

The Resistance Committee

Final Report

Committee Members

- Dr. Joseph Gorski (Chairman), Naval Surface Warfare Center, Carderock Div., United States of America
- Prof. Stephen Turnock (Secretary), University of Southampton, United Kingdom
- Dr. Bertrand Alessandrini, Ecole Centrale Nantes (ECN), France
- Prof. Ho-Hwan Chun, Pusan National University, Korea
- Dr. Uwe Hollenbach, Hamburg Ship Model Basin (HSVA), Germany
- Dr. Tommi Mikkola, Aalto University, Finland
- Dr. Yusuke Tahara, National Maritime Research Institute (NMRI), Japan
- Dr. Jesús Valle, Escuela Técnica Superior de Ingenieros Navales (ETSIN), Spain
- Dr. Liangmei Ying, China Ship Scientific Research Centre (CSSRC), China

Committee Meetings

CEHIPAR, Madrid, Spain; 13-15 Jan 2009

ASERC, Busan, Korea; 15-16 Sept 2009

ECN, Nantes, France; 18-19 May 2010

HSVA, Hamburg, Germany; 18-19 Jan 2011

Report Chapters

- Introduction
- Facility Bias Worldwide Campaign
- Trends in Experimental Fluid Dynamics (EFD)
- Trends in Computational Fluid Dynamics
- Scaling and Extrapolation
- Turbulence Stimulation
- Recommendations
- References

Tasks

- 1) Update the state-of-the-art for predicting the resistance of different ship concepts emphasising developments since the 2008 ITTC Conference. The committee report should include sections on:
 - a) the potential impact of **new technological** developments on the ITTC,
 - b) new experimental techniques and extrapolation methods,
 - c) new benchmark data,
 - d) the practical applications of computational methods to resistance predictions and scaling,
 - e) the need for R&D for improving methods of model experiments, numerical modelling and full-scale measurements.
- 3) Identify the parameters that cause the largest uncertainties in the results of model experiments, numerical modelling and full-scale measurements related to resistance.

Covered by Experimental and Computational chapters as well as the
Worldwide Campaign Chapter



Tasks

- 2) Review ITTC Recommended Procedures relevant to resistance (including procedures for uncertainty analysis).
 - a) Identify any requirements for changes in the light of current practice, and, if approved by the Advisory Council, update them.
 - b) Identify the need for new procedures and outline the purpose and content of these.
 - c) With the support of the Specialist Committee on Uncertainty Analysis, review and if necessary amend, Procedures 7.5-02-02-03, 04, 05 and 06 "Uncertainty Analysis spreadsheets for measurements of resistance, speed, sinkage and trim and wave profile" and Procedure 7.5-0302-01 "Uncertainty Analysis in CFD Example for Resistance and Flow to bring them into line with the ISO approach adopted by the ITTC.

Update of the Uncertainty Analysis
spreadsheets - deferred to next committee

- 1) Worldwide campaign has been ongoing since 24th ITTC with existing spreadsheets and cannot change in the middle
- 2) Making ISO compliant was more involved than originally thought and should have someone fully cognizant of the area involved in the updates

Tasks

- 4) Survey and document the range of practices adopted for turbulence stimulation. Update parts of Recommended Procedure 7.5-01-01-01, Model Manufacture which deal with turbulence stimulation, paying particular attention to different kinds of bulbous bows and high-speed ships. Liaise with the Specialist Committee on High-Speed Craft.
 - Updated Procedure 7.5-01-01-01, “Model Manufacture Ship Models”
 - Covered in Turbulence Stimulation Chapter

Tasks

- 5) Review ITTC Recommended Procedures relevant to scaling and extrapolation methods including theoretical and experimental investigations of the friction line. *Note: At the present time the ITTC does not consider introducing a new friction line without extensive validation.*
- 6) Make the concept of form factor consistent in all relevant ITTC procedures. Include the form factor in the formulation of the ITTC 1957 friction line as an option in ITTC Recommended Procedure 7.5-02-02-01, "Resistance Tests".
- 7) Review methods used for the scaling of appendage resistance, especially in relation to the problem of pod drag scaling. Ensure that the appendage drag scaling is treated consistently for resistance, propulsion and the 1978 Powering Performance Prediction Method. Liaise with the Propulsion Committee.

Updated Procedure 7.5-02-02-01, “Testing and Data Analysis Resistance Test”

Covered in Scaling and Extrapolation chapter

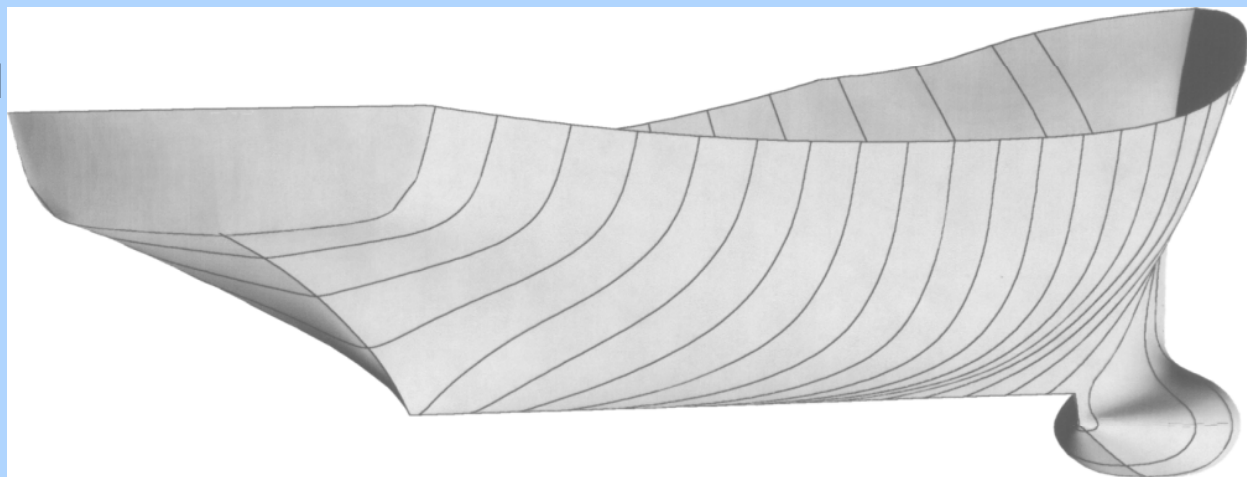
Pod drag scaling is significantly different than appendage resistance scaling and is very specific to propulsion. Consequently, it was recommended that pod drag scaling not be addressed by the Resistance Committee and be kept in the Propulsion Committee.

Tasks

- 8) Continue the tests in the ITTC worldwide series for identifying facility biases. Prepare a common calculation sheet to analyze the results of the tests. Check and record the model dimensions regularly.
- Covered in Worldwide Campaign Chapter

2. Facility Bias Worldwide Campaign

- Tests were done during the 24th, 25th and 26th ITTC periods
 - 24th: 20 institutions from 15 countries
 - 25th: 35 institutions from 19 countries
 - 26th: 41 institutions from 20 countries
- Two geosims of the DTMB 5415 Combatant with 5.720 and 3.048 meters length have been used.
- Froude numbers 0.1, 0.28 and 0.41
 - Tests on 4 different days
 - 10 runs each day



Facility biases have been analysed for:

- Resistance
- Sinkage and trim
- Wave profile and wave elevations

Each facility to use their standard testing techniques and corrections for blockage etc.

- Details not reported back to ITTC

5.720m model tests

Institution	Country	Reception
CEHIPAR	Spain	Jun 2004
INSEAN	Italy	Sep 2004
Helsinki University of Technology	Finland	Nov 2004
Krylov Shipbuilding Research Institute	Russia	Feb 2005
ICEPRONOV S. A.	Romania	Sep 2005
Vienna Model Basin	Austria	Dec 2005
Huazhong University of Science & Technology	China	-----
CSSRC	China	Sep 2007
Samsung Ship Model Basin	Korea	Dec 2007
MOERI	Korea	Feb 2008
Pusan National University	Korea	Apr 2008

Institution	Country	Reception
Akashi Laboratory	Japan	Aug 2008
IHI Corporation	Japan	
Universal Zosen	Japan	
Akisima Laboratory	Japan	
Ship Research Center (NMRI)	Japan	
Osaka University	Japan	Mar 2009
Naval Surface Warfare Center	USA	
Institute of Ocean Technology	Canada	Sep 2009
Qinetiq	UK	Apr 2010
Bassin d'Essais des Carenes	France	Aug 2010
CEHIPAR	Spain	Mar 2011

3.048m model tests

Institution	Country	Reception
CEHINAV	Spain	Feb 2005
LSMH/NTUA	Greece	Apr 2005
Inha University	Korea	Dec 2005
Seoul National University	Korea	Jan 2006
Pusan National University	Korea	Feb 2006
Ulsan University	Korea	Mar 2006
Harbin Engineering University	China	-----
University Teknologi Malaysia	Malaysia	Sep 2006
Australian Maritime College	Australia	Nov 2006
Canal de Experiencias de Arquitectura Naval	Argentina	Feb 2007
University of Iowa – IIHR	USA	July 2007

Institution	Country	Reception
Stevens Institute of Technology	USA	Jan 2009
First Memorial University	Canada	Sep 2009
Institute for Ocean Technology	Canada	Nov 2009
IPT – Instituto de Pesquisas Tecnológicas do Estado	Brasil	Apr 2010
University of Glasgow and Strathclyde	UK	Postponed
University of Liège – ANAST	Belgium	Postponed
Ecole Centrale de Nantes	France	Postponed
Istanbul Technical University	Turkey	Postponed
INSEAN	Italy	Postponed
CEHIPAR	Spain	Postponed 15

Control of the Model

- Minor scratches and paint failures were detected for both models and they were repaired when necessary. There were not important deformations of the model.
- A final complete comparison of the dimensions of the 5.720 m length model was done at CEHIPAR. There were not important deviations which could affect the tests.

Submitted Data

Model	Facilities tested the model	Facilities sent data	Valid data sets
5.720m	21	14	12
3.048m	15	10	10

- Double blind test has been problematic
 - Don't know who did/did not send data
 - When encountered problems with the data did not know who to contact to get it fixed
 - 30% of data had problems/ wrong formats
 - Many facilities used ITTC example spreadsheet uncertainties rather than changing for their own facility



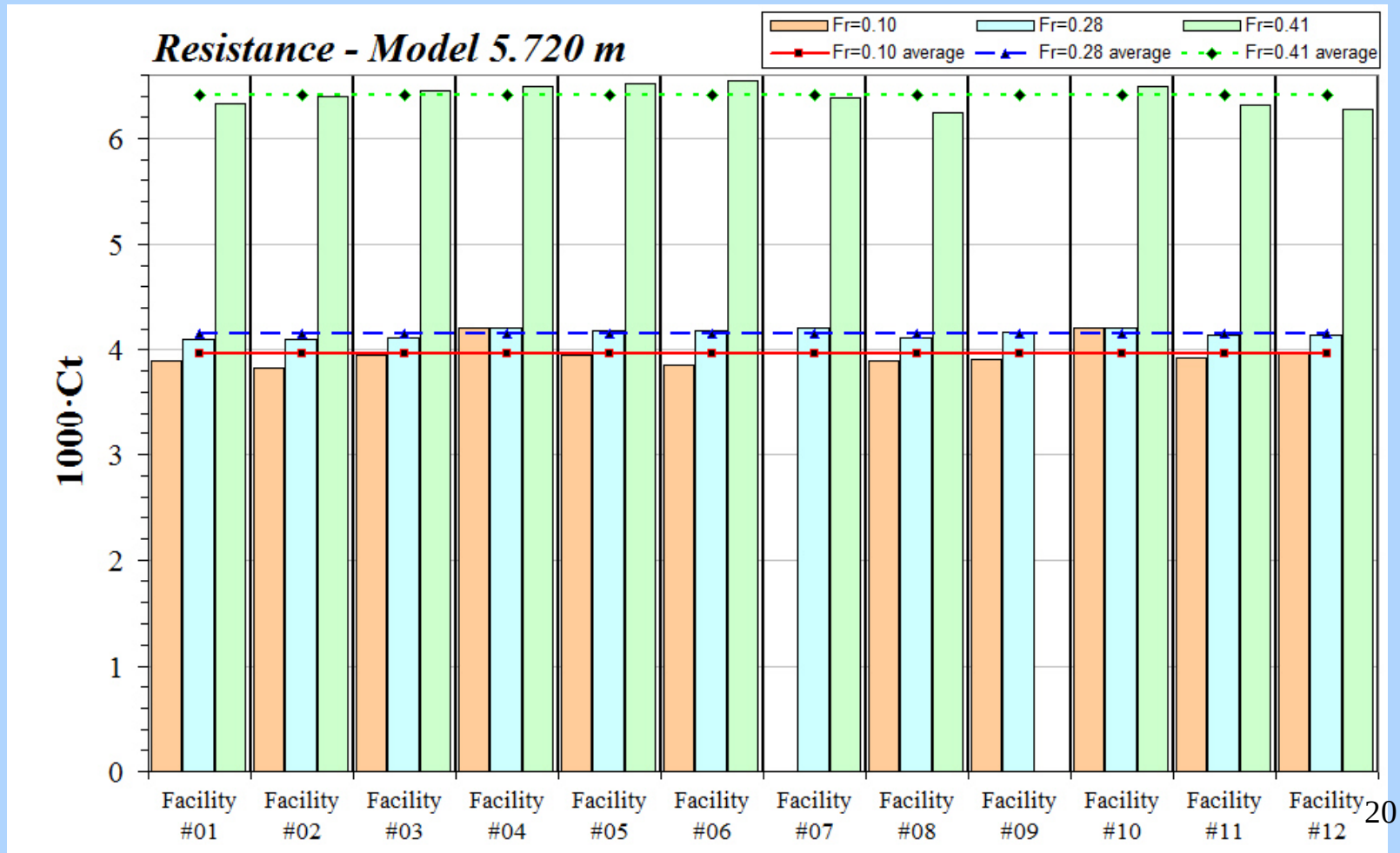
Resistance, Sinkage & Trim

- For each model the following data is presented:
 - The total value (Resistance coefficient, sinkage, trim) for each facility compared with their mean value
 - The uncertainties for each facility compared with their mean value, expressed in percentage of mean value
 - The uncertainties of the facility bias for each facility compared with their mean value, expressed in percentage of total mean value
 - The total uncertainties for each facility compared with the mean value, expressed in percentage of mean value

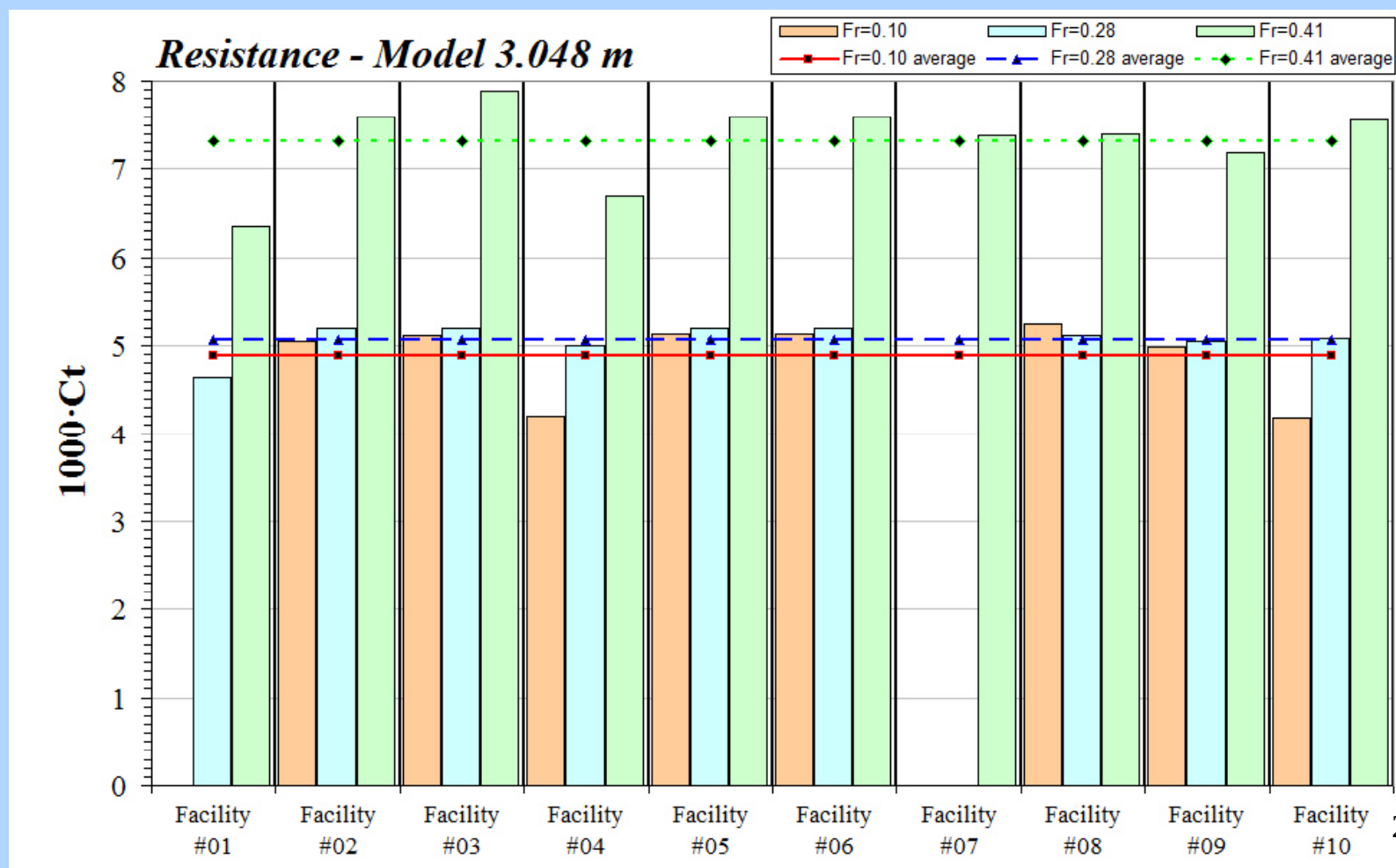


- Some errors were detected in the uncertainty analysis for some particular Froude numbers and in those cases the data was withdrawn and not used in the analysis
- Not enough sinkage and trim data was received for the small model at Froude number 0.1 to perform uncertainty analysis

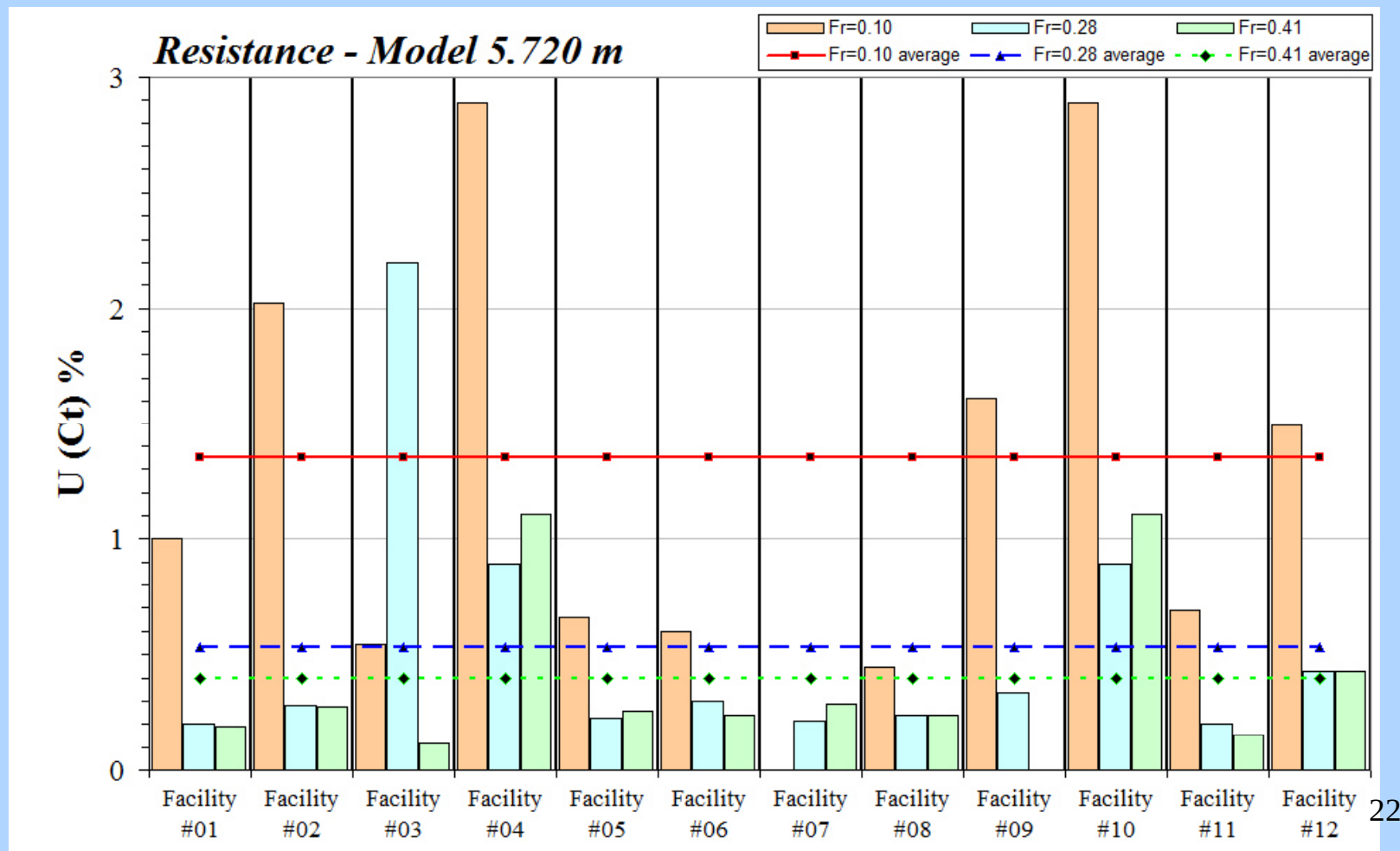
5.720m Model Resistance Coefficient Comparison



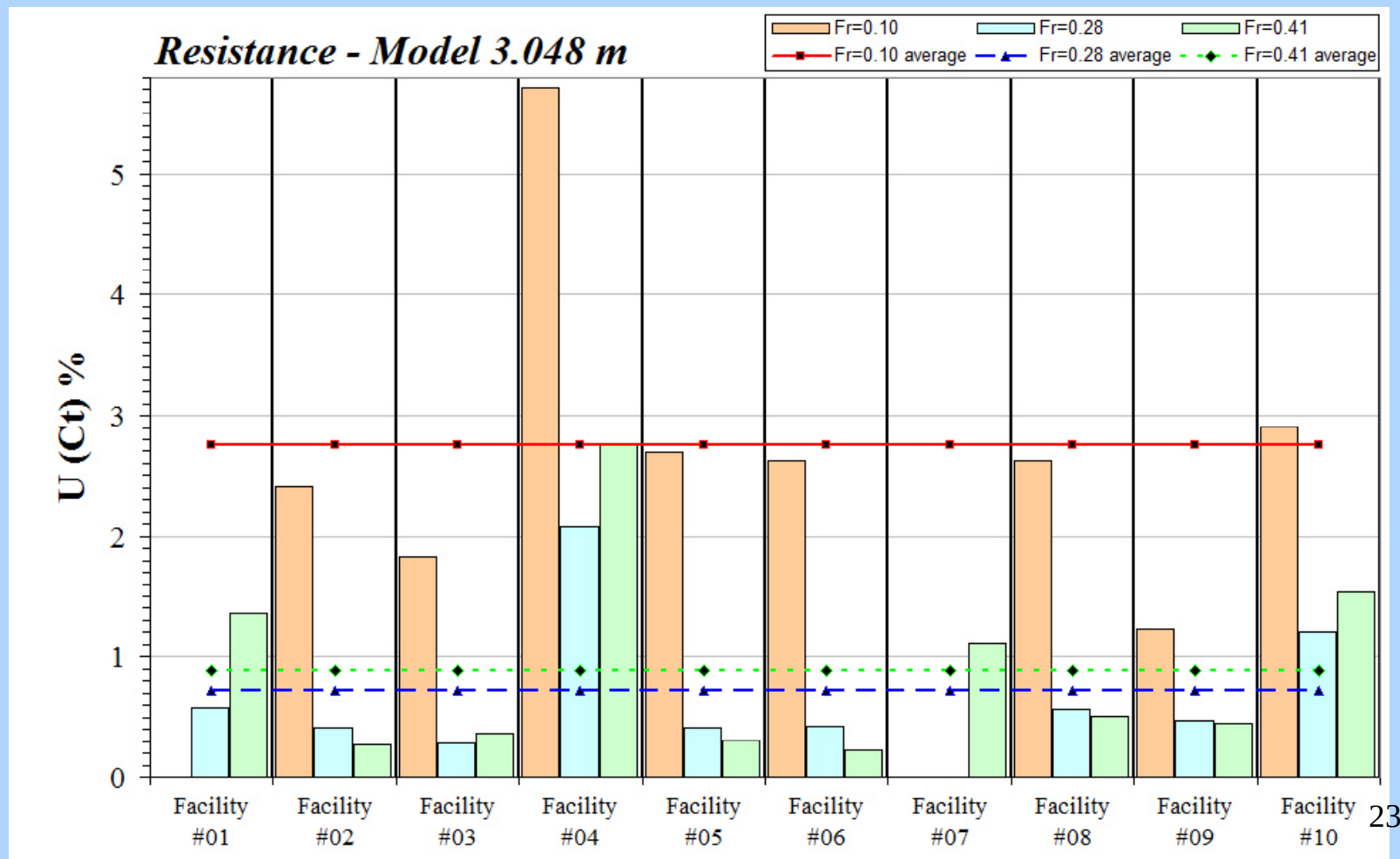
3.048m Model Resistance Coefficient Comparison



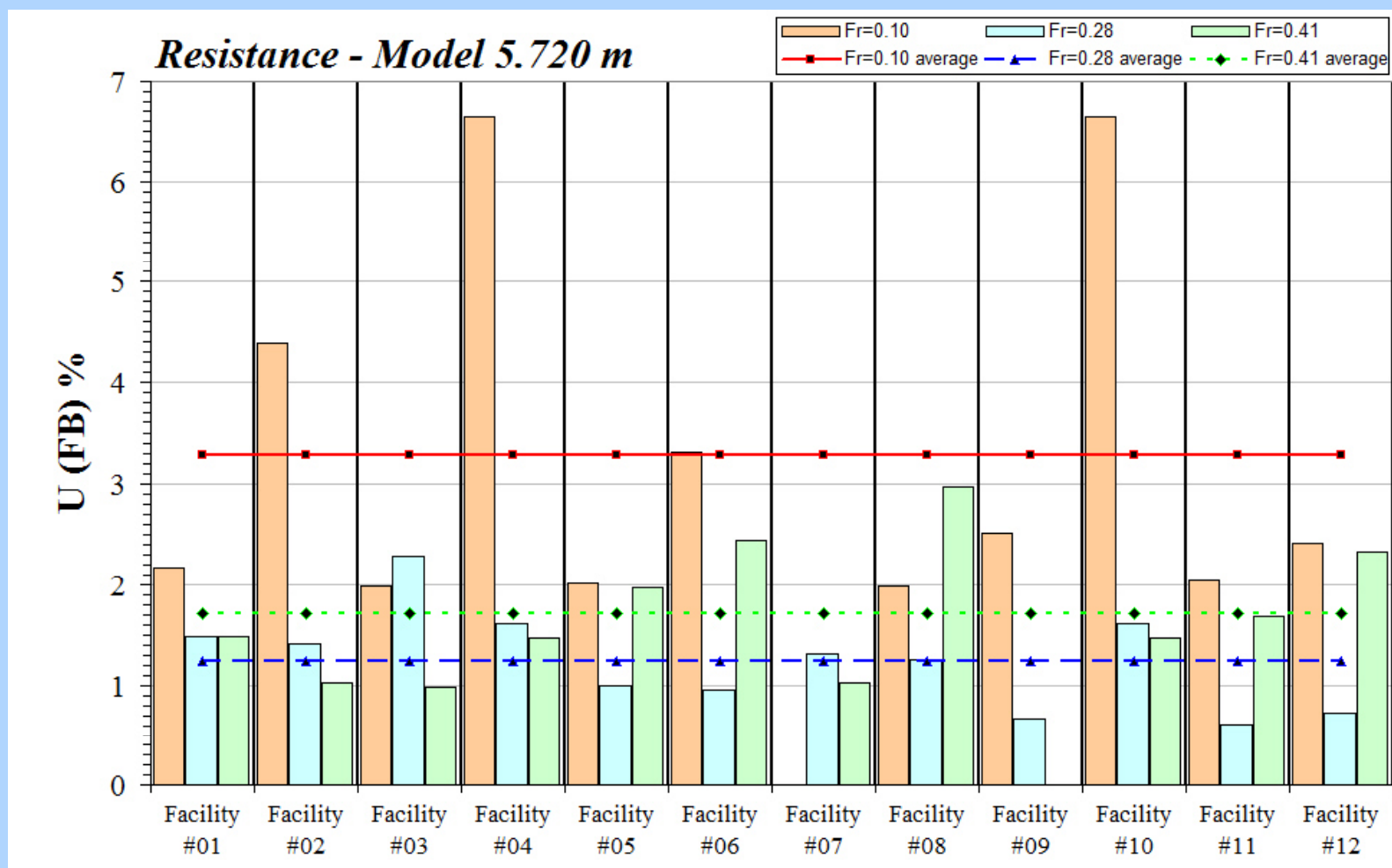
5.720m Model Resistance Coefficient Uncertainty



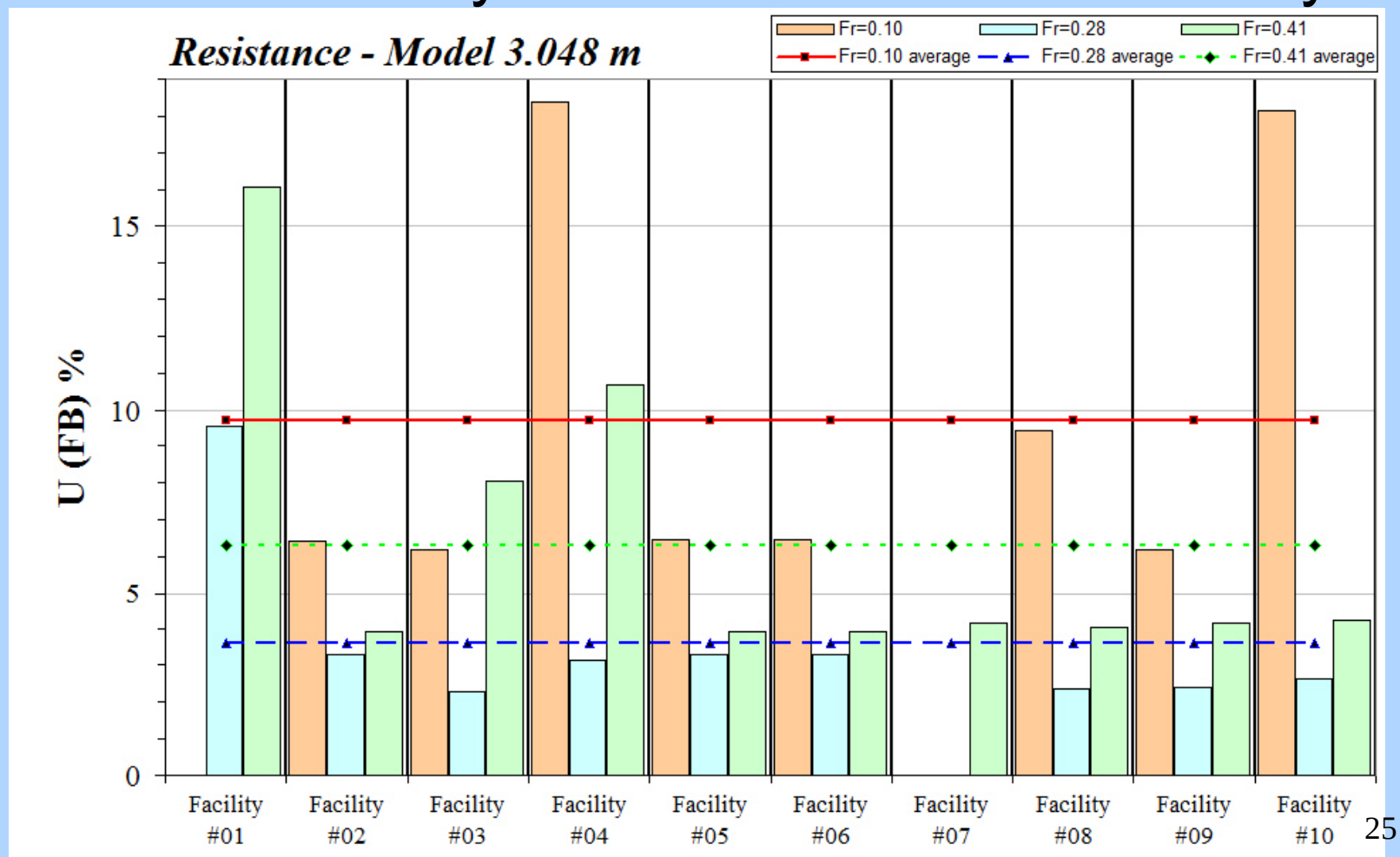
3.048m Model Resistance Coefficient Uncertainty



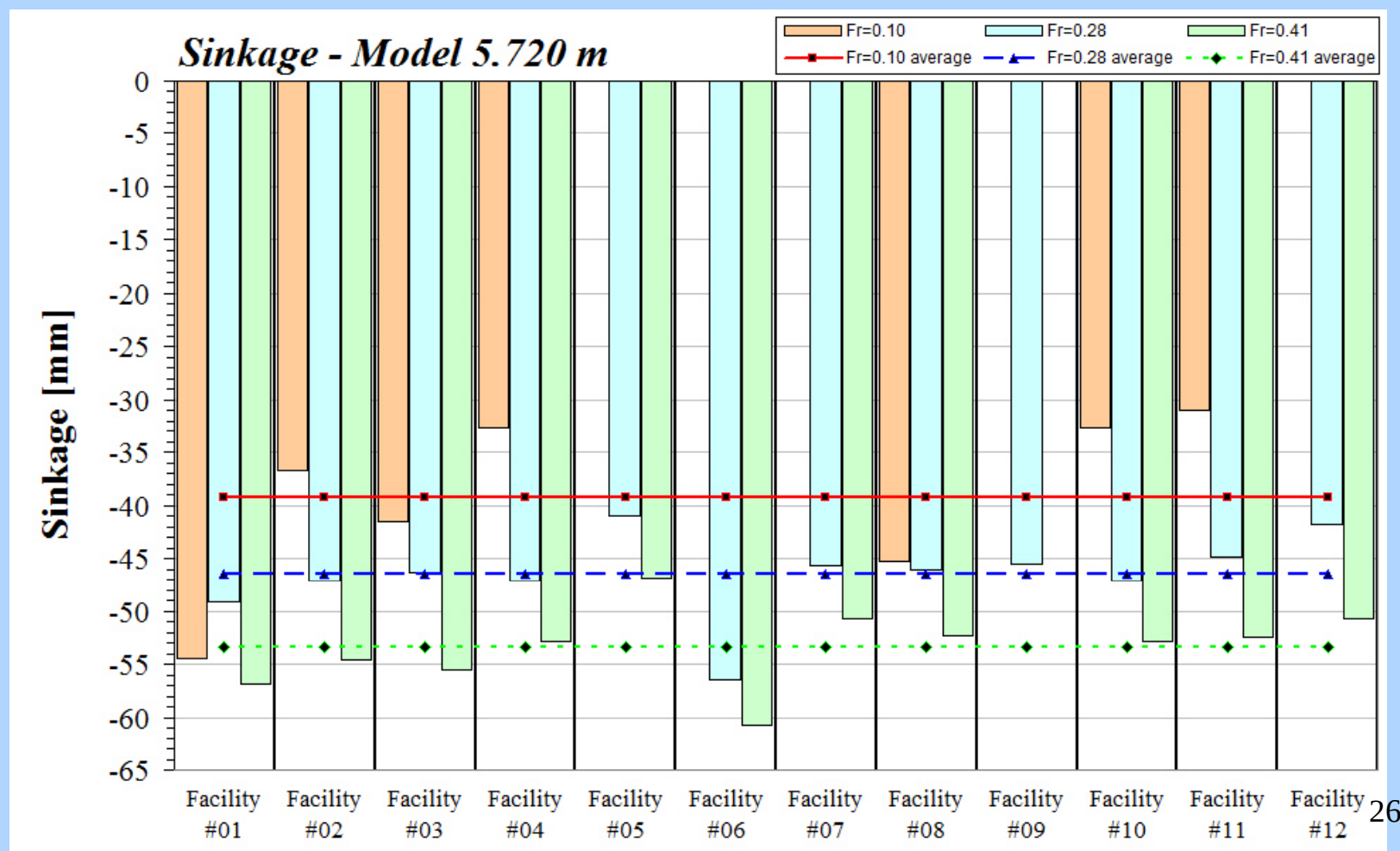
5.720m Model Facility Bias Uncertainty



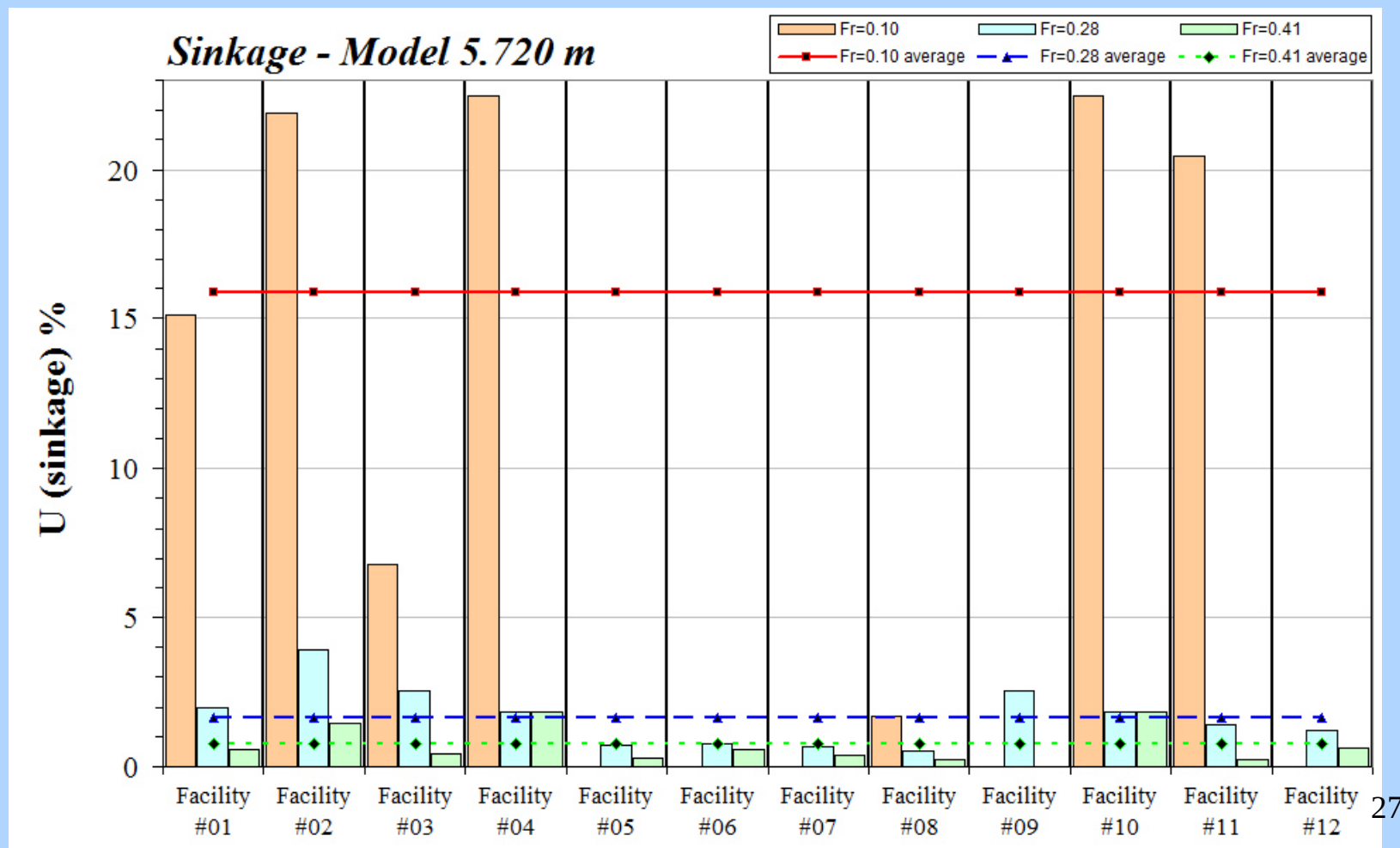
3.048m Facility Bias Resistance Uncertainty



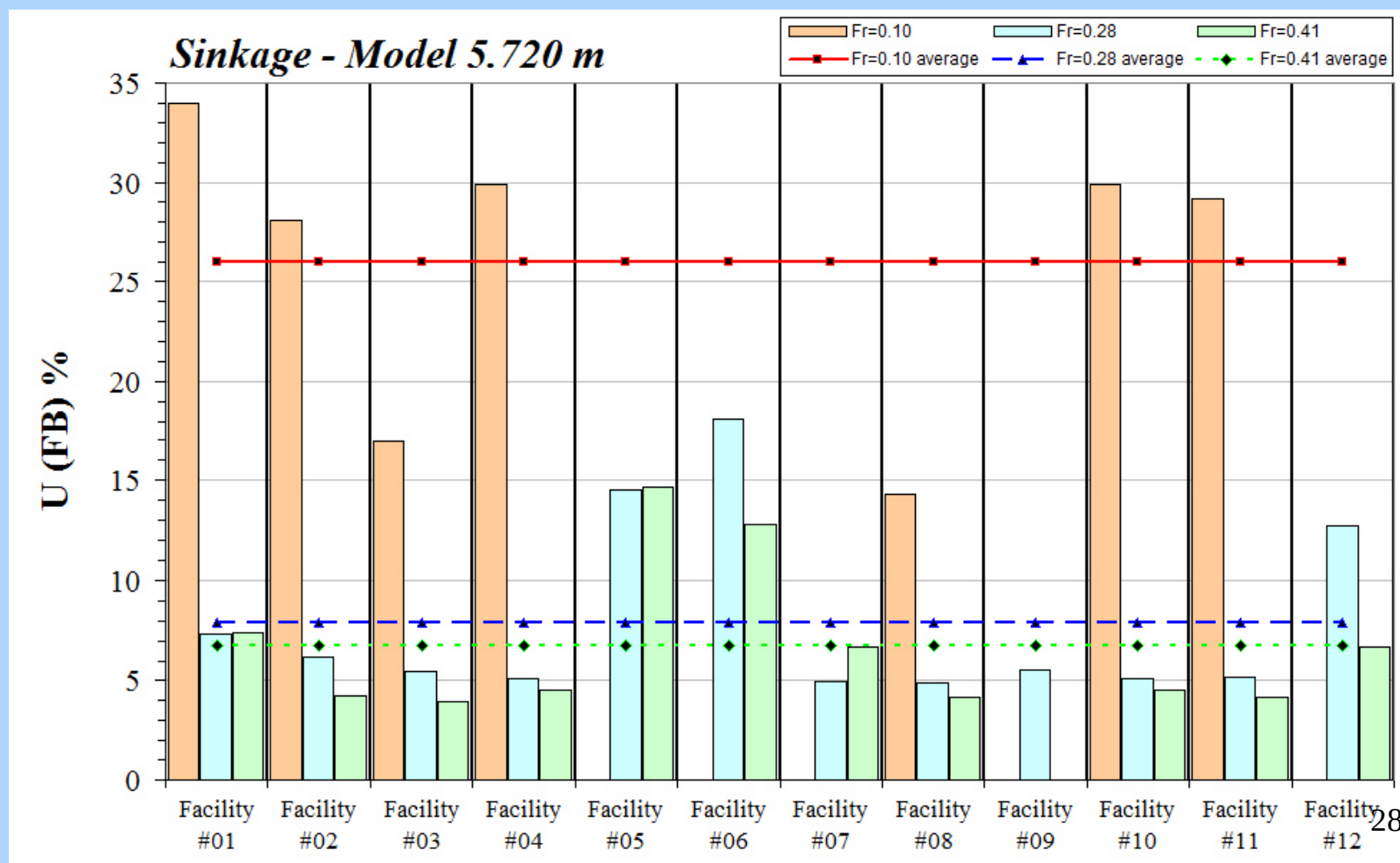
5.720m Model Sinkage Comparison



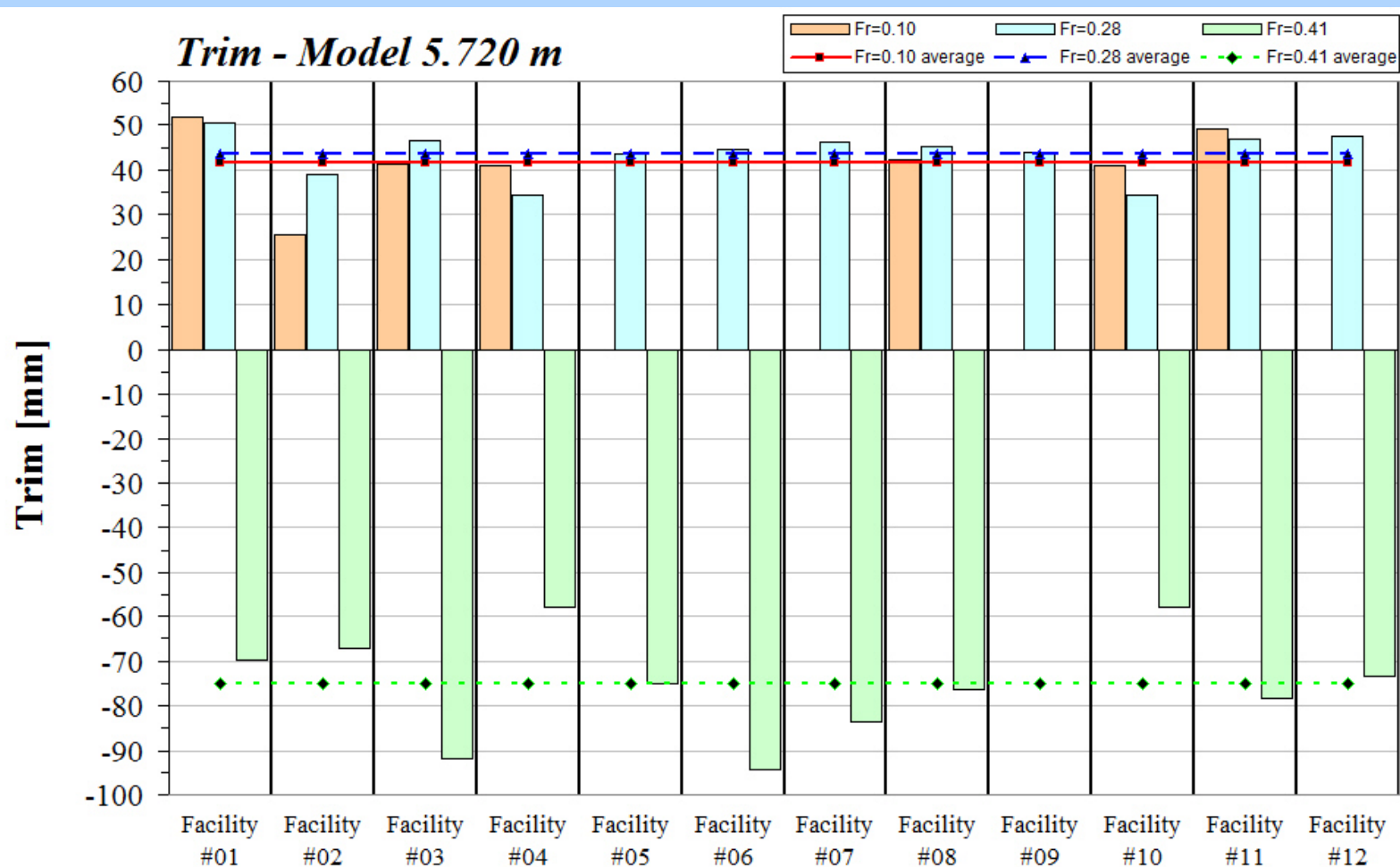
5.720m Model Sinkage Uncertainty Comparison



5.720m Sinkage Facility Uncertainty Comparison



5.720m Model Trim Comparison



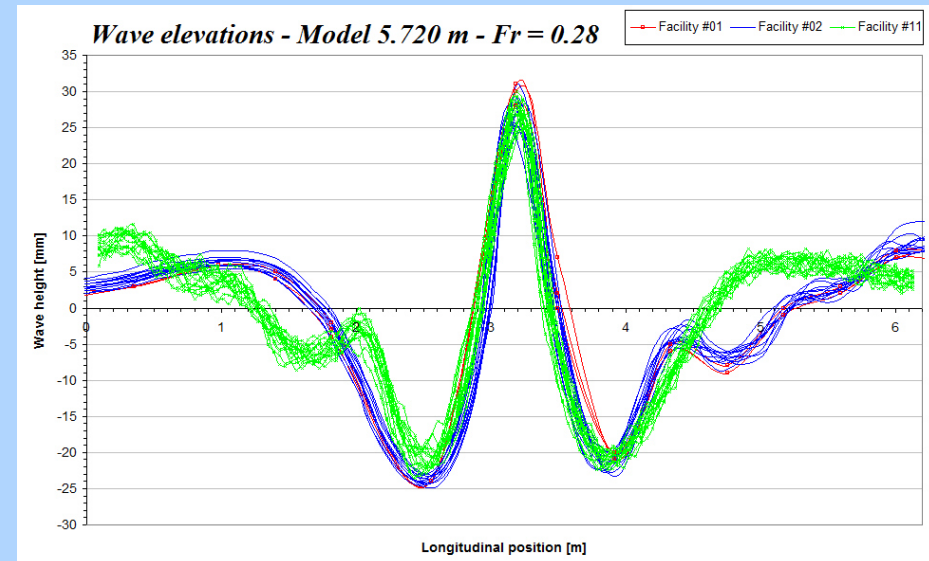
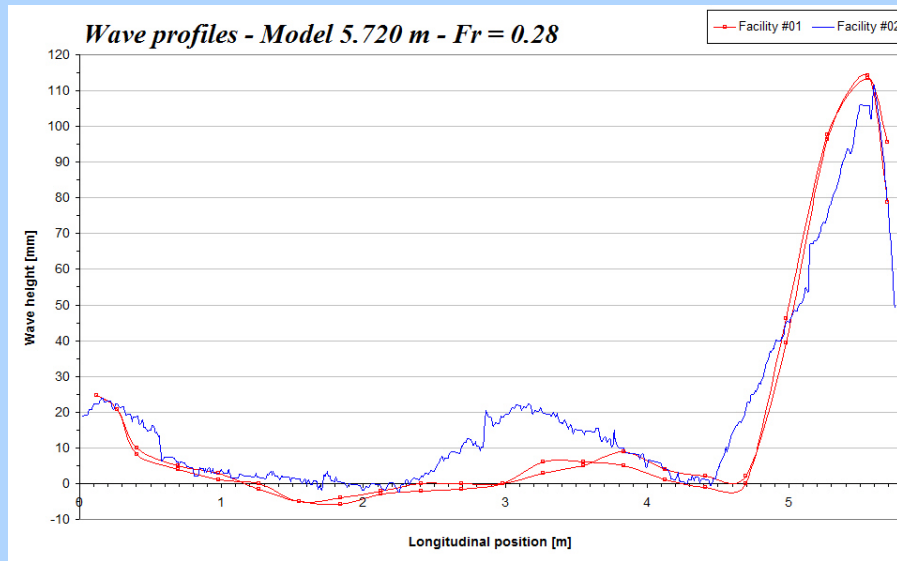
Median Total Uncertainties

Model	Fr	Resistance	Sinkage	Trim
5.720m	0.1	3.6%	30.8%	41.9%
	0.28	1.4%	8.2%	12.6%
	0.4`	1.8%	6.8%	17.0%
3.048m	0.1	10.1%	-----	-----
	0.28	3.7%	40.2%	52.0%
	0.41	6.4%	28.6%	24.3%

Largest uncertainties associated with the lowest speeds

Wave Data

- 5.720m model (2 facilities provided wave profile data and 3 wave elevation data)
- 3.048m model (1 facility provided wave profile data and 2 wave elevation data)





Summary

- Tests complete for large model
- Small model lost in customs
- A number of facilities have not sent in their data
 - Will be added to the database if it arrives
 - Database to be available on ITTC web page
- Largest uncertainties at the lowest speeds
 - Do not have details of the tests to determine what largest uncertainties are due to
 - A number of facilities did not correct ITTC example spreadsheet uncertainties for their own facilities
 - Appears related to dynamometer measurements
 - Implications for determining form factor with Prohaska test

3. Trends in Experimental Fluid Dynamics

- Review new techniques and trends in EFD
 - New and advanced EFD techniques
 - Experimental study on Drag Reduction

New and Advanced EFD Techniques

- The most notable and organized activity investigating advanced experimental techniques : the HTA (Hydro-Testing Alliance) project of EU, starting in September 2006 and is running for 5 years. See <http://hta-noe.eu/>
- The HTA consists of nine JRPs (Joint Research Program) as follows;
 - JRP1 PIV operation in hydrodynamic experimental facilities
 - JRP2 Flow data analysis and visualization
 - JRP3 3-D wave field measurements
 - JRP4 POD/Dynamic forces
 - JRP5 Wireless data transmission
 - JRP6 High speed video recording and analysis
 - JRP7 Intelligent materials and production methods
 - JRP8 Wetted surface
 - JRP9 Free running model technologies.
- The first conference, called AMT'09 was held with 34 paper presentations
Follow on conference too late for report AMT'11 in April (Newcastle)
- The Japanese Ship Propulsion Committee (JSPC) organized a symposium on the present status and perspective of tank testing techniques, see JSNAOE (2010).

PIV/LDV Flow Measurement Technologies

While LDV has become a very mature technique, PIV is still rapidly evolving both in terms of the hardware and the software. See various applications in Hallmann et al. (2009), Gjelstrup (2009), Liarokapis et al. (2009a), Grizzi et al. (2009), Anschau et al. (2009), Bouvy et al. (2009), Borleteau et al. (2009).

Wave Measurement Technologies

A number of advanced techniques to measure the three-dimensional wave field generated by a moving ship: See Fu and Fullerton (2009) and Drazen et al. (2010)

- scanning Light Detection and Ranging(LiDAR) system
- a laser sheet-optical quantitative visualization (QViz) system
- Nortek Acoustic Wave and Current (AWAC) profiler
- ultrasonic range finders, finger probes.
- A new generation of acoustic wave probes is developed to function well at high towing carriage speeds and high wave encounter frequencies with the support of the HTA project (Bouvy et al., 2009).

High Speed Video and Imaging Technologies

For the accurate wetted area estimation in high speed ships, Allenström et al. (2009) suggested image processing and computer vision techniques

Other Model Testing Technologies

A direct measurement disk sensor system of wall shear stress on low speed boundary layers under a flat surface was developed by Harleman et al. (2010)
Liarokapis et al. (2009b) developed a seven-hole pitot tube arrangement for measuring high quality wake flows in the towing tank.

Experimental Study on Drag Reduction

Air Lubrication

In Japan, air lubrication to reduce ship frictional drag was reported in quite a few papers. Full scale test with 126.6m length cement carrier, see Hinatsu et al. (2008), Kodama et al. (2008), Murakami et al. (2008) and Kawanami and Hinatsu (2010).

Test summary: maximum of 11% reduction in ship resistance, power savings of 4 % and 6% for full and ballast loads, respectively, and 40% reduction in local skin friction on the hull bottom.

Mitsubishi Heavy Industries also tested a module carrier *YAMATAI* and *YAMATO* overall length 162m with an air lubrication system, see Takano et al. (2010) Kawakita (2010) and Takano et al. (2010).

Test summary: a maximum of 12% power saving was achieved for 7mm thickness in air layer and more effective benefits can be achieved with more air flux.

Air Layer/Cavity Drag Reduction

Activities in Europe during the SMOOTH (Sustainable Methods for Optimal design and Operation of ships with air-lubricated Hulls) project have been compiled and reported in the international conference on ship drag reduction (SMOOTH-Ships) 2010 in Istanbul, Turkey.

The micro bubble lubricated test ship Till Deymann showed hardly any improvement in terms of power saving and even a negative net energy saving by considering the air compressor power input (reported in keynote speech, Thill (2010)).



Experimental Study on Drag Reduction

Kulik et al. (2010) reported that a new type of “stiff” compliant coating with enough endurance for real application led to drag reduction in a fully turbulent boundary layer.

There are frequently found controversies regarding the drag reduction efficiency of superhydrophobic surfaces.

A comparative evaluation of skin friction reduction capability, which was performed by the Ceccio group at the University of Michigan, gave no evidence that any of the currently reported skin-friction reducing superhydrophobic coatings really leads to skin friction reduction.

Kawashima et al. (2010) reported an experimental investigation of the frictional drag reduction by using polymer released from the painted surfaces.

4.0 Trends in Computational Fluid Dynamics

- Major trends
 - Wider adoption of CFD outside the community of method developers
 - Application of CFD for a wider spectrum of problems
- Review of the activities since the 25th conference
 - New CFD applications
 - Full scale predictions and scaling
 - Uncertainties in CFD
- Primary focus on the prediction and scaling of resistance according to the terms of reference

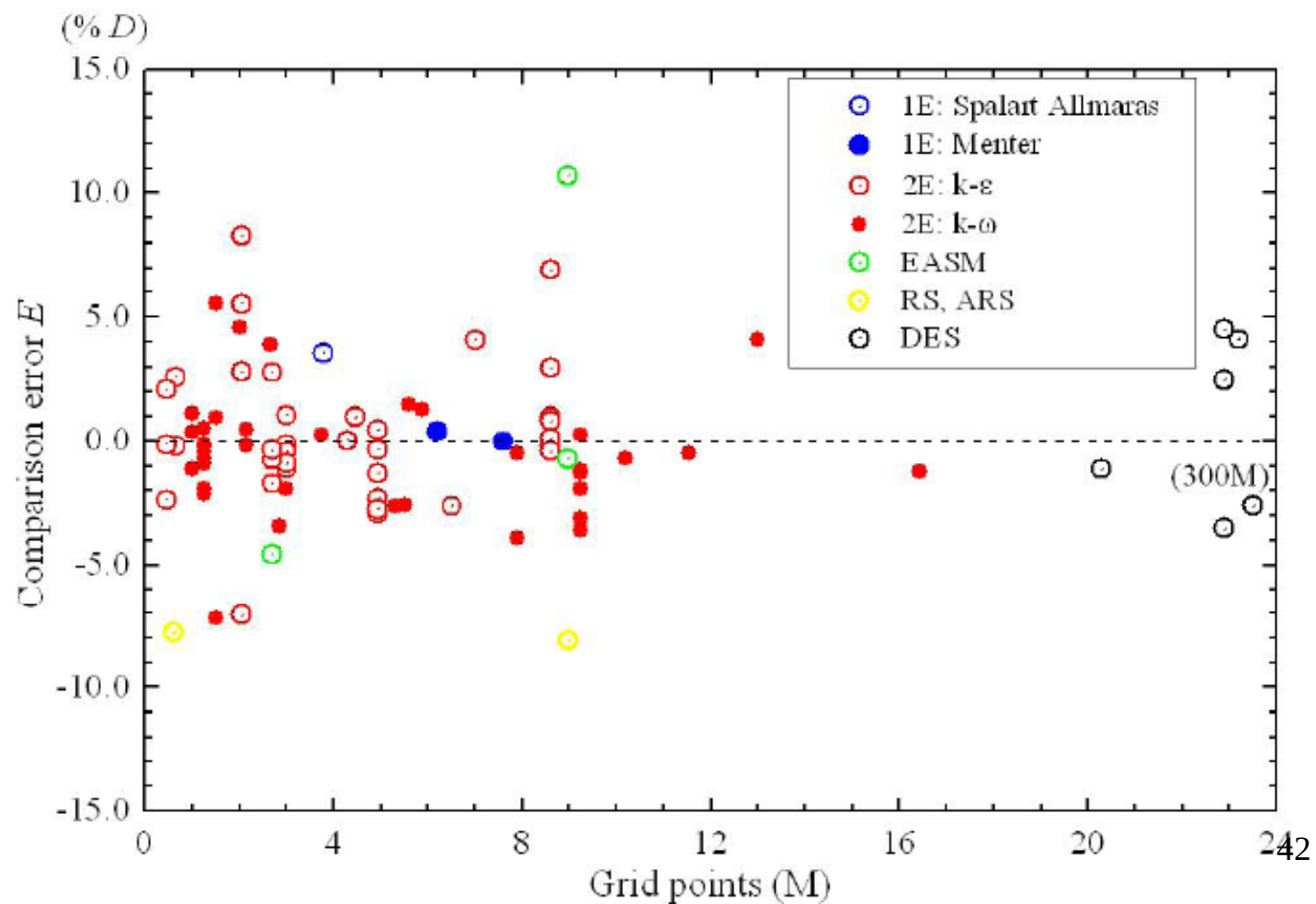
State of Affairs

- Turbulence modelling
 - RANS dominates
 - Some examples of LES and DES based studies as well
- Free surface modelling
 - Surface capturing (VOF, level-set) dominates; surface tracking clearly in minority
- Grid topology
 - Mostly of unstructured or structured multiblock or overset type
 - Cartesian grids with immersed boundary method gaining some popularity

Gothenburg 2.01k

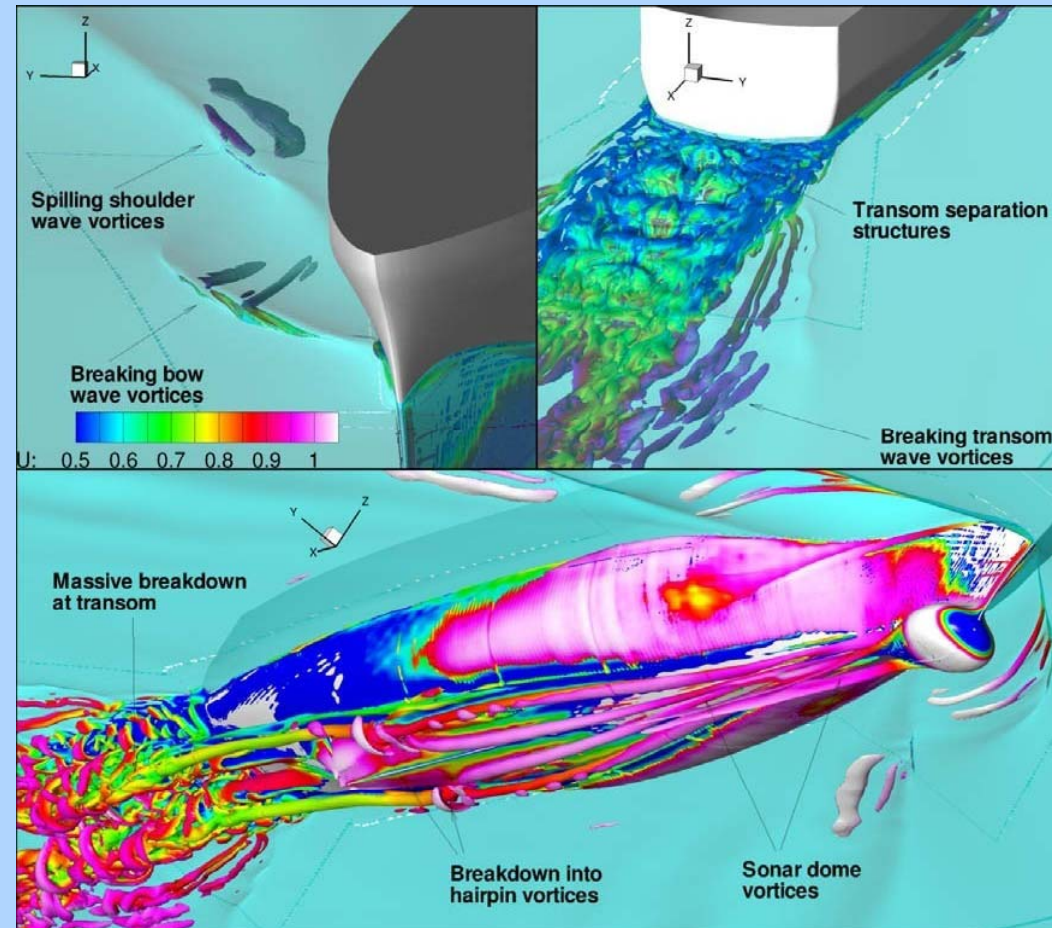
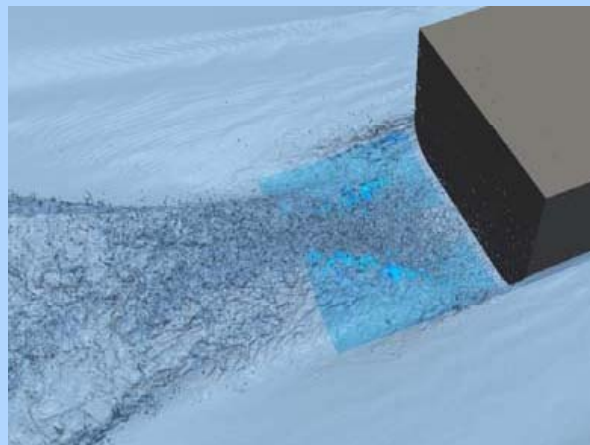
- 89 test cases evaluated resistance (and components) using CFD
- Arithmetic mean of errors similar to Tokyo workshop(2005)
- But standard deviation significantly reduced
- It is not just mesh size that is driving error

Turbulence models



New CFD Applications

- Increasing computational resources (parallel computing) and experience on CFD has resulted in
 - More detailed studies
 - Tackling of more complex problems
 - Extending range of CFD applications
- Examples include
 - Massively parallel (10^8 - 10^9 cell) studies
 - Added resistance with viscous field methods
 - Wind drag reduction, shallow water resistance, flow liners in cavitation tunnel, energy saving devices, single run resistance curve etc.



Drazen et al., 2010; 10^9 cells

Carrica et al., 2010; 114×10^6
points

Full scale predictions and scaling

- Clear trend of using CFD increasingly to make full scale predictions and to study the scaling of resistance
 - A number of studies directed at flat plate friction line
- CFD offers several advantages: full scale predictions directly available, detailed information on resistance division, isolation of particular components
- Roughness receiving more attention by some groups

Resistance Scaling

- Selected conclusions include
 - For friction lines significant variation between different models and proposals observed
 - Form factor shown to depend on the choice of the friction line
 - Choice of wetted surface influences resistance extrapolation
 - Wave making and the associated resistance components shown to be scale dependent
 - Various approaches to combine traditional resistance extrapolation and CFD have been presented
 - Computations challenging traditional assumptions

Uncertainties in CFD I

- Uncertainty still driven by turbulence models, grids, boundary conditions, user experience
- Convergence and round-off related errors can usually be made negligible
- Turbulence modelling is the main source of modelling error in resistance predictions
 - Depends on the suitability of the model for the case at hand
 - Largely varying predictions with different models possible
- Discretisation related uncertainties depend on scheme
 - Most schemes 2nd order with some higher order schemes available

Uncertainties in CFD II

- Boundary conditions and domain size can be another significant source of error
- Grid resolution is improving with larger computers and adaptive gridding
 - Grid quality still not often addressed
- Uncertainty prediction itself not straight forward
 - Quantification of the uncertainty is non-trivial and has to be based on prior validation with similar cases
- Code User has significant responsibility!

5. Scaling & Extrapolation

- CFD and other studies are challenging some of the traditional scaling assumptions
 - Different Friction lines proposed
 - Form factor dependence on scale and/or friction line
 - Wave drag dependence on scale

ITTC-57 Line

- ITTC-57 line is NOT a flat plate correlation line
- ITTC-57 line is a ship model correlation line that already contains a form factor added to the Hughes flat plate line

$$C_F = \frac{0.067}{(\log_{10} Re - 2)^2}$$

Hughes

$$C_F = \frac{0.075}{(\log_{10} Re - 2)^2} = (1 + 0.1194) \frac{0.067}{(\log_{10} Re - 2)^2}$$

ITTC-57

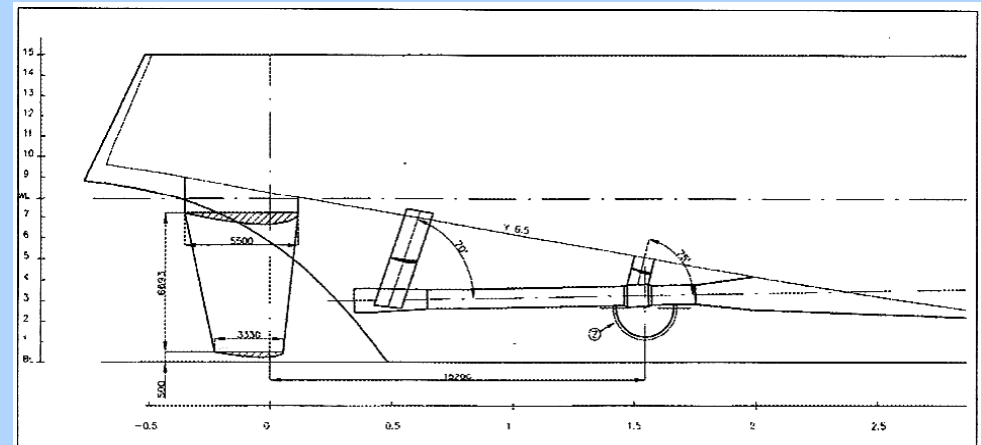
- Clarified in Procedure 7.5-02-02-01
- Original intent was to produce on average a better correlation among Geosim models of a variety of forms at different scales

Form Factor

- Form factor can increase accuracy where no bulbous bow and no immersed transom stern is present
- Determination of a suitable form factor is sensitive to modern hull form features
 - Modern bulbous bows
 - “Off-design” conditions, e.g. smaller draughts,
 - Wetted transom sterns
 - Typical RoRo stern shapes with flat low overhang
- Usually obtained from a low speed or Prohaska test
 - Largest errors seen in low speed tests in the worldwide campaign
- May be larger source of error than ITTC-57 or other line

Appendage Scaling

- HSVA and SVA “scale effect on appendage study” of a twin-screw passenger vessel
- CFD and model tests for three different model scale: $\lambda=36.25$ (SVA model), 23.2 (HSVA model), 11.2 and full scale



Appendage Scaling

	$(1+k_2)_{\text{Model}}$	f_C	$(1+k_2)_{\text{Model}} * f_C$ $= (1+k_2)_{\text{Ship}}$
Appendages			
Rudders	2.8	1.0	2.8
Shafts, hull bossings	2.2	0.7	1.8
V-brackets	11.0	1.0	11.0
I-brackets	3.0	1.3	3.5
Openings			
Stabilizer pockets	2.0	1.6	3.7
Forward thrusters	4.8	1.4	5.6
Aft thrusters	4.6	1.2	5.8

- More of an art than a science as constants not well known or defined
- Different scaling coefficients needed for different components
- CFD based methods may provide a role in this regards

6. Turbulence stimulation (TS)

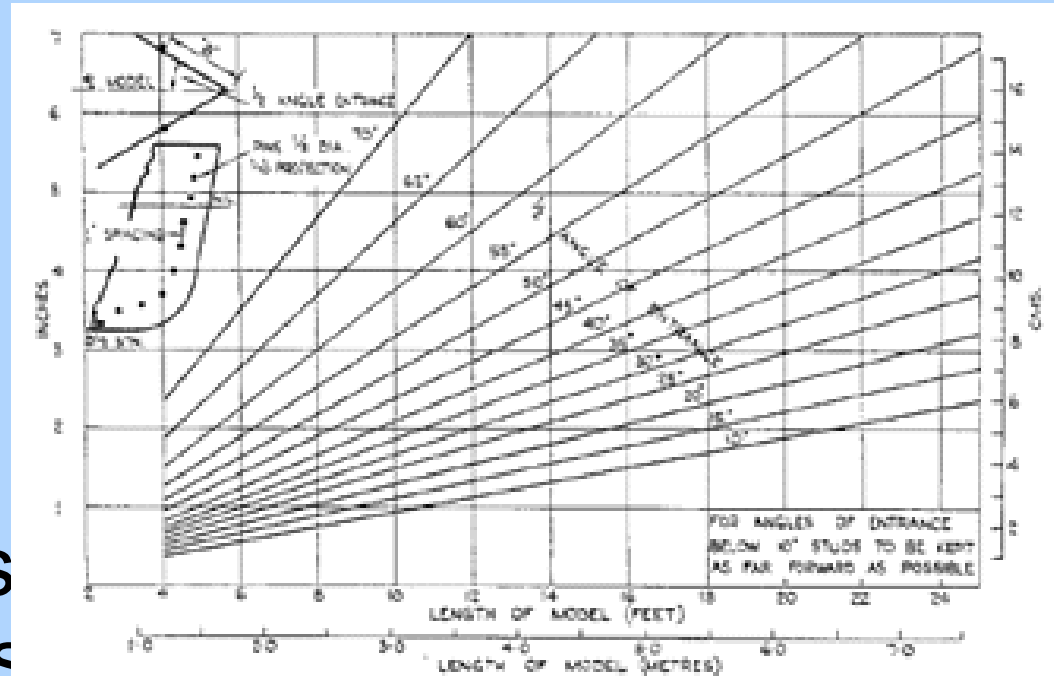
- Developments of new (innovative) ship types requires correct understanding of TS
- Historical review conducted
- Procedure 7.5-01-01-01 'Model manufacture ship models' updated to give reference to 26th ITTC RC report for greater detail with regard to physical/modelling improvements

History of Turbulence Stimulation

Proc.	Comments	Page No
9th	Incl. in name of committee –many and varied incl. triangles/rotating upstream cylinders, thermistor for detection, effect of tank turbulence	33-37, 51, 81-83,152-158, 165-168,172-174,179-187,194-199,204,211
10th ,	Three specific papers incl. details of many diff. types of stimulator	10a(13,17), 10b(4-7,48-55,56-78)
17th , 16th , 15th	One page section	17(112-113, 122, 131, 136,138), 16(22-23,33), 15(25)
18th , 14th , 13th , 11th a ,	Limited Reference, 13a recommends studs, notes that smaller wake maybe good for SP	18(49,63,95), 14(15,102,103), 11a(10,11,15)
21st , 20th , 19th , 12th ,	No mention	20(38),19(56)
24th , 23rd , 22nd	Request further work	24(18,23,38), 23(54), 22(7,48,56)

Main TS devices

- Roughness strips (sand grain on tape)
- Trip studs
- Trip wires
- Fig. 44 from 7.5-01-01-01 identifies location for various bow entry angles



Review

- Limited (published) work has been done since the 60's.
- This is reflected in procedure that quotes papers from same timescale 50's but does not include directly the later material available via ITTC.
- Most tank tests now regularly use trips of some form but maybe some knowledge is forgotten as to why.
- There are still problems with full form, low speed hulls, bulbous bows, and appendages
- There should be scope to revisit problem of appropriate TS design selection based on improved understanding of how transition occurs
- New types of stimulators are now used

Physics

- TS is passive flow control device (Gad-el-Hak 2000)
- Stability of laminar boundary layer velocity profile is critical as to whether and how quickly transition will occur
- Below a certain Rn threshold transition is not possible and TS just adds form drag
- TS devices typically mix momentum, into lower regions of boundary layer to promote transition e.g. trip stud flow features
- Critical parameter is non-dimensional height of TS device
- $Y^+ > 300$ for 3D stud and > 600 for trip wire

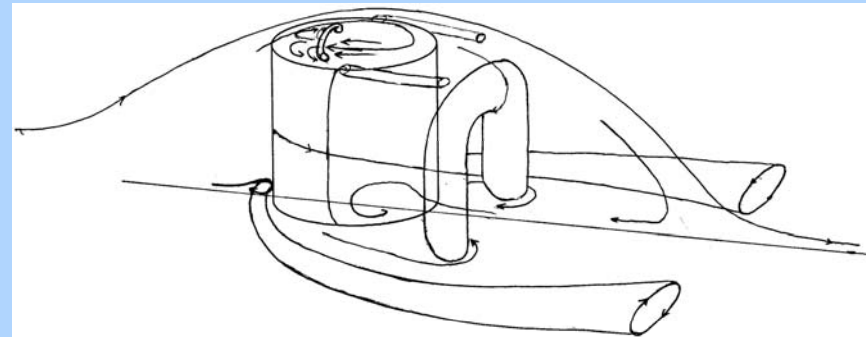


Figure 45 A schematic of typical vortical flow features around an aspect ratio 1 cylinder



Turbulent Stimulators, TS, (at 5%L_{pp})

- Wire, diameter >0.8 – 1.5mm, not as reliable a method of initiating turbulence at low Reynolds Number
- Roughness strip. Tape with sprinkling of suitable roughness elements. Often used with far too high a density. A fewer larger elements are better at initiating transition
- Tape on its own, due to its thickness, and best with a wavy edge to create longitudinal vortices
- Stud elements – typically straight cylinder, although many and varied shapes have been used. More recently micro dots. Problems at too low Re can get large streaks of laminar flow between studs. Multiple staggered rows.

Model scale resistance correction

TS device add form drag and changes skin friction – need to correct to scale friction change

$$\Delta D = D_{unstimulated} - D_{turbulent} - D_{laminar} - D_{stud}$$

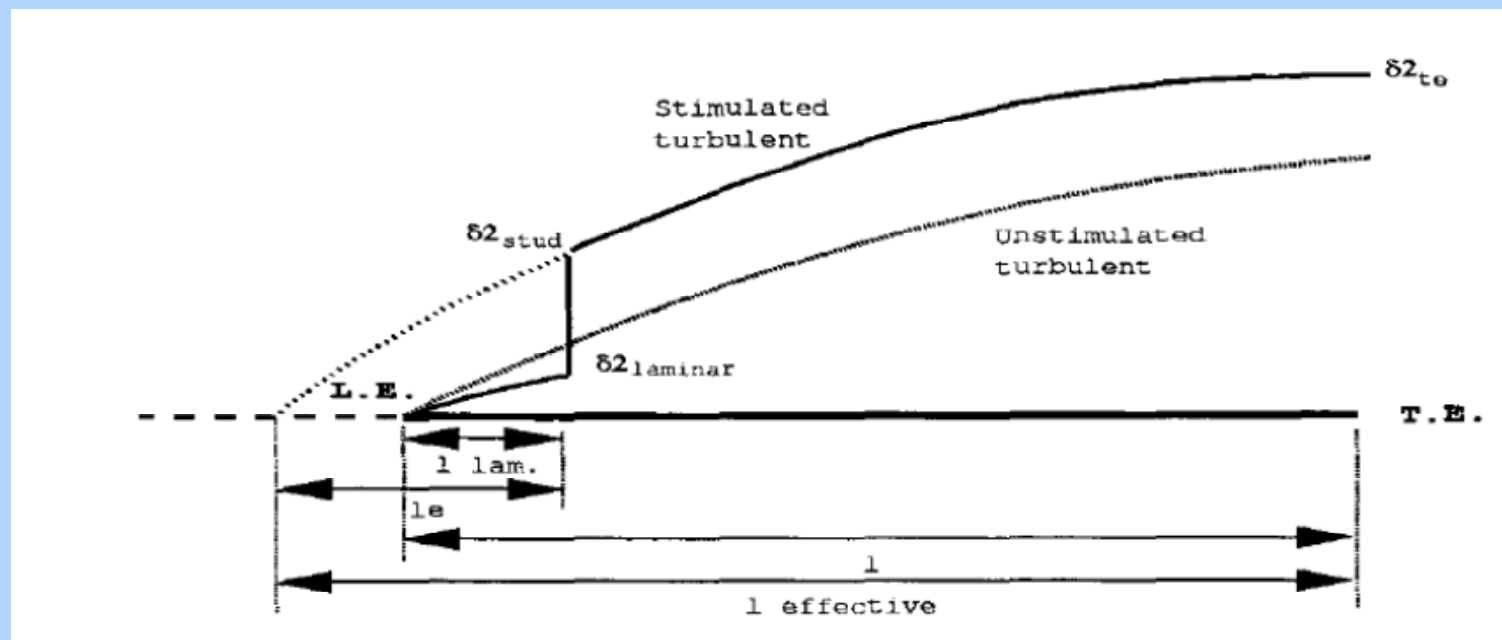


Table 10 Stud correction for model 6b at two speeds (Molland et al., 1994) All forces in N.

U [m/s]	R	D _{stud}	D _{turb}	D _{lam}	D _{unstim}	Correct	%
2.0	3.5	-0.140	1.642	0.047	1.767	-0.062	1.8
4.0	8.9	0.610	5.713	0.134	6.199	-0.260	2.9

Table 8 Length based Reynolds number with numbers in bold with a high proportion or a completely laminar flow regime

Model/appendage length (m)						
Fr	0.01	0.1	1	2	5	10
0.1	2.72E+02	8.61E+03	2.72E+05	7.70E+05	3.05E+06	6.16E+06
0.2	5.45E+02	1.72E+04	5.45E+05	1.54E+06	6.09E+06	1.23E+07
0.3	8.17E+02	2.58E+04	8.17E+05	2.31E+06	9.14E+06	1.85E+07
0.5	1.36E+03	4.31E+04	1.36E+06	3.85E+06	1.52E+07	3.08E+07
0.7	1.91E+03	6.03E+04	1.91E+06	5.39E+06	2.13E+07	4.31E+07
0.9	2.45E+03	7.75E+04	2.45E+06	6.93E+06	2.74E+07	5.55E+07



Appendage Resistance TS

1. For each appendage component classify the device as bluff, faired or lifting.
2. Evaluate for the range of Fr to be tested what the expected Reynolds number range is
3. Select a suitable TS device that is of a appropriate size and spacing to force transition without adding a significant amount of extra momentum loss that will alter the wake downstream.
4. Examine whether for those devices where there is a risk of flow separation or which will remain mostly laminar. What is the chosen strategy to mitigate the altered flow regime, either for example by using a rough surfaced appendage or altering its section profile.
5. Conduct progressive component stripping process, progressively adding appendages starting with the furthest forward.
6. Evaluate the resistance increase due to each component.
7. Scale the correct resistance contribution.

TS Conclusions

- Most explicit TS work took place over 50 years ago
- Basic principles still apply(!) and procedure valid but greater thought required as to when/where to use especially for appendages
- Appropriate scaling is required for TS devices based on their flow regime

RECOMMENDATIONS

Adopt the updated procedure No. 7.5-01-01-01 Model Manufacture Ship Models.

Adopt the updated procedure No. 7.5-02-02-01 Testing and Data Analysis
Resistance Test.

Thank-you