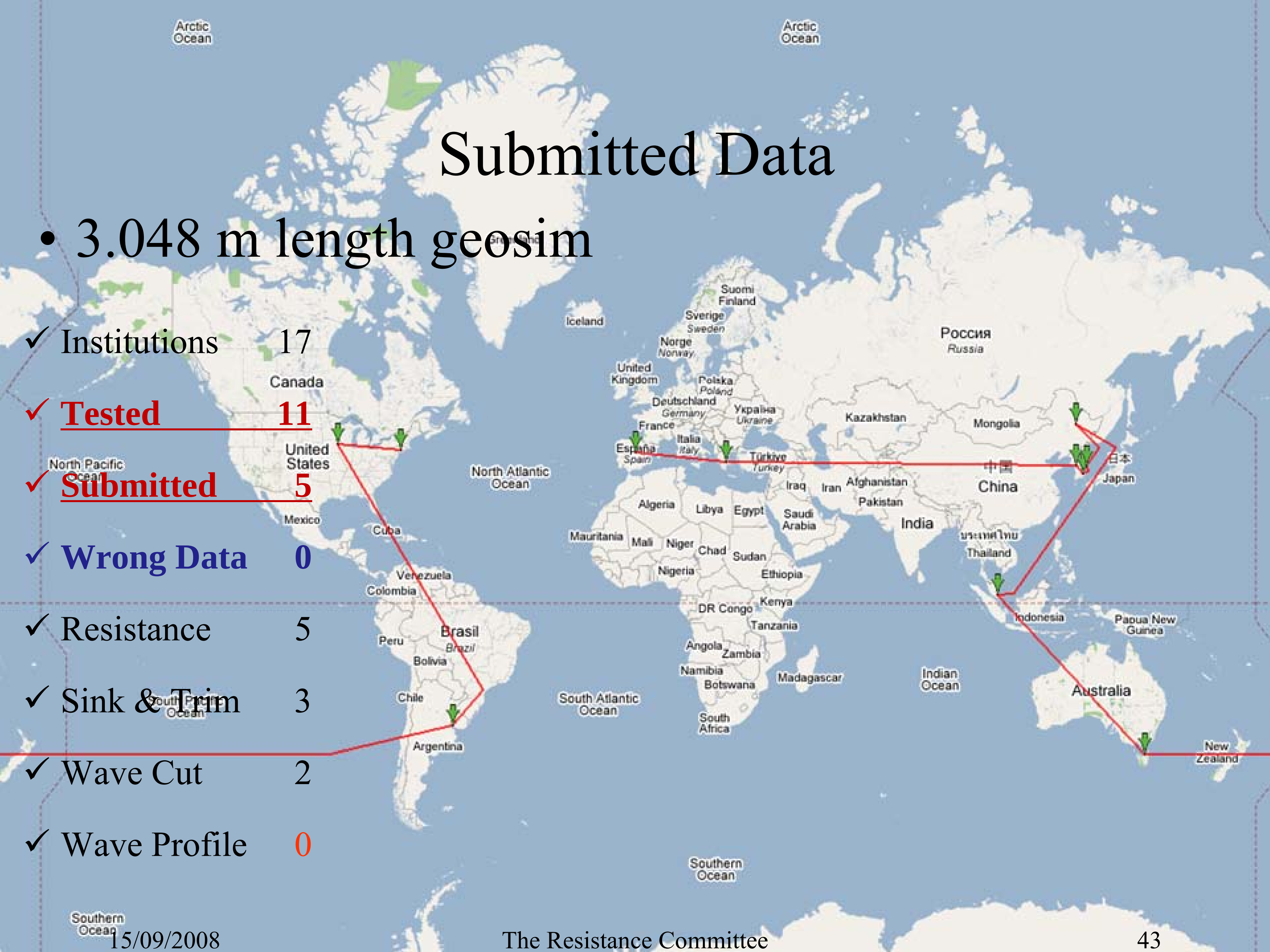
- 3.048 m length geosim
  - ✓ Institutions 17



Submitted Data

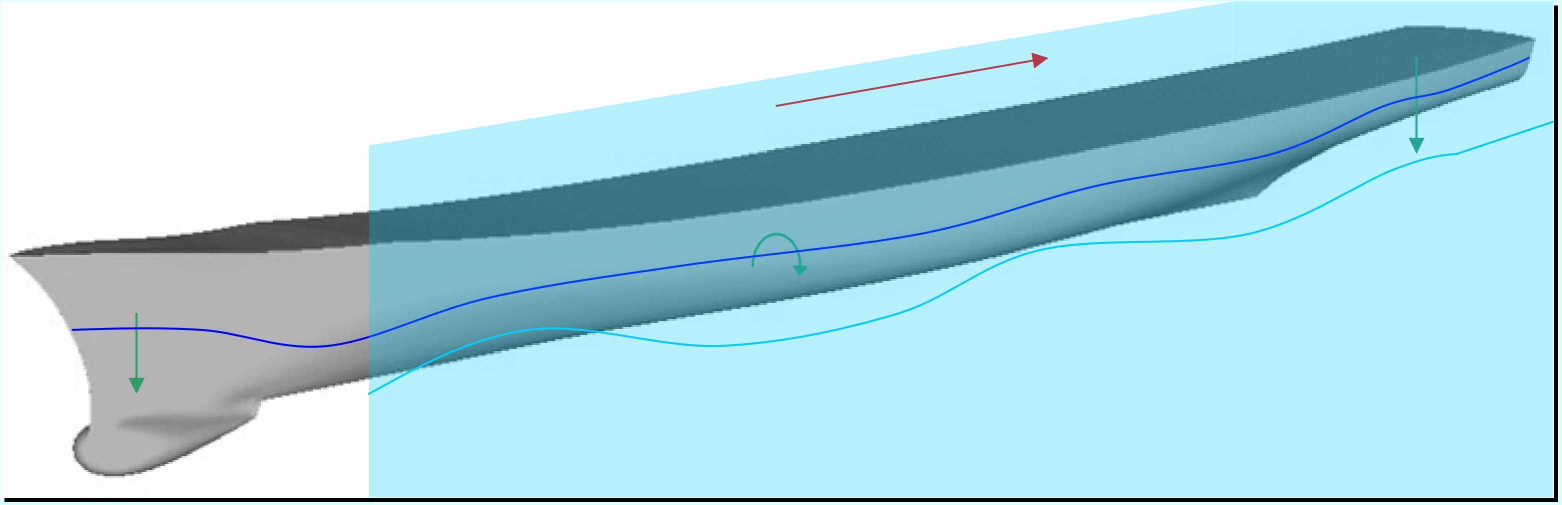
- 3.048 m length geosim

✓ Institutions	17
✓ **Tested**	**11**
✓ **Submitted**	**5**
✓ **Wrong Data**	**0**
✓ Resistance	5
✓ Sink & Trim	3
✓ Wave Cut	2
✓ Wave Profile	0



Facility Biases Analysis for:

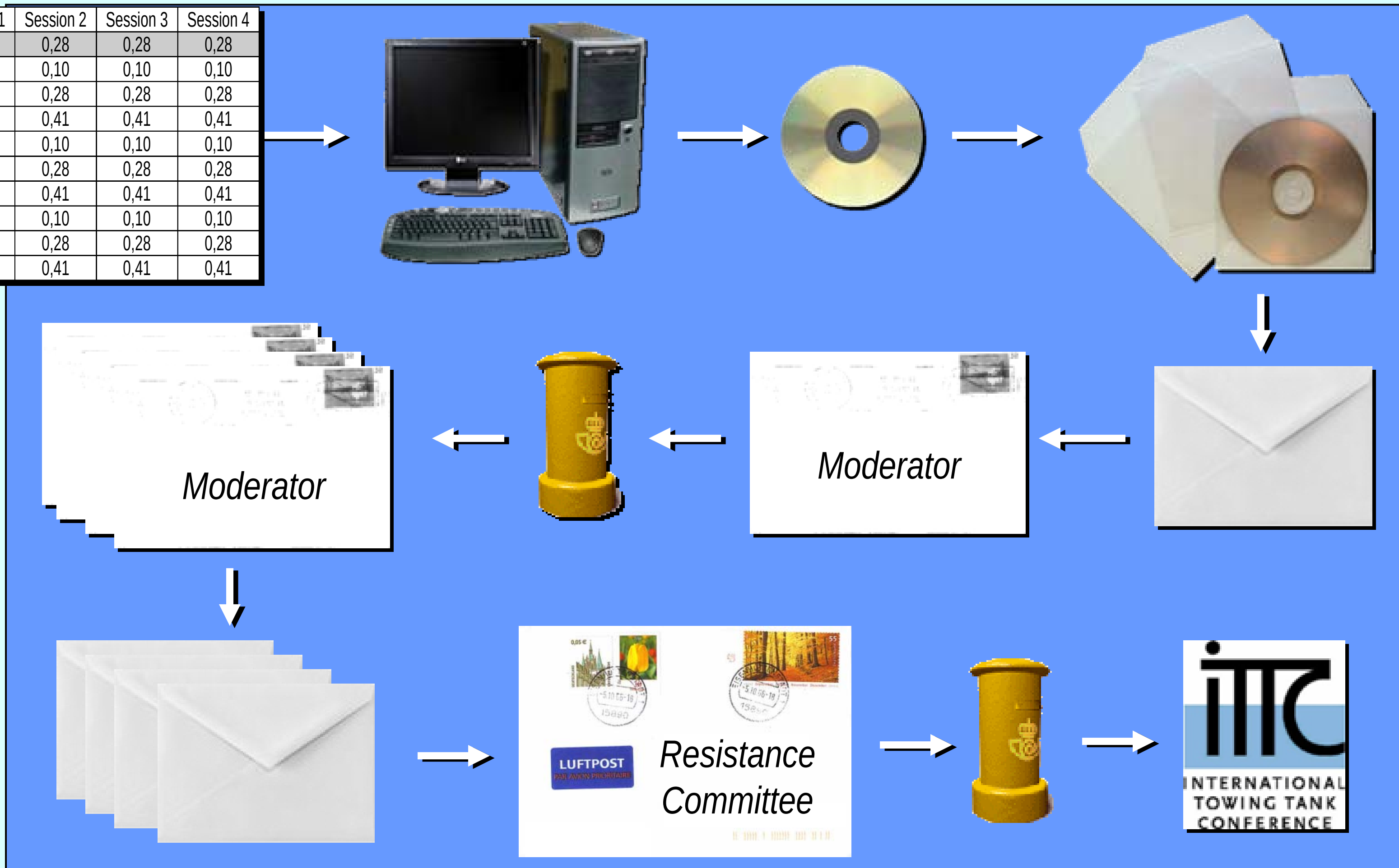
- Resistance (Procedure 7.5-02-02-03)
- Sinkage and Trim (Procedure 7.5-02-02-05)
- Wave Profile (Procedure 7.5-02-02-06)
- Wave Cut (Procedure 7.5-02-02-06)



Precedents

- Data Submission Procedure ⇒ Confidentiality

Fr	Session 1	Session 2	Session 3	Session 4
Speed 1	0,28	0,28	0,28	0,28
Speed 2	0,10	0,10	0,10	0,10
Speed 3	0,28	0,28	0,28	0,28
Speed 4	0,41	0,41	0,41	0,41
Speed 5	0,10	0,10	0,10	0,10
Speed 6	0,28	0,28	0,28	0,28
Speed 7	0,41	0,41	0,41	0,41
Speed 8	0,10	0,10	0,10	0,10
Speed 9	0,28	0,28	0,28	0,28
Speed 10	0,41	0,41	0,41	0,41



Analysis Procedure *(Stern et al., 2005)*

- For M Facilities testing N times the variable X

  ✓ Medium value of X $$\overline{X} = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} X_i^j$$

  ✓ Uncertainty of $\overline{X}$ $$U_{\overline{X}} = \sqrt{B_{\overline{X}}^2 + P_{\overline{X}}^2}$$

  where

  Precision limit $$P_{\overline{X}} = \frac{2}{\sqrt{M}} \sqrt{\frac{\sum_{i=1}^{M} \left(\overline{X}_i - \overline{X}\right)^2}{M-1}} = \frac{2}{\sqrt{M}} \sqrt{\frac{\sum_{i=1}^{M} D_i^2}{M-1}}$$

  Bias limit $$B_{\overline{X}} = \frac{1}{M} \sqrt{\sum_{i=1}^{M} B_{\overline{X}_i}^2}$$ and $B_{\overline{X}} \to 0$ if $M \to \infty$

Analysis Procedure *(Stern et al., 2005)*

- Certification of the Facility Bias Uncertainty

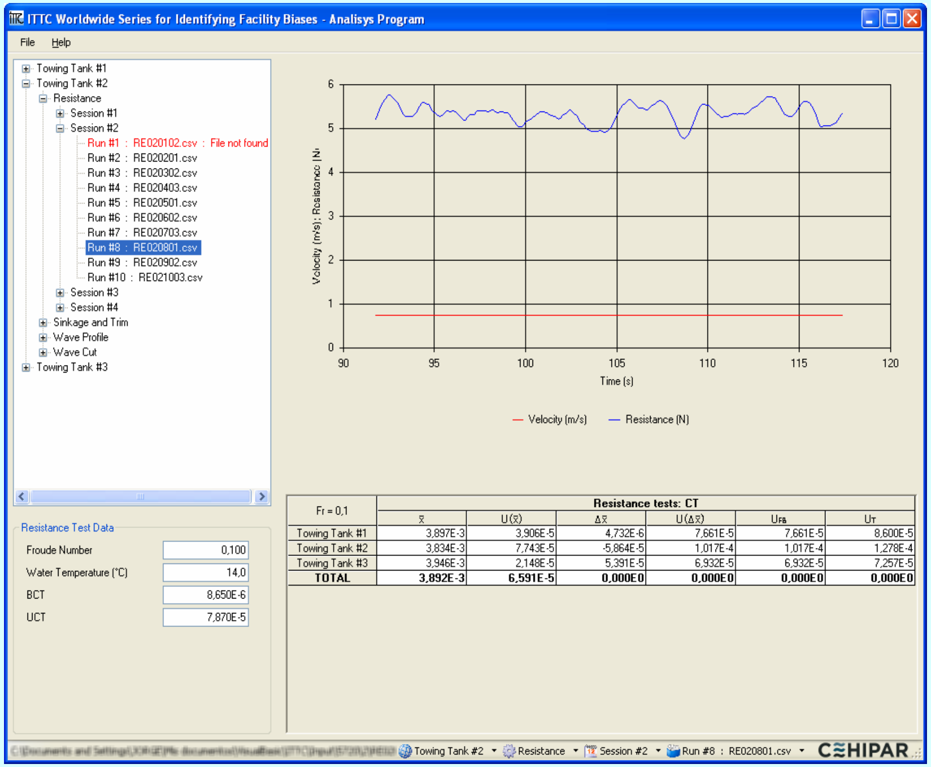
$$U_{D_i} = \sqrt{U_{\overline{X}_i}^{\,2} + U_{\overline{X}}^{\,2}}$$

$$\left| D_i \right| \le U_{D_i} \Rightarrow U_{FB_i} = U_{D_i}$$

$$\left| D_i \right| > U_{D_i} \Rightarrow U_{FB_i} = \sqrt{D_i^2 - U_{D_i}^2}$$

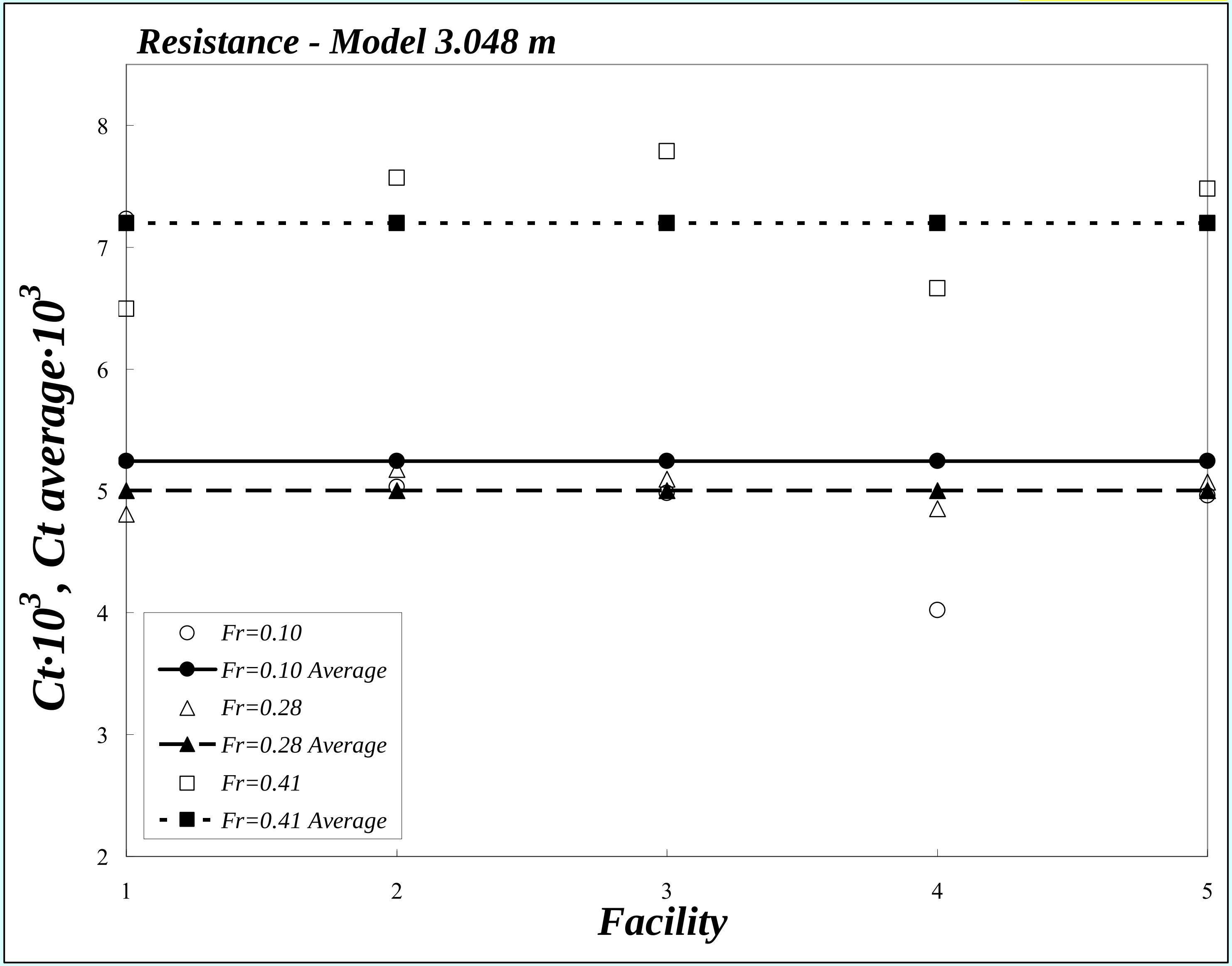
RC Analysis Program *(J. Valle)*

- An analysis program has been developed to facilitate data comparison and analysis.
- The program will be distributed to the participants.



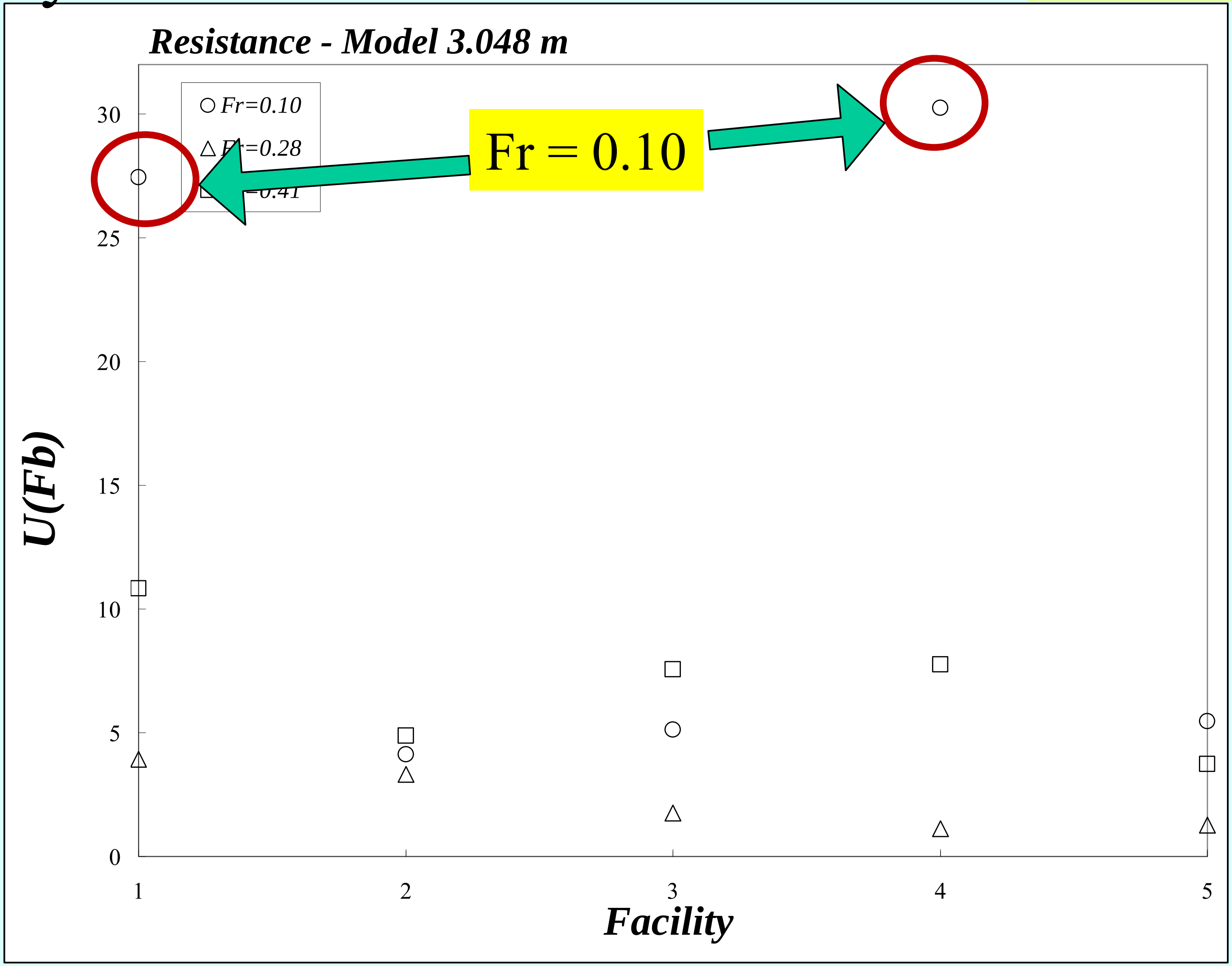
Results: Resistance

3.048 m



Facility Bias Unc.

3.048 m



Conclusions

- The data is still very short to analyze uncertainties.
- ITTC recommended procedures 7.5-02-02-03, 7.5-02-02-05 and 7.5-02-02-06 and referenced worksheets have been used.
- Some resistance files present significant oscillations.
- Facility bias uncertainties are normally larger for the smaller Froude numbers.
- Sinkage and trim results are not available for all the facilities. Uncertainties obtained for the trim are very large in some cases.

Conclusions

- Only two facilities have sent wave profile data and in both cases data was incomplete.
- Only four facilities, two for each model, have sent wave elevation data.
- Wave elevation and wave profile analysis have presented some special problems due to the phase of the waves.
- **Please, send the data ASAP and submit the data in the required format**

8. Design and Optimization

Methods and problems

- Variable Fidelity and Metamodels
- Grid Regeneration and Deformation
- Derivative Based and Derivative Free Methods
- Uncertainty in Design Optimization

Applications

Developments in CFD and computer power lead to some progress in Simulation Based Design (SBD)

<u>Variable Fidelity and Metamodels</u>

- Maximize the use of low fidelity, cheaper models in iterative procedures with occasional, but systematic (*trust region*), recourse to higher fidelity
- Use of surrogated model to reduce the computational cost

<u>Grid Regeneration and Deformation</u>

- Robustness still an issue

<u>Derivative Based and Derivative Free Methods</u>

- Adjoint methods: efficient but only for single objective and for local optimization problems
- Derivative free: more expensive but suited for multiobjective and global optimization

Applications

Doctors and Scrace (2003) optimized the configuration of a trimaran using a potential flow model.

Tahara et al. (2007) Optimized a high speed catamaran comparing PF-based and RANS-based SBD with global optimization algorithms

Zalek et al. (2006), Resistance and seakeeping optimization

Parsons et al. (2004) different multicriteria formulations to be computed with a conventional scalar method.

Conclusions

Lack of confidence in CFD reflects in sporadic use of SBD from shipyards

Navies and sailboat design seems to lead the use of SBD

9. Far Field Waves and Wash

- Prediction of Wake Wash based on EFD
- Prediction of Wake Wash based on CFD
  - Linear Theory
  - Nonlinear Theory

Vessel operation risk assessments now often required for high-speed craft

Far Field Waves and Wash
EFD Prediction

- Limitations in facility width has likely contributed to increase in site-specific full scale experiments
  - Recent examples include: Parnell et al. (2007), Soomere (2005), Velegrakis et al. (2006), Kumar et al. (2007), Varyani (2006), Balzerek and Koslowski (2007), Macfarlane and Cox (2004)
- Use of large scale manned models
  - (Chalkias and Grigoropoulos, 2007)
- Correlation between model and full scale experiments
  - (MacFarlane 2006,2008)

Far Field Waves and Wash
CFD Prediction - Linear Theory

- Potential flow panel methods
  - (Chalkias and Grigoropoulos, 2005)
- Michell's thin ship wave resistance theory
  - (Lazauskas, 2007)
- Soomere et al (2005) suggest that linear wave theory is not applicable for long period waves generated by high-speed craft operating in shallow water

Far Field Waves and Wash
CFD Prediction - Nonlinear Theory

- The Korteweg-de Vries (KdV) equation is proposed for modelling long waves in shallow water (Soomere et al 2005)
- Sakamoto et al (2007) suggest use of URANS method
- Soomere (2007) review many various methods to predict the generation of solitons
- Soding (2006) suggests use of nonlinear Rankine source methods for near-field waves, combined with constant-depth method for far field waves

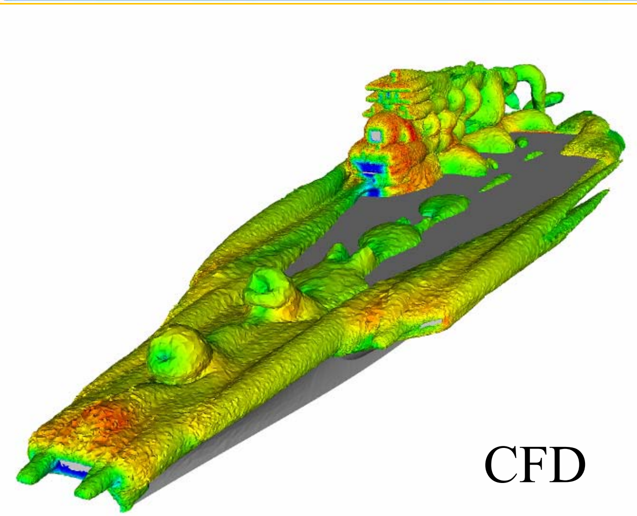
Far Field Waves and Wash
CFD Prediction - Nonlinear Theory (cont.)

- Prediction of ship wash near the shore
  - Hong and Doi (2006), Erikson et al (2005)

- Prediction of ship wash during the passage through trans-critical speed regime (unsteady effects)
  - Torsvik et al. (2006) and Torsvik (2006)

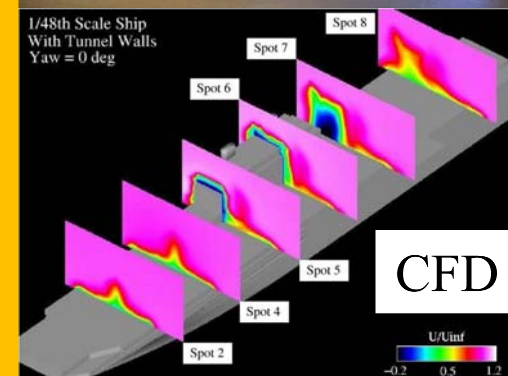
Far Field Waves and Wash Conclusions

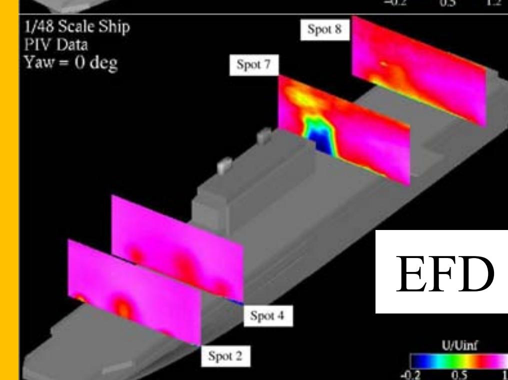
- Conclusions drawn by 24th ITTC RC largely still hold
- It is necessary to validate numerical models
- There remains a lack of appropriate benchmark data publicly available
- Insufficient experience presently exists to propose general guidelines for prediction of far field waves and wash effects



9. Airwakes

First ITTC review of past and ongoing research on ship airwakes.





- EFD Work, Modelling of Aerodynamic Forces, and New Applications
- CFD Work and Experimental Validation

EFD Work, Modeling of Aerodynamic Forces, and New Applications

- Early Work:
  - The first comprehensive and very systematic EFD work was reported by Hughes (1930).
- In the 1950s:
  - Investigation on effect of wind on the maneuverability of train ferries, and relatively small ships, e.g., fishing boats and small cargo ships.
- In the 1960s through 1970s:
  - Effort was directed toward very detailed wind tunnel measurements for other commercial ships and naval ships.
  - Many studies on modeling of aerodynamic forces and moments to develop empirical formula were initiated.

EFD Work, Modeling of Aerodynamic Forces, and New Applications

- In the 1980s and 1990s:
  - As ship design was modernized, continuous efforts on developing EFD databases and modeling of aerodynamic forces and moments were made. For example, VLCC, PCC, and LNG became new applications.
- More recent work:
  - EFD techniques were more advanced, and more realistic and complex wind and ship conditions were considered.
- New Applications (In the 2000s):
  - Prediction and control of ship airwakes and the interactions with aircraft (airplanes or helicopters).

CFD Work and Experimental Validation

- CFD work on ship airwakes was initiated in the late 1990s.
- In the 2000s, the number of reports rapidly increased, which is clearly due to the advent of powerful computational environments.
- Applications cover naval ships, commercial and research ships.
  - For naval ships: main interest still on prediction and control of ship airwakes and the interactions with aircraft.
  - For commercial and research ships: the interest is on the effects of flow distortion created by the ship hull and superstructure on onboard anemometry.

The Resistance Committee

Final Report

Discussers: **Xing & Stern**

<u>Stern, 2007</u>

Very latest developments in the field of verification and validation (V&V)

<u>Xing and Stern, 2008</u>

Discuss the improvements in the correction factor (CF) approach for quantitative estimation of uncertainties.

Particularly valuable for the development of the ITTC Recommended Procedure 7.5-03-01-01.

<u>Xing et al., 2008</u>

Presents a comprehensive example of an **attempt to reach the asymptotic range for a practical application continuously refining the grid**, and discuss the issues related to this.