Resistance Committee

Final Report

1.1 Committee Members

- Stephen Turnock , University of Southampton
- Hisao Tanaka, Japan Marine United Corporation
- Jin Kim, Maritime and Ocean Engineering Research Institute
- Baoshan Wu, China Ship Scientific Research Centre
- Thomas C. Fu, Naval Surface Warfare Center,
- Ali Can Takinaci, Istanbul Technical University
- Tommi Mikkola, Aalto University

1.1 Meetings

- Istanbul, Turkey, 27-28 February 2012 at the Istanbul Technical University.
- Bethesda, Maryland, U.S.A., 13-14 September 2012 at the Naval Surface Warfare Center, Carderock Division.
- Espoo, Finland, 10-11 June 2013 at Aalto University, Otaniemi Campus.
- Southampton, United Kingdom, 14-15 January 2014 at the University of Southampton.

1.2 Tasks

1. Update the state-of-the-art for predicting the resistance of different ship concepts emphasising developments since the 2011 ITTC Conference.
2. Review ITTC Recommended Procedures relevant to resistance
3. Continue the analysis of the ITTC worldwide series for identifying facility biases.
4. Review definitions of surface roughness and develop a guideline for its measurement.

1.2 Tasks con't

5. Review results from tests that correlate skin friction with surface roughness.
6. Review trends and new developments in experimental techniques on unsteady flows and dynamic free surface phenomena.
7. Review new developments on model manufacturing devices and methods.
8. Review the development and evaluate improvements in design methods and the capabilities of numerical optimization applications, such as Simulation Based Design environments

Task2

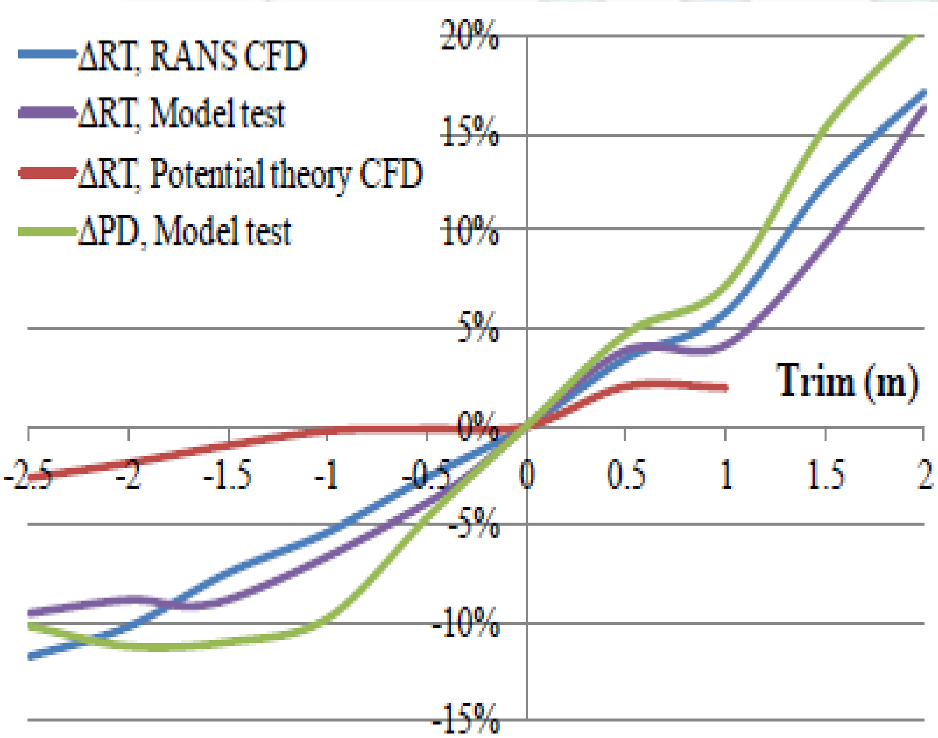
2. STATE OF THE ART

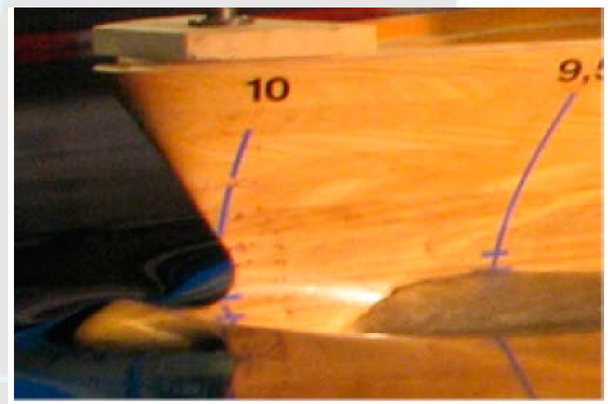
2. State of the art

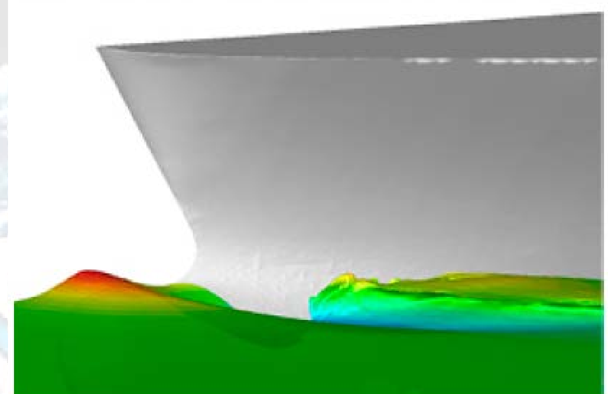
- Reducing fuel cost and emissions places greater emphasis on the ability to accurately resolve at design small changes in hull and appendage resistance.
- This has driven many of the state-of-the-art improvements seen since 2011 as research programmes focussed on the energy efficiency design index (EEDI) start to reach maturity.
- For example Investigations into air drag reductions using a combination of CFD and wind tunnel tests are expected to result in a new generation of streamlined ships.

Trim Optimisation

- Larsen et al (2012) examined the physics of how adjusting trim can modify both the form and wave resistance.
- A 10% drop in power could be achieved with 80% originating from residuary resistance changes around the bulbous bow

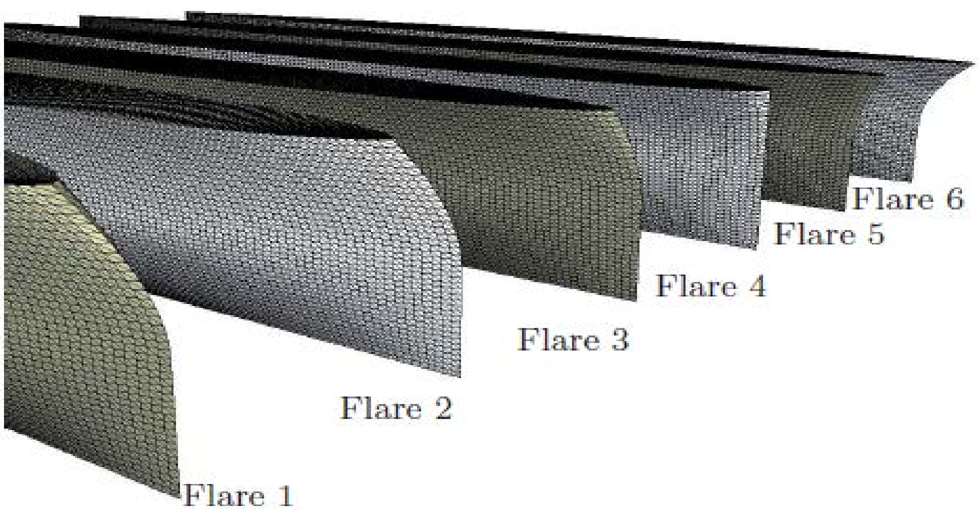


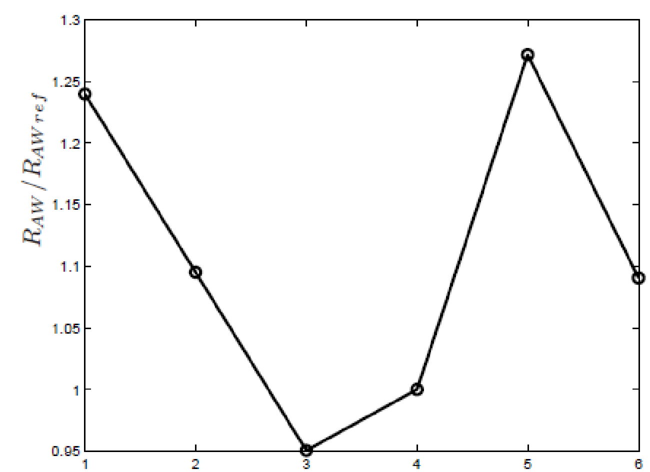




Resistance in waves

- Influence of the installed power term in the EEDI formula challenges how the performance of the ship across its whole operational profile can be quantified.





Six flares used to assess influence on added resistance (Winden et al, 2013).

2.1 Air lubrication

- **To develop practical bubble generation devices for full scale ships for drag reduction**
- **To estimate net energy-saving by bubble injection in a full scale ship based on experiments with 50m length flat plate**

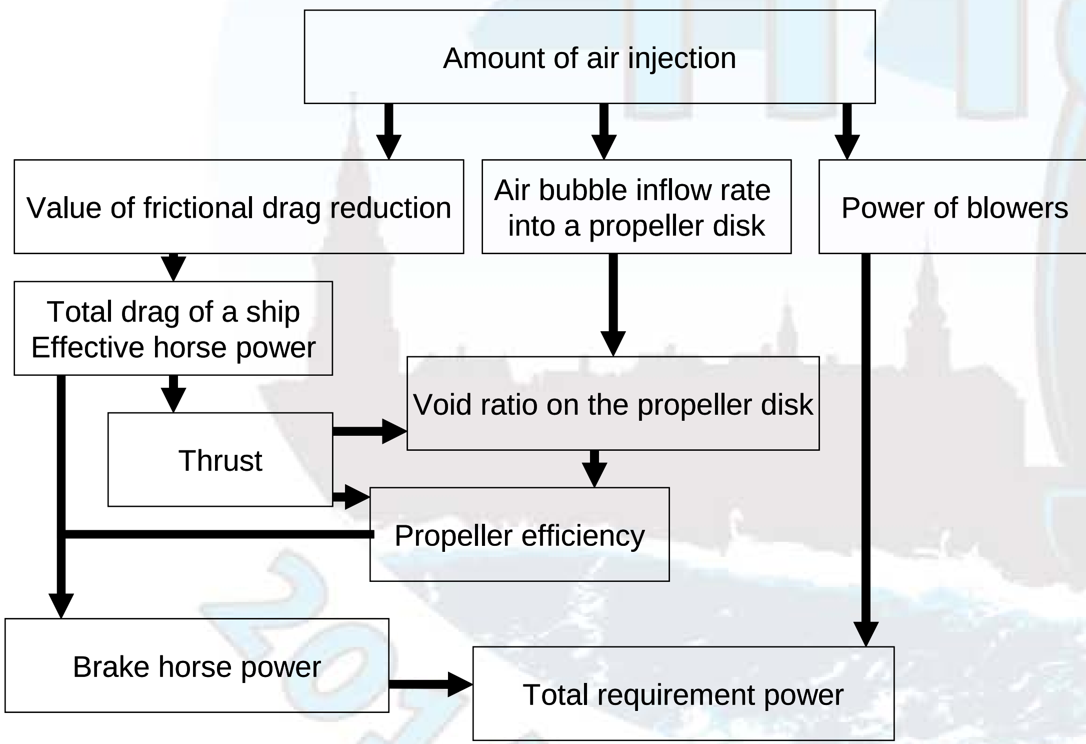
Principal particulars of the 50m flat plate

Principal particulars of 50m flat plate	
Length	50.0(m)
Breadth	1.0(m)
draft	0.05(m)
Towing speed	6.173(m/s)(12.0(kt))
Particulars of air injection device	
Length	100(mm)
Breadth	750(mm)
Locations of air injection (Distance from the bow)	
F : 3(m), G : 10(m), M : 26.2(m)	

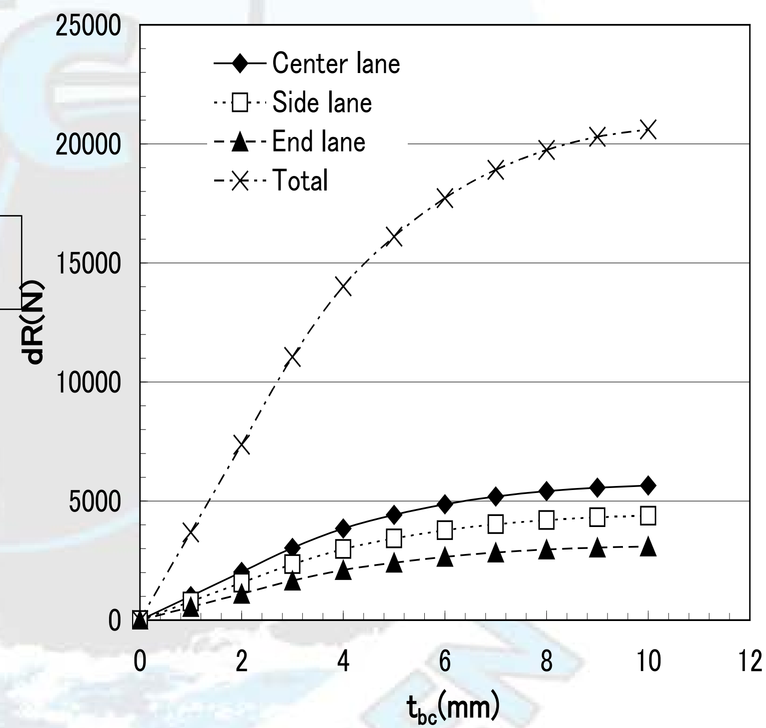
Photograph of the 50m flat plate

Full Scale Ship Power Estimation

- **The drag reduction values by air lubrication flow in full scale ship are estimated based on tank test result of 50m length flat plate.**



Schematic diagram of full scale ship power estimation with air lubrication



Estimated drag reduction value in full scale ship with air lubrication

2.2 Experimental techniques and extrapolation

- 3rd advanced model measurement technology conference series organised via an EU sponsored research programme, the hydro testing alliance http://www.hta-forum.eu/, Gdansk in September 2013, Atlar and Wilczynski, (2013).
- The sessions concentrated on noise measurements, PIV applications, optical measurements, coating assessment and drag reduction, uncertainty, control technologies, free running models and smart tank testing.

Waterline registration using fluorescence, Geerts et al (2013)

Used in assessing squat, freeboard and bow wave dynamics.

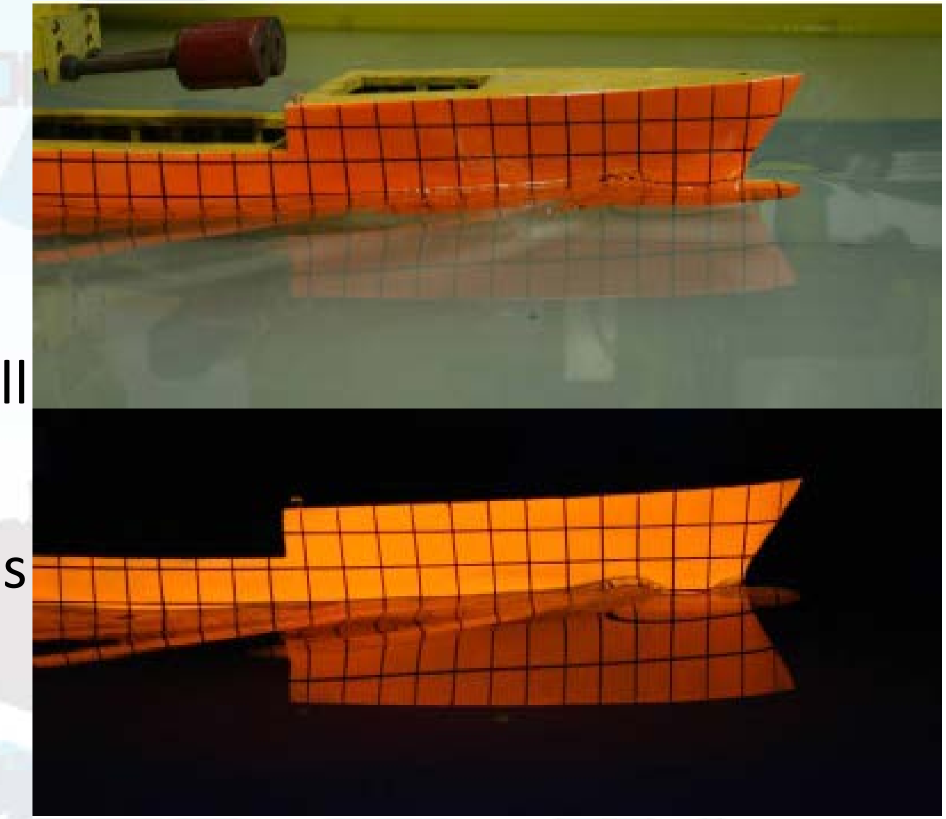
Fluorescent light source:

1.applied as a coating to the hull

2.illuminated by UV

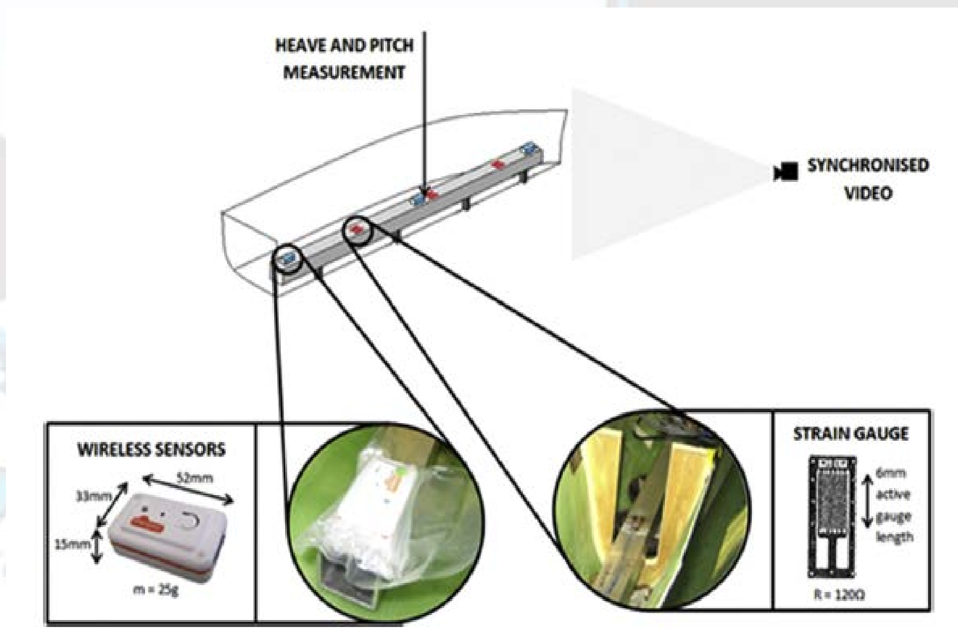
3.prevents unwanted reflections

4.accurate capture of the dynamic surface waterline



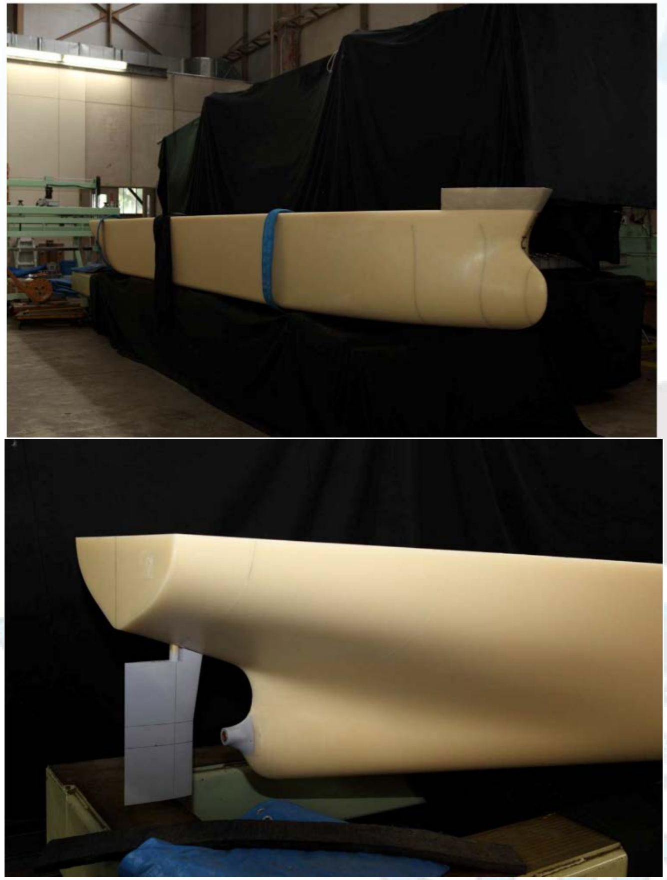
Inertial Measurement Units

- Bennett et al(2014) used three 9 degree of freedom wireless sensors, conventional heave and trim potentiometers and video analysis.
- Achieved comparable accuracy with 3 IMUs compared to conventional sinkage and trim system

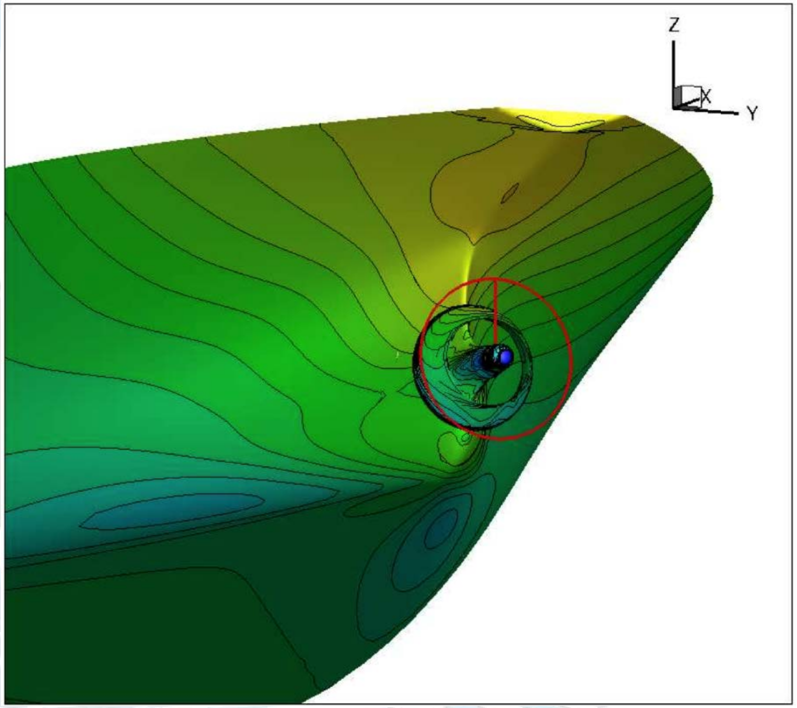


2.3 New Benchmark Data

- Plan of new measurements from the Steering Committee for CFD Workshop 2015 (December 2-4, 2015 @Tokyo, http://www.t2015.nmri.go.jp)
- Japan Bulk Carrier(JBC) w/ & w/o Energy Saving Device



Model Ship at NMRI



Pre-Computational Results for JBC

New Benchmark Data (2/2)

Condition	Hull	Measurement	Towing Tank
Towing	7m BH	X, M	NMRI
	7m BH w/o ESD	V, T	NMRI
	7m BH w/ ESD	V, T	NMRI
	3m BH w/o ESD	V, T	OU
	3m BH w/ ESD	V, T	OU
Self Propulsion	7m BH	SP, M	NMRI
	7m BH w/o ESD	V, T	NMRI
	7m BH w/ ESD	V, T	NMRI
	3m BH w/o ESD	V, T	OU
	3m BH w/ ESD	V, T	OU

*X: Resistance, M: Trim and Sinkage, SP: Self-propulsion data, V: Velocities, T: Turbulence, NMRI: National Maritime Research Institute, OU: Osaka University

2.4 Practical applications of CFD

- Good overview of CFD capabilities provided by the CFD workshop series
- Some collected conclusions related to resistance from the G2014 (Larsson et al, 2014)
  - Accuracy
    - mean comparison error for resistance practically zero (-0.1%) and the std deviation reduced considerably since T2005 (from 4.7% to 2.1%); most resistance solutions validated
    - for Fr>0.2 the mean comparison errors for sinkage and trim are around 4%
    - wave profiles on the hull and at the closest cut generally well predicted, but larger deviations further from the hull

Practical applications of CFD

- Turbulence modelling
  - Turbulence models more advanced than the two-equation models do not improve the resistance predictions
  - The anisotropic explicit algebraic Reynolds stress model the best option for predicting aft body flow of U shaped hulls with strong bilge vortex
  - The hybrid RANS/LES models seem promising, but have problems in case of limited separation or triggering turbulence for slender bodies and require significantly higher grid resolution than pure RANS

Practical applications of CFD

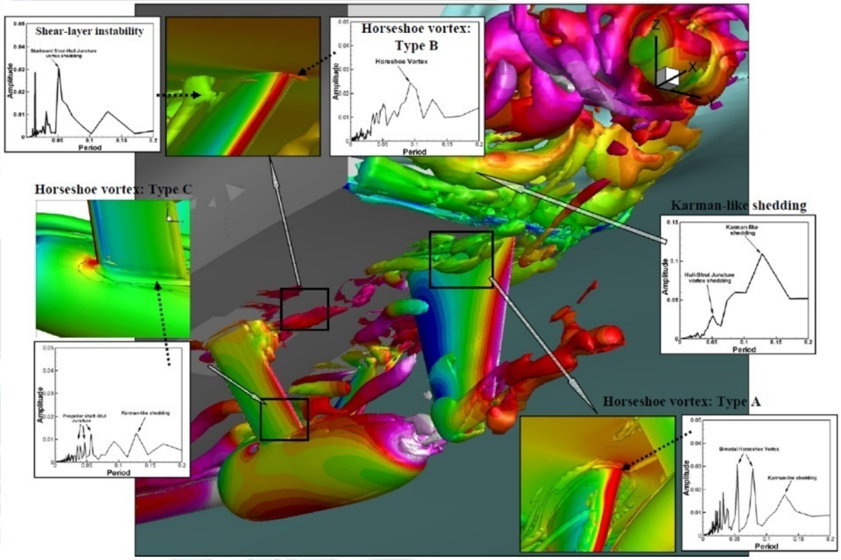
- Grid size and type
  - Grid sizes above 3M cells do not significantly improve resistance predictions with RANS (4 and 8% comparison error above and below this limit)
  - Finer grids (up to tens of millions of cells) required for local flow predictions
  - Free surface for DTMB 5415 accurate already with 2M cells, finer grids required for KVLCC2
  - Easier to reach grid convergence with structured than unstructured grids
  - Different uncertainty estimation methods give consistent results in the vicinity of the asymptotic range, but not when far from it

Practical applications of CFD

- Distribution of resistance for a segmented KVLCC2 model (Guo et al, 2013)
- Calm water resistance of a surface effect ship (Maki et al, 2013)
- Performance analysis of a very-large high-speed ship at 36+ kts (Takai et al, 2011)
- Catamaran in shallow water (Castiglione et al, 2014)
- Vortical structures and instability of transom flow, sinkage and trim of the appended Athena (Bhushan et al, 2012)
- Fully resolved LES for KVLCC2 in model scale using 32×10^9 cells (Nishikawa et al, 2013)
- Flow field and resistance of planning hull forms with $1\text{-}8 \times 10^8$ cells (Fu et al, 2013)

		$E\%D$	$U_G\%D$	$U_D\%D$	$U_{\mathrm{Val}}\%D$
SST	R_t	−0.50%	4.04%	1.00%	4.16%
EASM		2.60%	3.39%	1.00%	3.53%
SST	R_{fore}	−0.83%	8.11%	0.77%	8.15%
EASM		0.52%	7.84%	0.77%	7.88%
SST	R_{aft}	9.26%	−12.7%	0.76%	12.72%
EASM		3.34%	−5.89%	0.76%	5.94%
SST	η_3	−12.96%	5.26%	1.26%	5.41%
EASM		−12.10%	5.76%	1.26%	5.90%
SST	η_5	2.30%	4.28%	0.88%	4.37%
EASM		1.35%	5.07%	0.88%	5.15%

(Guo et al, 2013)



(Bhushan et al, 2012)

Task 3

3. REVIEW & REVISE PROCEDURES

3. Procedures and Guidelines

- **Guidelines for Uncertainty Analysis in Resistance Tests**

History of Revising before 27th ITTC:

Procedures/Guidelines for UA in resistance tests			Remarks
1	7.5-02-01-01 (1999/Rev00)	Uncertainty Analysis in EFD, Uncertainty Analysis Methodology.	AIAA
	(2008/Rev01)	Guide to the Expression of Uncertainty in Experimental Hydrodynamics.	ISO-GUM
2	7.5-02-01-02 (1999/Rev00)	Uncertainty Analysis in EFD, Guidelines for Resistance Towing Tank Tests.	AIAA
	7.5-02-02-02 (2008/Rev01)	General Guidelines for Uncertainty Analysis in Resistance Towing tank Tests.	ISO-GUM
	~~7.5-02-02-02 (2002/Rev01)~~	~~Uncertainty Analysis, Example for Resistance Test.~~ (Dropped since 2008)	~~AIAA~~
3	7.5-02-02-03 (2002/rev00)	Uncertainty Analysis Spreadsheet for Resistance Measurements.	AIAA
4	7.5-02-02-04 (2002/rev00)	Uncertainty Analysis Spreadsheet for Speed Measurements.	AIAA
5	7.5-02-02-05 (2002/rev00)	Uncertainty Analysis Spreadsheet for Sinkage and Trim Measurements.	AIAA
6	7.5-02-02-06 (2002/rev00)	Uncertainty Analysis Spreadsheet for Wave Profile Measurements.	AIAA

Guidelines for Uncertainty Analysis in Resistance Tests

General Considerations for Revising during 27th ITTC:

(1) Purpose: to provide practical guides for routine tests performed commercially in towing tanks;

(2) For model tests, the object of measurement is the total resistance; UA for resistance tests focuses on the total resistance (coefficient);

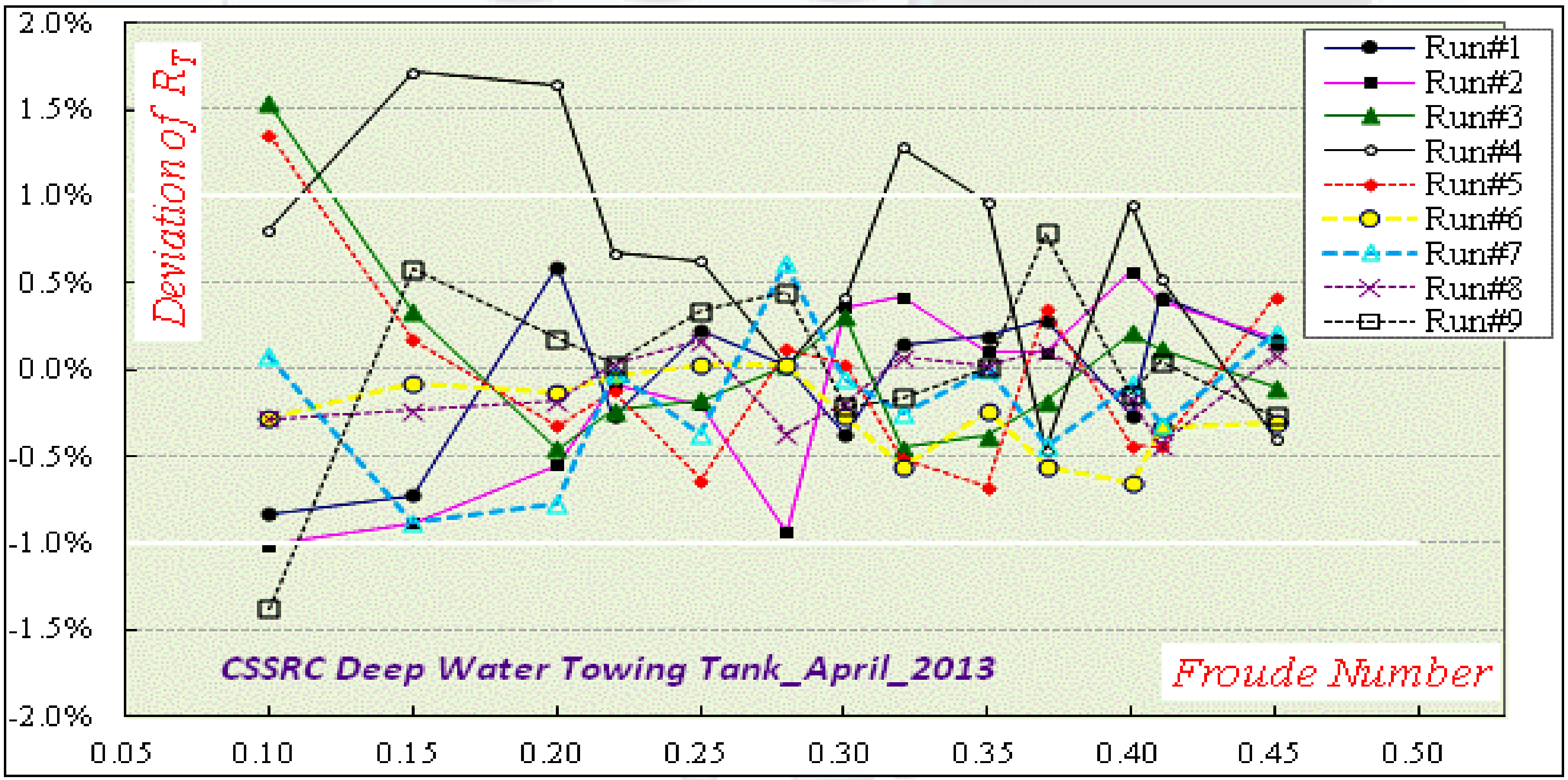
(3) Scaling effect related to C_f calculation and data reduction for $(1+k)$ and C_R should be included into that of extrapolation ;

(4) Uncertainty related to installation (at different time), more like reproducibility, may be evaluated practically with database of individual tanks.

Guidelines for Uncertainty Analysis in Resistance Tests

Detailed Example for UA of DTMB5415 (5.72m) Tests:

Performed as commercial service, but with 9 (nine) repeat tests



- **Guidelines for Uncertainty Analysis in Resistance Tests**

Detailed Example for UA of DTMB5415 (5.72m) Tests:

Evaluation of Uncertainty Components in details

Single Run

Total Uncertainty **0.98%**

Component of Uncertainty in R_T	**Type**	**Uncertainty Component in R_T (Fr = 0.28)**
Wetted Surface Area	B	0.035 % *negligible*
Dynamometer (v=32)	A	**0.19 %** *minor*
Towing Speed	B	0.067 % *negligible*
Water Temperature	B	0.024 % *negligible*
Repeatability (N=9) *for single measurement*	A	**0.45 %** *dominating*
Combined uncertainty *for single measurement*		**0.49 %**
Expanded uncertainty *for single measurement*		**0.98 %** (k_P=2)

- **Guidelines for Uncertainty Analysis in Resistance Tests**

Detailed Example for UA of DTMB5415 (5.72m) Tests:

To reduce Total Uncertainty, it is better to use the mean value of repeat tests as the measuring result.

Mean of 9 Runs

Total Uncertainty **0.51%**

Component of Uncertainty in R_T	Type	Uncertainty Component in R_T (Fr = 0.28)
Wetted Surface Area	B	0.035 % *negligible*
Dynamometer (v=32)	A	**0.19 %** *dominating*
Towing Speed	B	0.067 % *minor*
Water Temperature	B	0.024 % *negligible*
Repeatability (N=9) *for mean of 9 runs*	A	**0.15 %** *dominating*
Combined uncertainty *for mean of 9 runs*		**0.26 %**
Expanded uncertainty *For mean of 9 runs*		**0.51 %** (k_P=2)

Guidelines for Uncertainty Analysis in Resistance Tests

Detailed Example for UA of DTMB5415 (5.72m) Tests:

Practical guides for practice in routine/commercial tests:

only dominating uncertainties are significant; Spreadsheet unnecessary

Procedures/Guidelines for UA in resistance tests		Remarks
7.5-02-02-02 (2014/Rev02)	**General Guidelines** for Uncertainty Analysis in Resistance Towing tank Tests.	ISO-GUM
7.5-02-02-02 .1 (2014/Rev00)	Guideline, **Example** for Uncertainty Analysis of Resistance Tests in Towing Tank	ISO-GUM
7.5-02-02-02 .2 (2014/Rev00)	**Best Practice Guideline** for Uncertainty Analysis in Routine Resistance Tests	ISO-GUM
~~7.5-02-02-03 (2002/rev00)~~	~~Uncertainty Analysis Spreadsheet for Resistance Measurements.~~ (to be dropped)	~~AIAA~~
~~7.5-02-02-04 (2002/rev00)~~	~~Uncertainty Analysis Spreadsheet for Speed Measurements.~~ (to be dropped)	~~AIAA~~
~~7.5-02-02-05 (2002/rev00)~~	~~Uncertainty Analysis Spreadsheet for Sinkage and Trim Measurements.~~ (to be dropped)	~~AIAA~~
~~7.5-02-02-06 (2002/rev00)~~	~~Uncertainty Analysis Spreadsheet for Wave Profile Measurements.~~ (to be dropped)	~~AIAA~~

•Guidelines for Uncertainty Analysis in Resistance Tests

Detailed Example for UA of DTMB5415 (5.72m) Tests:

Some special attention to geometry uncertainties:

(1) The nominal displacement volume and surface area of ship model can be obtained through the numerical CAD model (e.g., IGES) for NC milling machine. These geometric parameters maybe vary with towing tanks/model workshops, because of different fairing by individual workshop. If a specific towing tank use its own model ship to carry out testing, the geometric parameters of model should be calculated by its own CAD model.

•Guidelines for Uncertainty Analysis in Resistance Tests

Detailed Example for UA of DTMB5415 (5.72m) Tests:

Some special attention to geometry uncertainties:

(2) The wetted surface area is an important geometric parameter in resistance test.

✓ **For submerged vessel:**

Displacement volume: $\nabla \propto L \cdot B \cdot H$

Uncertainty estimate: $$\left(\frac{\delta\nabla}{\nabla}\right)^2 \approx \left(\frac{\delta L}{L}\right)^2 + \left(\frac{\delta B}{B}\right)^2 + \left(\frac{\delta H}{H}\right)^2$$

Wetted surface area: $$u'_\nabla \equiv \frac{u_\nabla}{\nabla} \approx \sqrt{(u'_L)^2 + (u'_B)^2 + (u'_H)^2}$$

Uncertainty estimate: $$S \propto \left[(\nabla)^{1/3}\right]^2$$

$$u'_S \equiv \frac{u_S}{S} \approx (u'_\nabla)^{2/3}$$

Guidelines for Uncertainty Analysis in Resistance Tests

Detailed Example for UA of DTMB5415 (5.72m) Tests:

Viewpoint: UA methodology for resistance measurement of model tests may be different from UA for resistance prediction (extrapolation to full scale).

Action in future: A new guideline for UA of extrapolation should be developed in future, where special consideration should be given to the uncertainties of the ITTC-1957 frictional line/frictional resistance calculation, the data reduction process for (1+k) and residuary resistance. the allowance for surface roughness, air drag concerned and etc. in full scale prediction. Suggest to develop *7.5-02-02-02.3 Guideline, Uncertainty Analysis in Extrapolation of model resistance to Full Scale*

Task 4

4. WORLDWIDE SERIES

4.1 Inter-Tank Comparison

Large model - 5.72m DTMB5415

Froude numbers: 0.1, 0.28, 0.41

Total resistance: 15°C fresh water

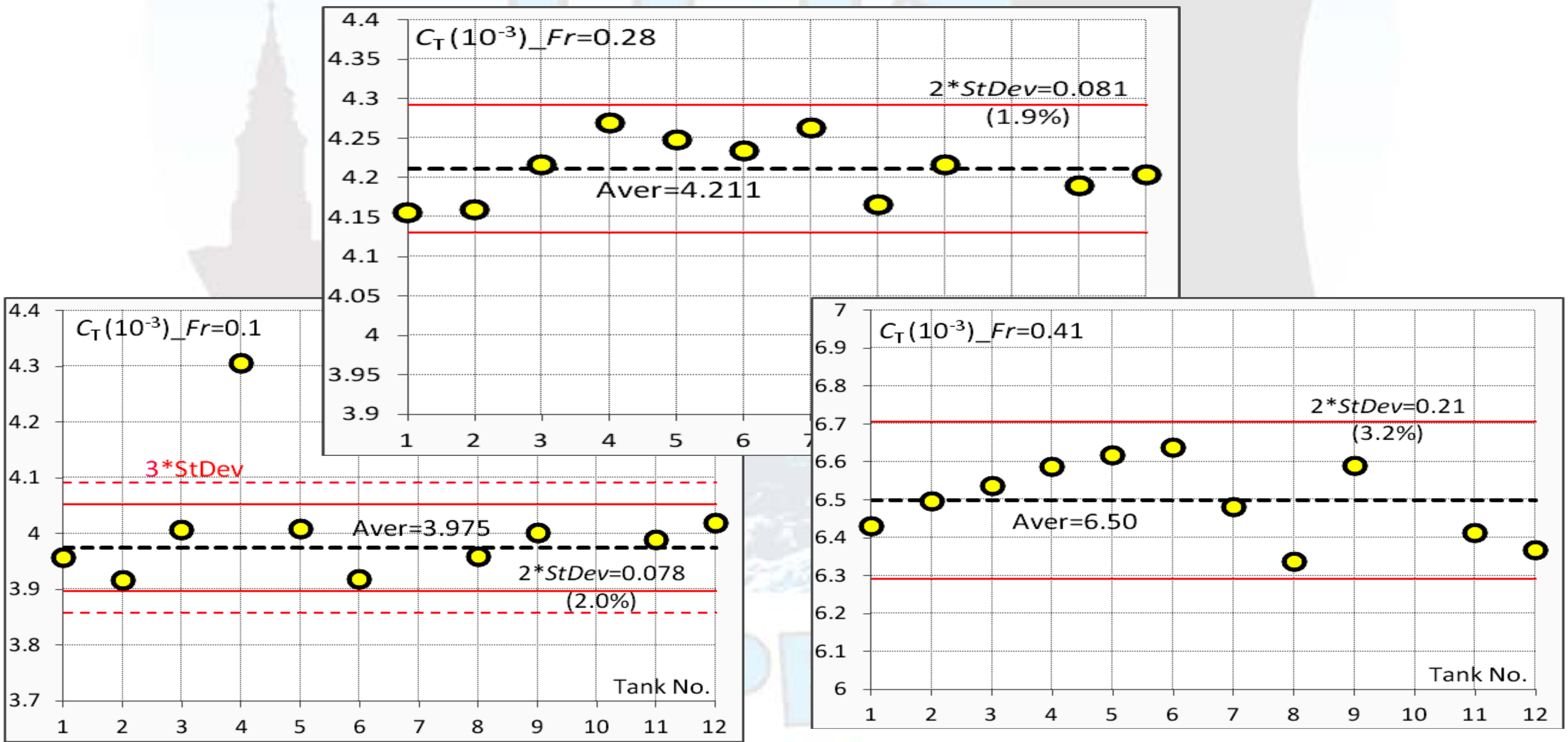
Tank No.	$C_T(10^{-3})$_15deg_Fresh Water (S=4.786m^2)					
	Fr =0.1		*Fr* =0.28		*Fr* =0.41	
	Mean	***StDev***	**Mean**	***StDev***	**Mean**	***StDev***
# 1	3.956	1.2%	4.156	0.2%	6.429	0.2%
# 2	3.917	1.6%	4.160	0.5%	6.497	0.5%
# 3	4.007	0.9%	4.216	0.2%	6.536	0.2%
# 4	4.306	3.6%	4.270	1.8%	6.587	1.9%
# 5	4.008	1.2%	4.248	0.4%	6.617	0.3%
# 6	3.918	1.1%	4.234	0.6%	6.639	0.3%
# 7	N/A		4.263	0.4%	6.480	0.5%
# 8	3.959	0.5%	4.166	0.5%	6.336	0.8%
# 9	4.001	1.9%	4.216	0.7%	6.590	1.9%
# 10	(#4)					
# 11	3.989	1.1%	4.190	0.4%	6.412	0.2%
# 12	4.019	2.3%	4.203	0.7%	6.368	0.7%

- **Inter-Tank Comparison**

Large model - 5.72m DTMB5415

Froude numbers: 0.1, 0.28, 0.41

Total resistance: 15℃ fresh water

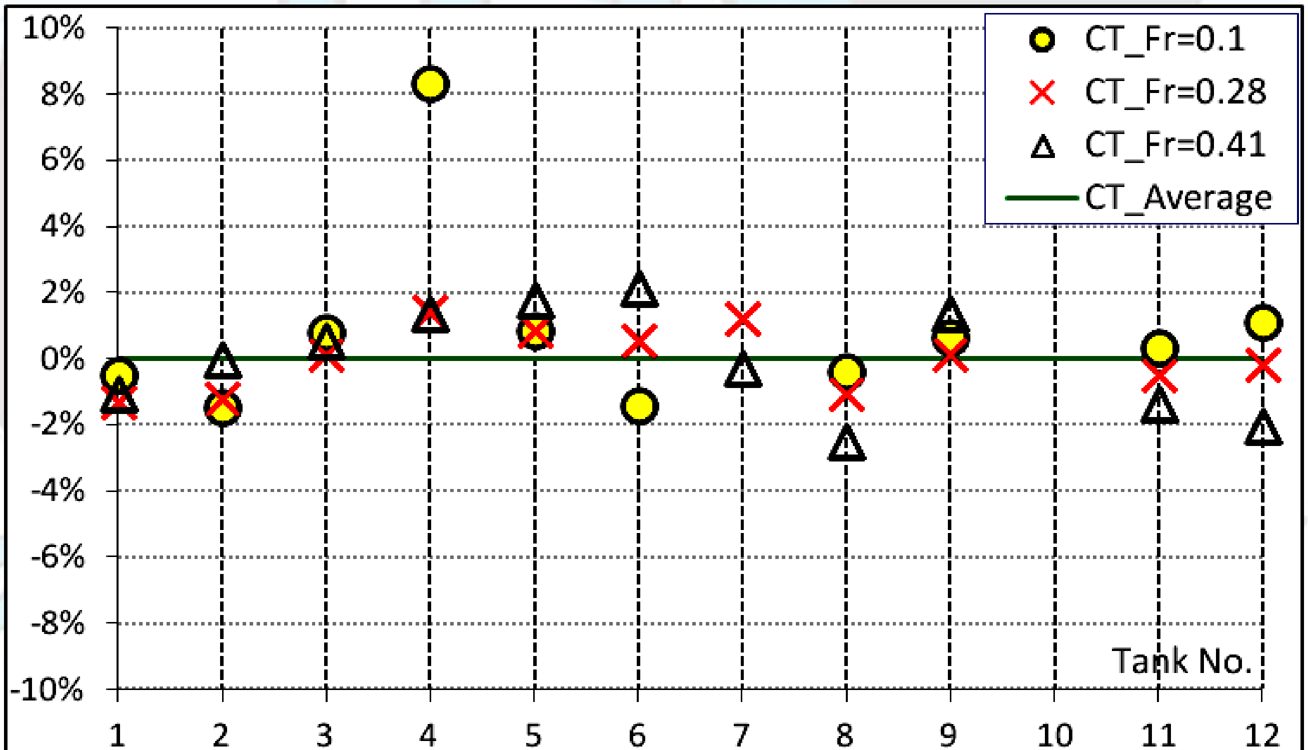


- **Inter-Tank Comparison**

Large model - 5.72m DTMB5415

Froude numbers: 0.1, 0.28, 0.41

Total resistance: 15℃ fresh water



Scattering of means of resistance by 11 towing tanks: ±**2%**

- **Inter-Tank Comparison**

  Large model - 5.72m DTMB5415

  Froude numbers: 0.1, 0.28, 0.41

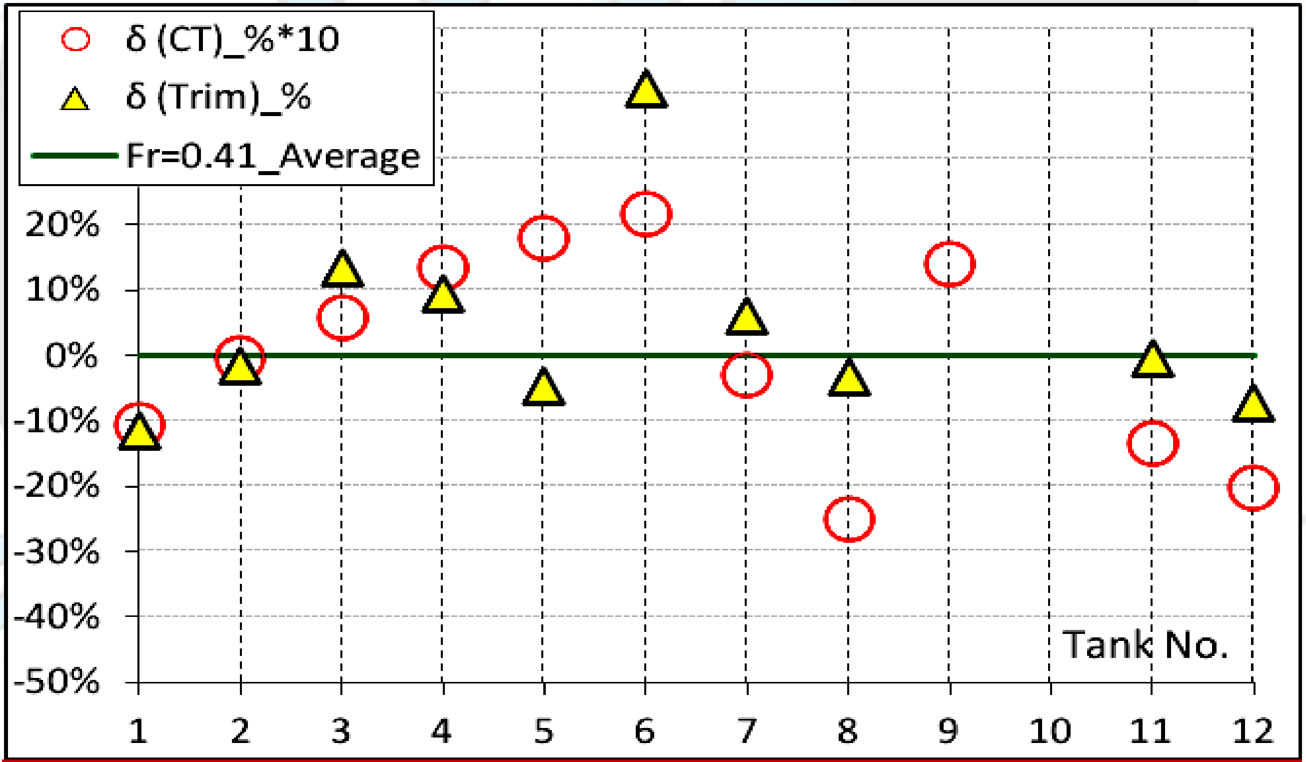
  Running sinkage and trim: 15°C fresh water

Tank No.	Mean of Running sinkage (mm) and trim (degree)					
	Fr =0.1		*Fr* =0.28		*Fr* =0.41	
	Sinkage	Trim	Sinkage	Trim	Sinkage	Trim
# 1	-1.64	-0.015	-10.95	-0.113	-27.35	0.335
# 2	-1.05	-0.008	-10.75	-0.103	-26.30	0.373
# 3	-1.19	-0.012	-10.49	-0.102	-26.67	0.430
# 4	-0.85	-0.018	-10.39	-0.111	-25.96	0.415
# 5	N/A		-9.21	-0.098	-22.52	0.361
# 6	N/A		-12.59	-0.118	-29.45	0.535
# 7	N/A		-10.23	-0.104	-24.40	0.403
# 8	-1.30	-0.012	-10.34	-0.101	-25.21	0.367
# 9	N/A		-10.32	-0.097	N/A	
# 10	(#4)					
# 11	-0.89	-0.014	-10.05	-0.015	-25.24	0.378
# 12	N/A		-9.35	-0.016	-24.39	0.352

- Large model - 5.72m DTMB5415

Froude numbers: 0.1, 0.28, 0.41

Running sinkage and trim: 15℃ fresh water



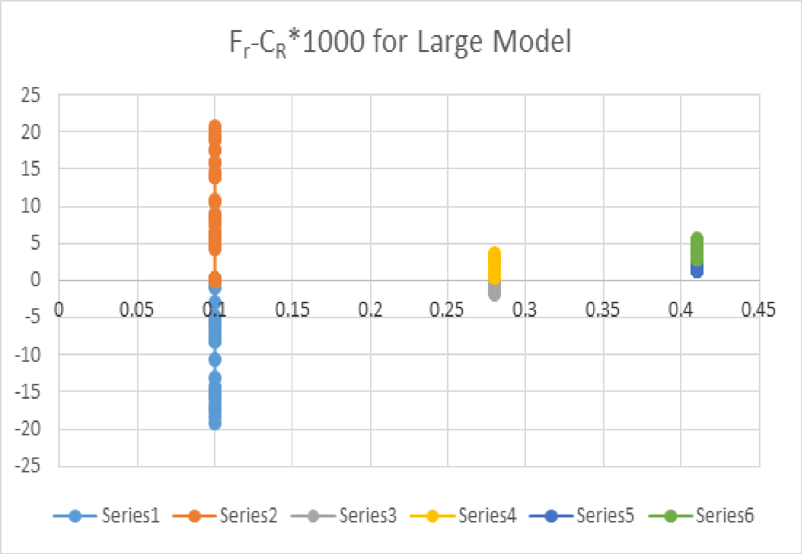
Not all deviation of trim is closely correlated to that of resistance

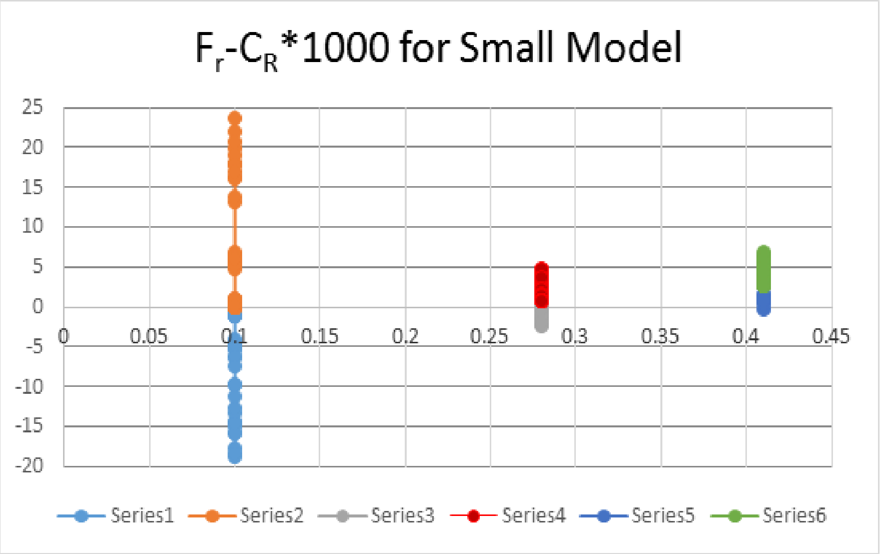
4.2 Wave resistance evaluation

Table 11. Maximum and minimum values of residuary resistance

Form factor equals to k=0.15 (Stern et al, 2010)

Fr	LARGE MODEL (5.72m)		SMALL MODEL (3.048m)	
	Min C_R*1000	Max.C_R*1000	Min C_R*1000	Max.C_R*1000
0.10	-19.0788	20.84345	-18.79000	23.66018
0.28	-1.8363	3.5725	-2.43352	4.82622
0.41	1.2535	5.6700	-0.33806	6.75376





4.3 Comparison with variation from Gothenburg 2010 study

Case	Fn	%E	σ %	No. of Submissions
3.1a Fixed S &T	0.28	2.5	5.3	11
3.1b Fixed S & T	0.28	-2.6	4.4	5
3.2 Free	0.138	-2.8	4.4	5
	0.28	0.1	2.1	6
	0.41	4.3	1.4	5

Tasks 4 and 5

5. SURFACE ROUGHNESS

Measurement and Evaluation

Full Ship

- **Many shipyards measure hull surface roughness with BMT roughness analyzer, but it seems to be difficult to understand various characteristics of roughness by the results.**
- **ISO-4287 definitions of roughness are possible to represent various characteristics of roughness.**
- **It is necessary to clarify correlation between BMT roughness and ISO-4287.**

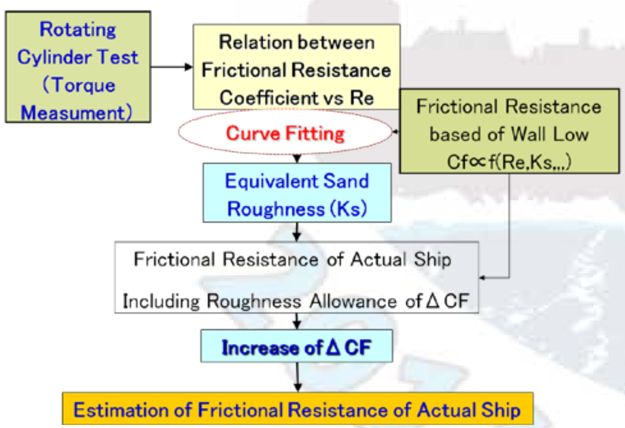
Model Ship

- **Roughness measurements on ship models are carried out at few model basins.**
- **The results of the measurements are used for quality assurance and not for further investigation.**

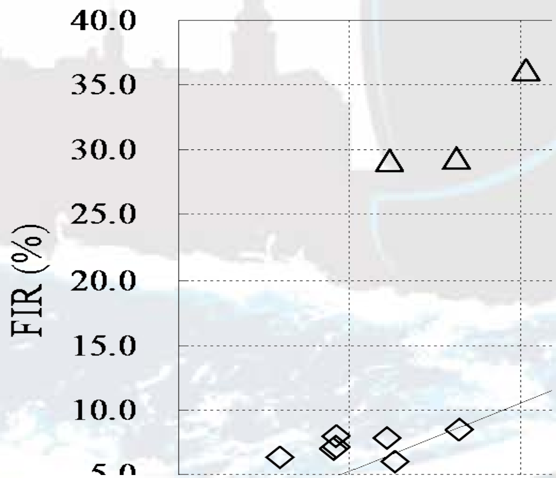
Experimental approach of roughness influence

Roughness Allowance Estimation by Rotating Cylinder Test

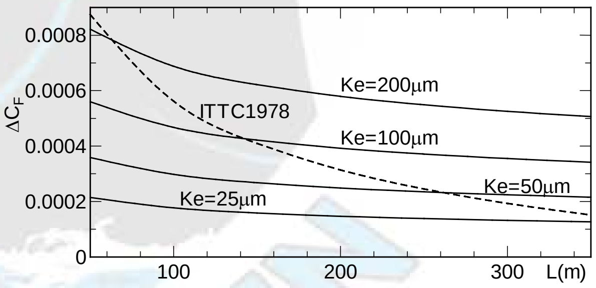
- **Roughness allowance ΔCF estimation method based on the results of rotating cylinder experiments is proposed.**
- **Estimating roughness function ΔB, frictional resistance including influence of roughness can be easily obtained by boundary layer calculation.**



Schematic flow of ΔCF estimation by rotating cylinder method



Correlation between Rz^2/Sm and FIR(Friction Increasing Ratio)

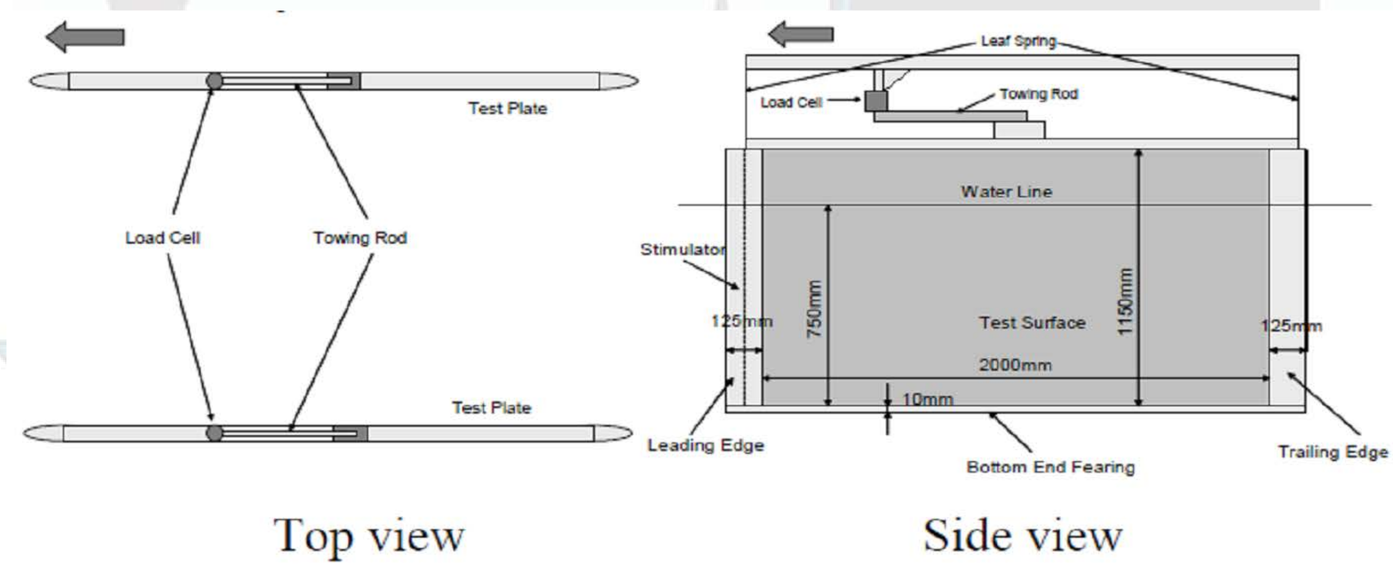


Example of estimated ΔCF allowance for actual ship

Experimental approach of roughness influence

New Experiment Technique with 2 Parallel Flat Plate

- **New experimental method using 2 parallel flat plate are proposed to clarify the relationship between friction resistance and various roughness parameter.**
- **Frictional resistance increase becomes smaller as roughness height length ratio H/L becomes larger.**

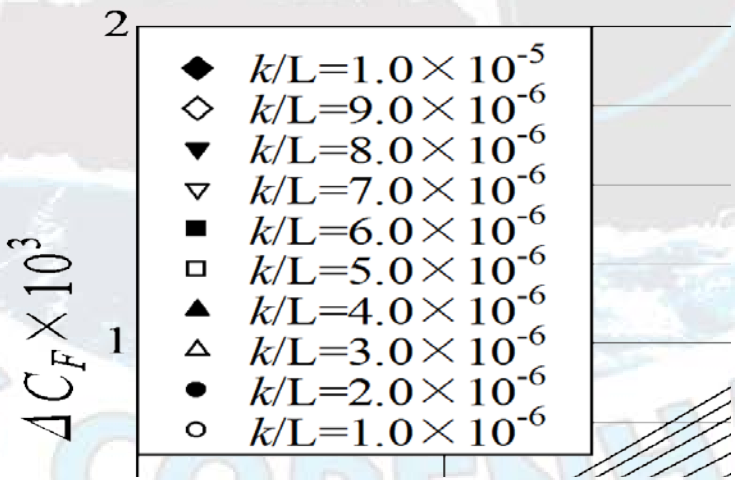


Schematic view of measurement system with 2 Parallel flat Plate

Theoretical approach of roughness influence

New Flat Plate Friction Formula

- **Considering roughness influence, a new flat plate friction formula for wide Reynolds number range based on momentum-integral equation and Coles' wall-wake law are proposed.**
- **The flat plate frictional coefficient is evaluated by solving a differential equation introduced White's roughness function.**

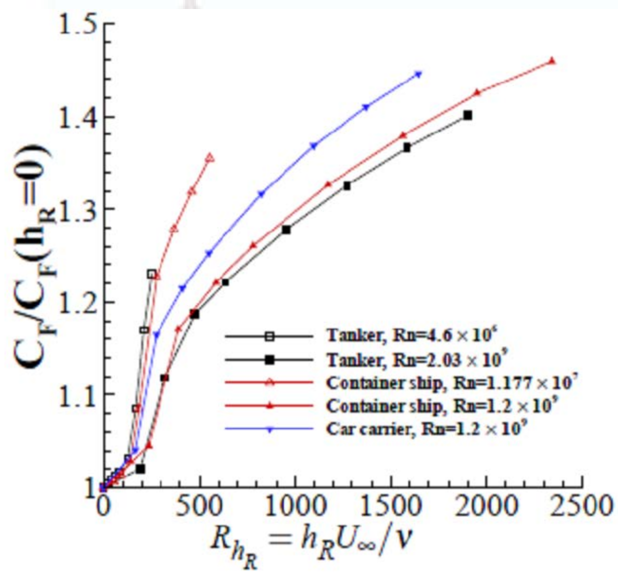


Added frictional resistance due to surface roughness

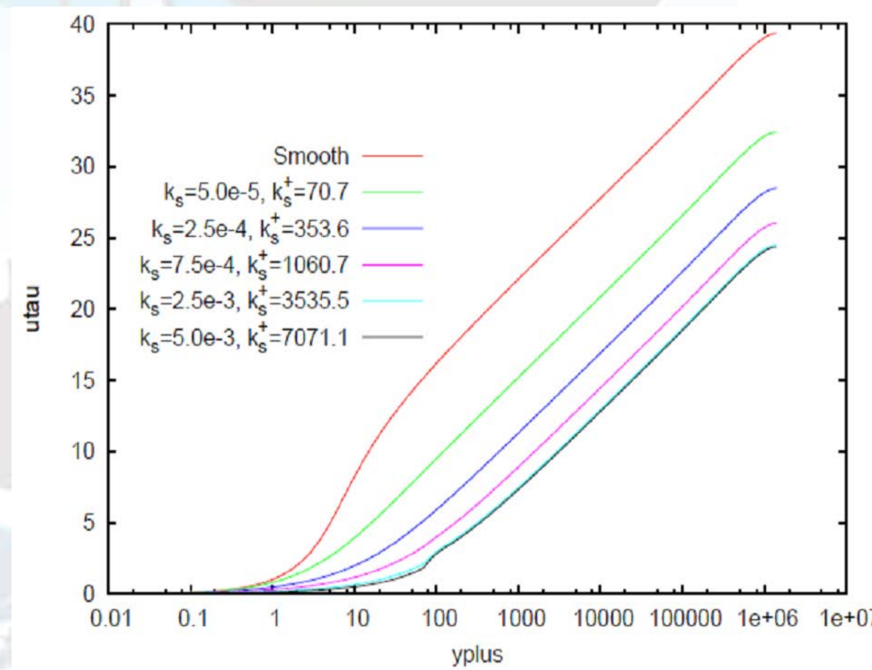
Numerical approach of roughness influence

Numerical Investigation for Roughness Surface with CFD

- **The effects of hull roughness on viscous flows around ships or flat plate are investigated by CFD calculation with turbulance model.**



Ratio between friction resistance coefficients predicted with and without sand-grain roughness



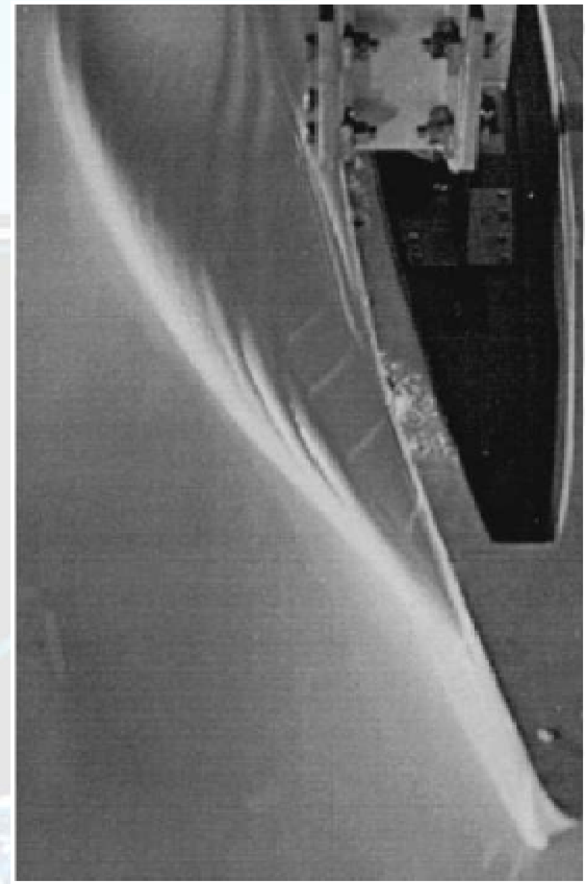
Logarithmic plots of velocity profiles by SST model at Rn ≈ 10^8

Task 6

6. UNSTEADY AND FREE SURFACE FLOWS

UNSTEADY FREE SURFACE

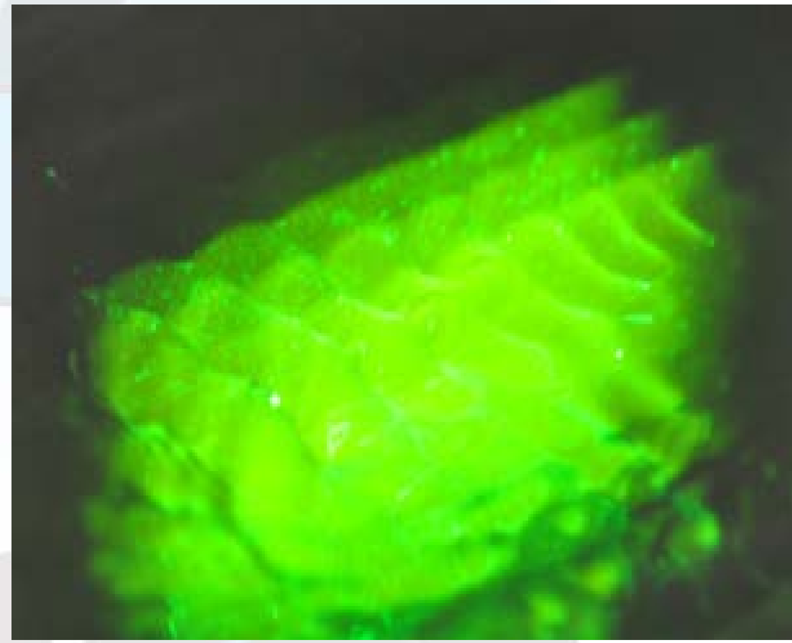
- Experimental tow tank and full-scale measurement techniques have focused on unsteady flows and free-surface phenomena including wave breaking.
- These techniques have been motivated by interest in wave impact and slamming, spray generation, air entrainment/bubble generation, and wave breaking.



Overhead view of the bow wave generated by towing a ship model, from Dong et al (1998).

UNSTEADY FREE SURFACE

- While standard planar laser induced fluorescence (PLIF) has been used to identify 2-dimension wave profiles, only recently have they been extended to 3-dimensions and coupled with PIV measurements.



A multi-plane PLIF sample to demonstrate principle of optical configuration for 3-D surface profile reconstruction (courtesy of Philippe Bardet).

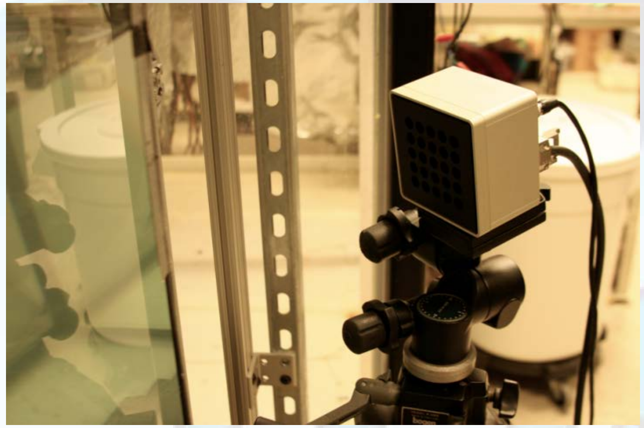
UNSTEADY FREE SURFACE

3D Flow Fields Using Lightfield Imaging and Synthetic Aperture Refocusing

- The lower cost of high-resolution digital cameras and the development of light field-imaging which involves sampling a large number of light rays from a scene to allow for scene reparameterization (Isaksen et al, 2000) and synthetic aperture refocusing.
- Synthetic aperture refocusing allows individual planes in the scene to be focused on, while planes not of interest are blurred and has allowed for the development 3-D imaging systems capable of simultaneously measuring a fluid volume and “seeing-through” partial occlusions (see Belden et al, 2010; Belden et al, 2011; and Belden and Techet, 2014).

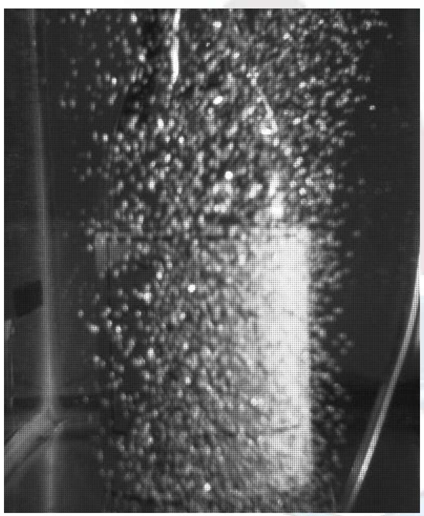
Light Field Camera Array: Bubbly Flow Experiment

5x5 Camera Array



Prof. Alexandra Techet,
ahtechet@mit.edu
June 2009

Technique allows visualization of object occluded by a bubbly flow



Raw image from one camera

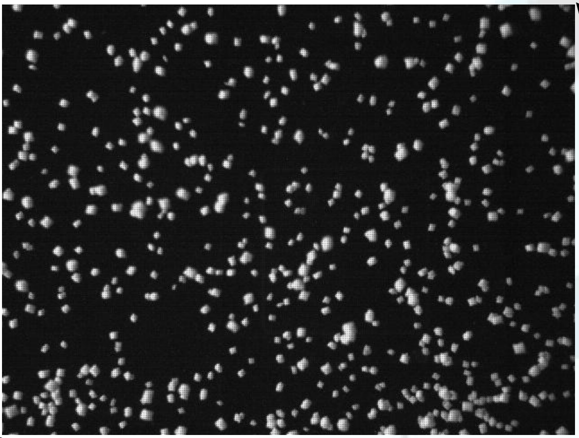
SA Refocused Image

Result of Time Averaging SA Refocused Images

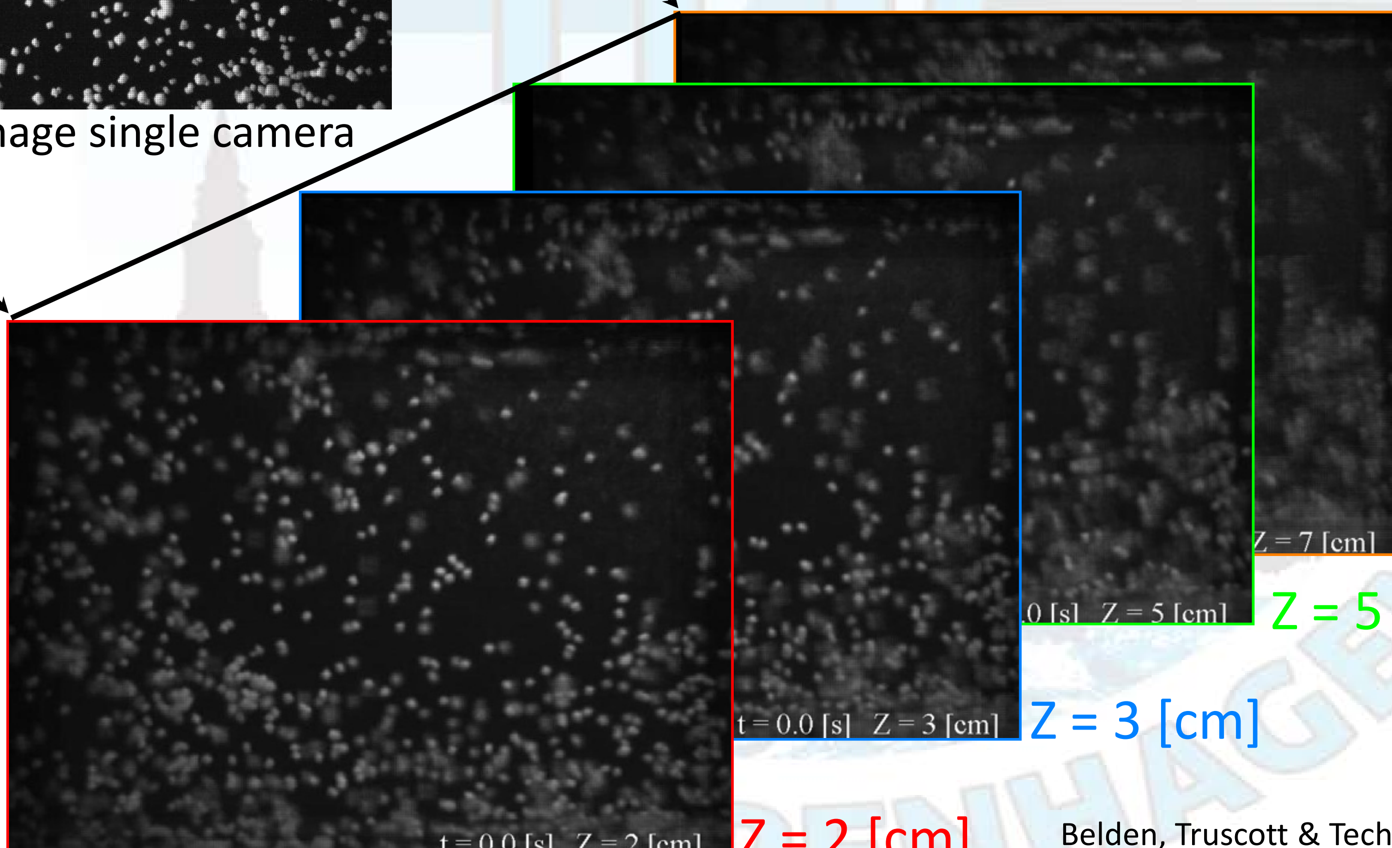
Light Field Camera Array: Particle Experiment

Prof. Alexandra Techet,
ahtechet@mit.edu
June 2009

Focus on different z-planes
using data from all cameras



Raw image single camera



Z = 7 [cm]

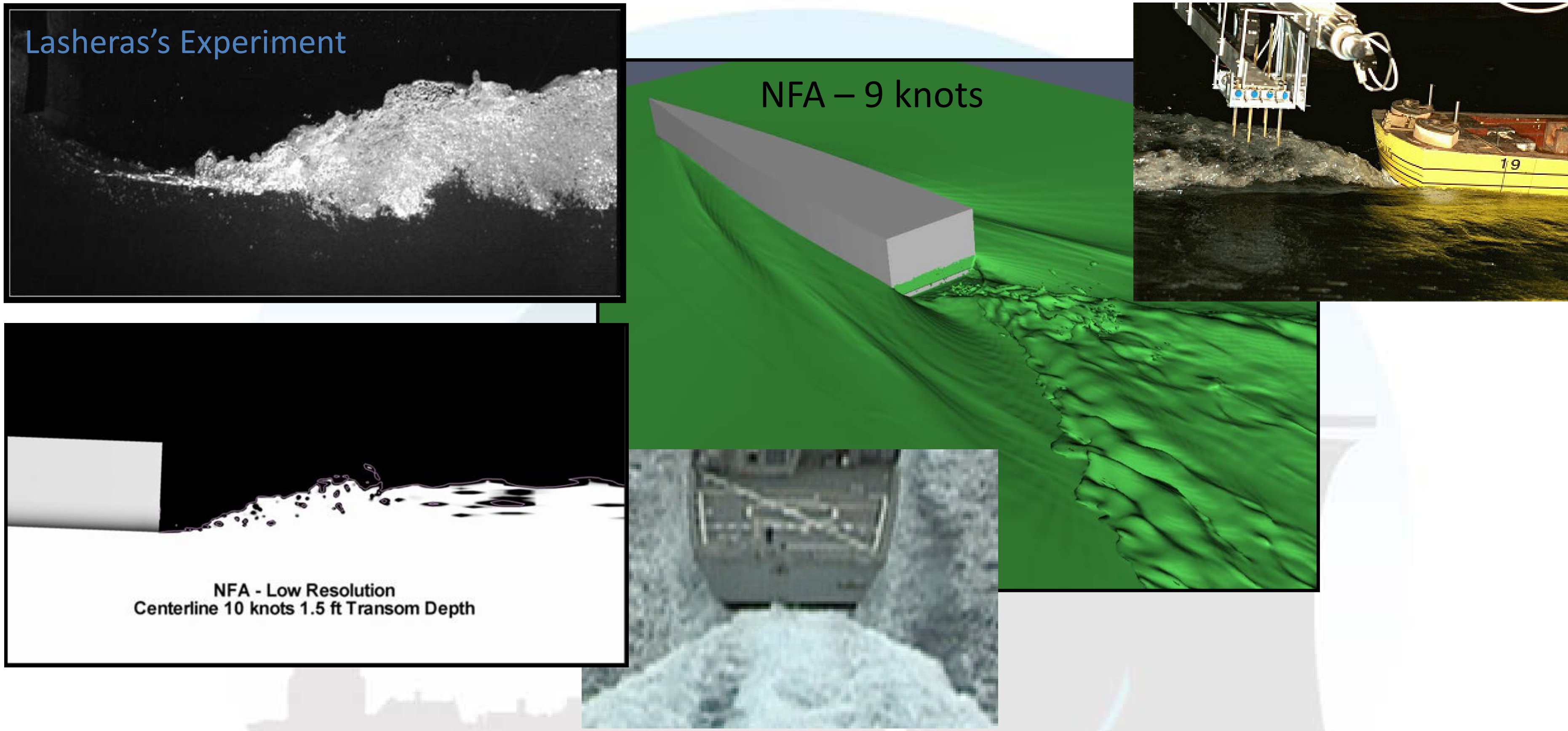
Z = 5 [cm]

Z = 3 [cm]

Z = 2 [cm]

Refocused images

Belden, Truscott & Techet, 2009 3D Flow Fields
Using Synthetic Aperture PIV, *PIV2009*

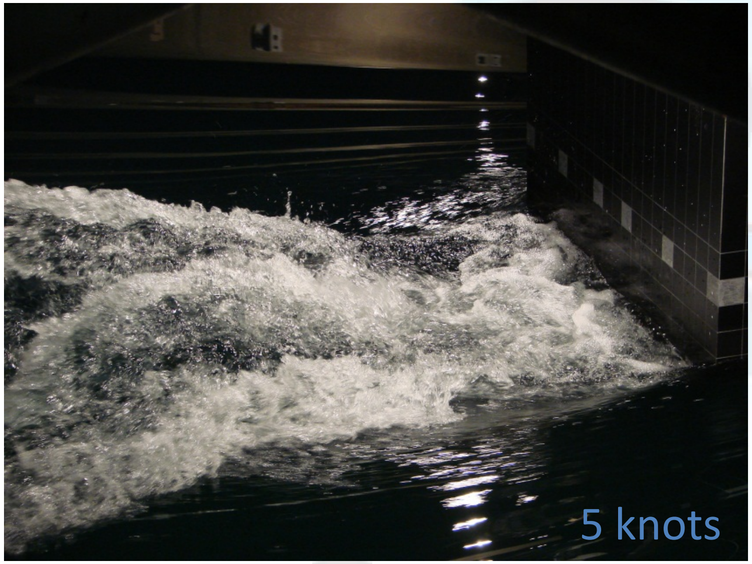


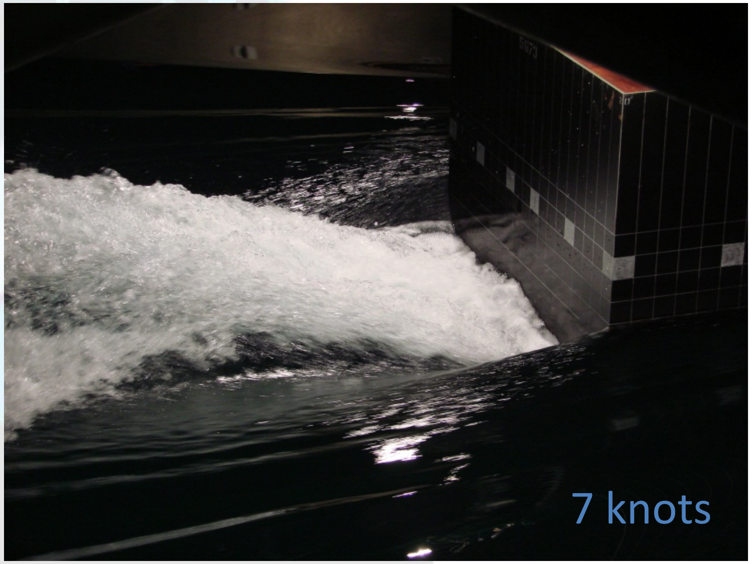
DATA GOALS

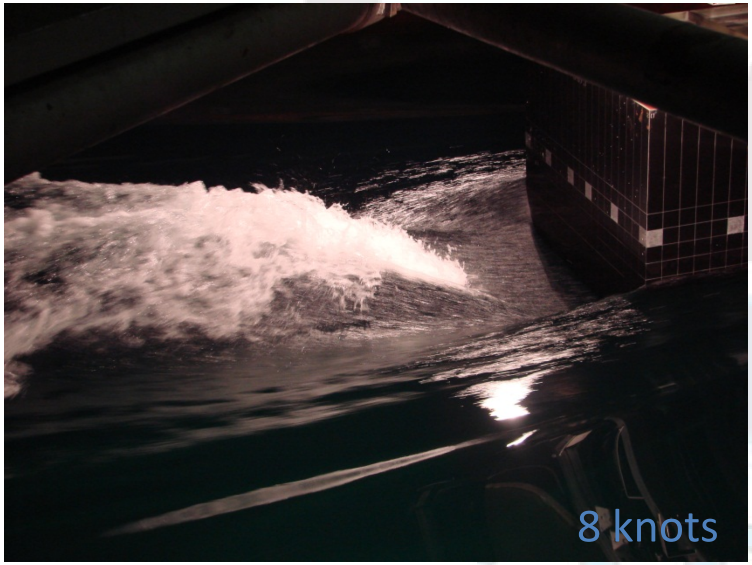
1. Time accurate measurement of the free-surface elevation.
2. Measurement of the entrained air
   - Simultaneous measurements
3. Turbulence
   - Ensemble averaged
4. Coherent structures

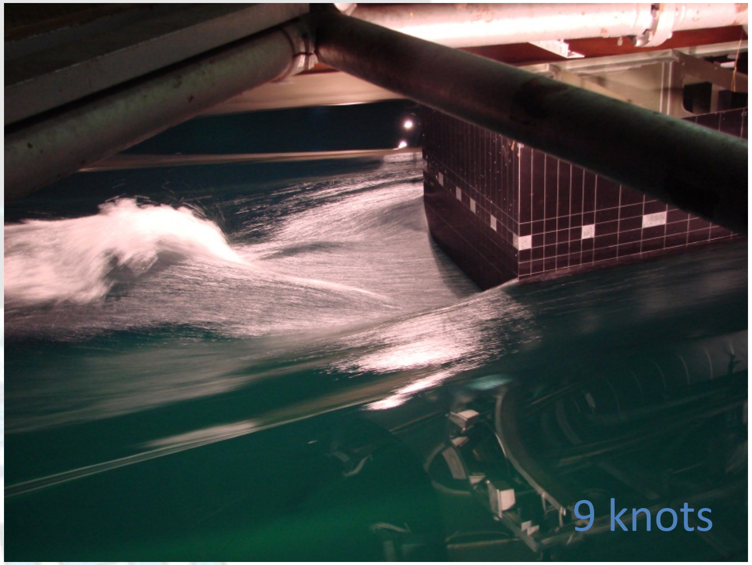
UNSTEADY FREE SURFACE

Flow
Field





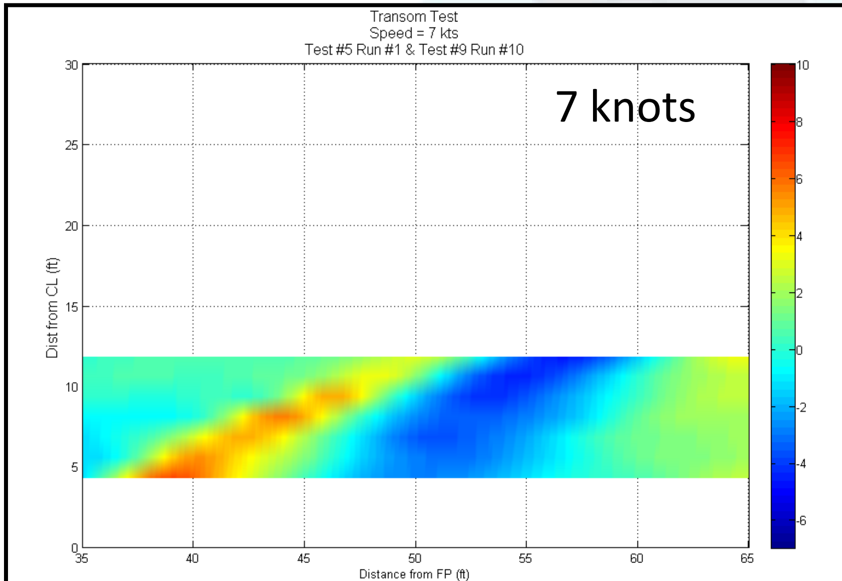


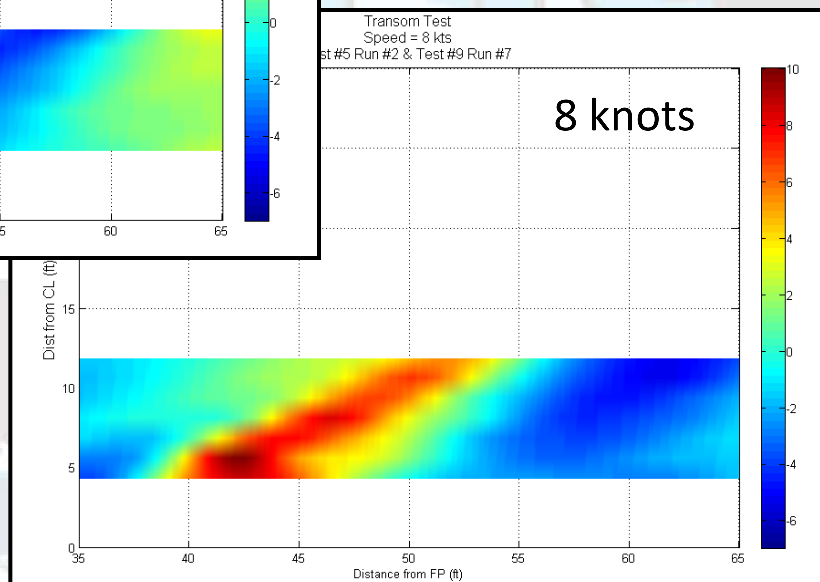


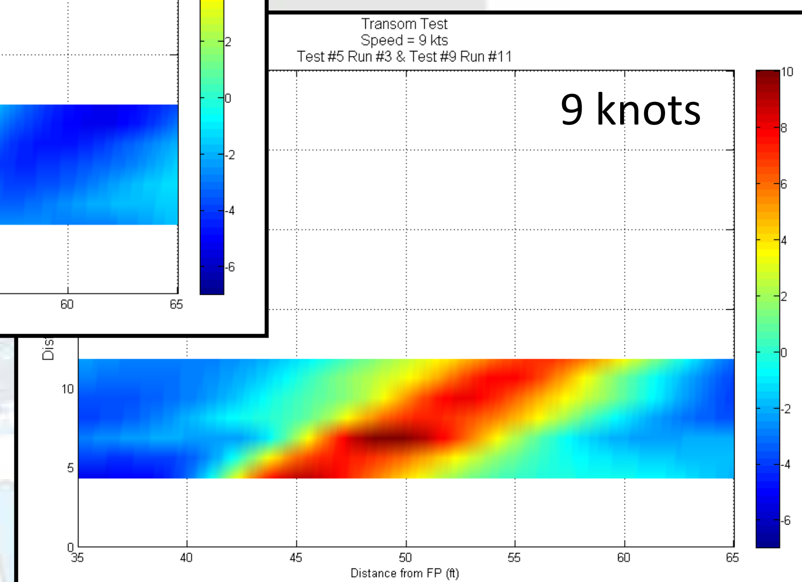
UNSTEADY FREE SURFACE

Stern Wave Topology

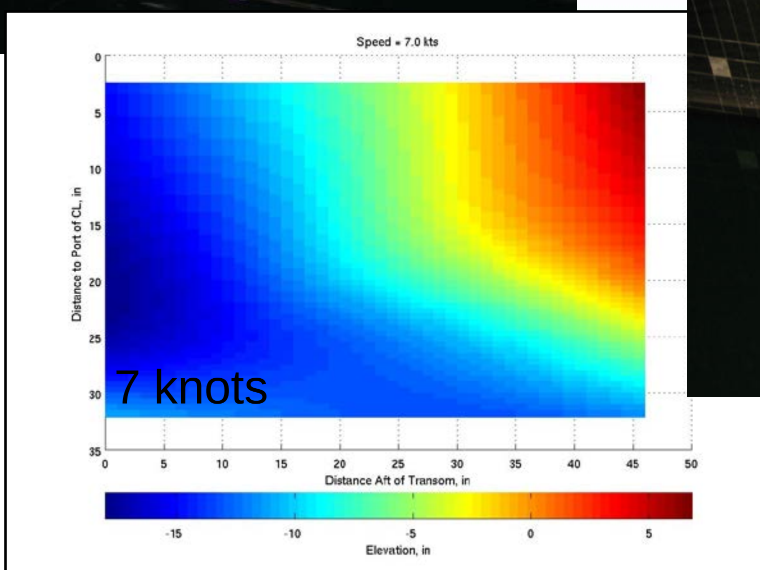
Ultrasonic Sensors

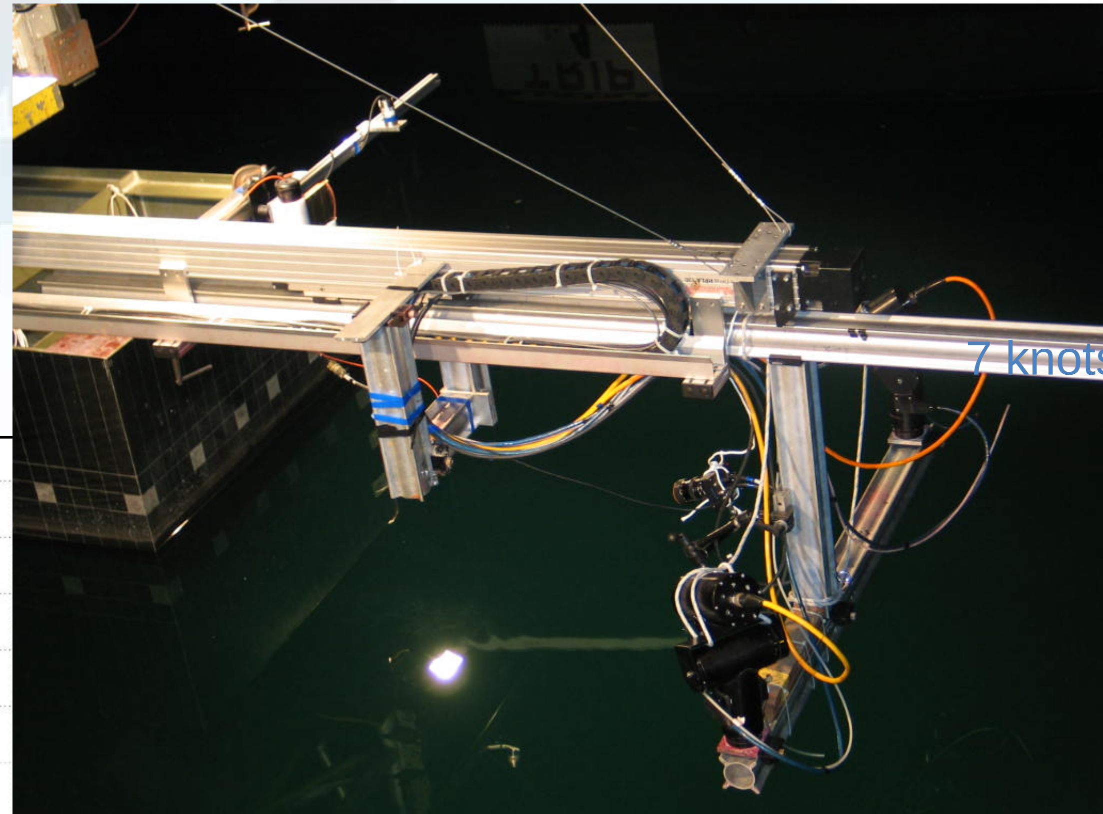




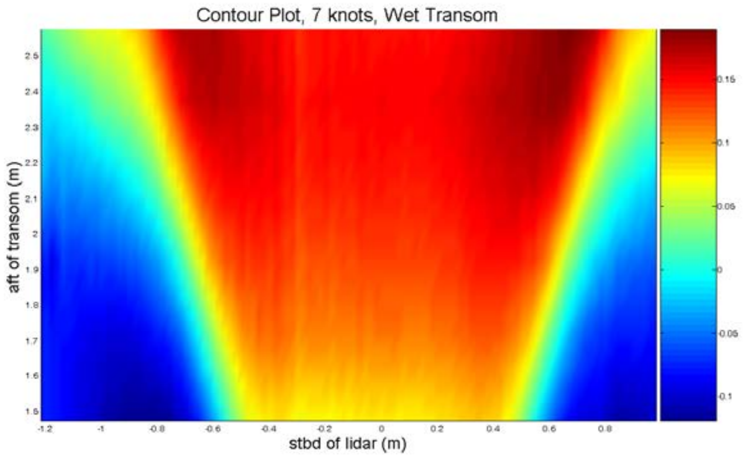


UNSTEADY FREE SURFACE
PLIF Results

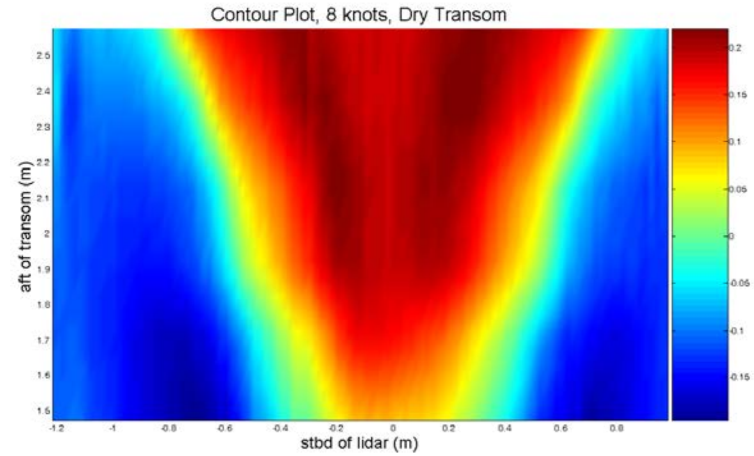




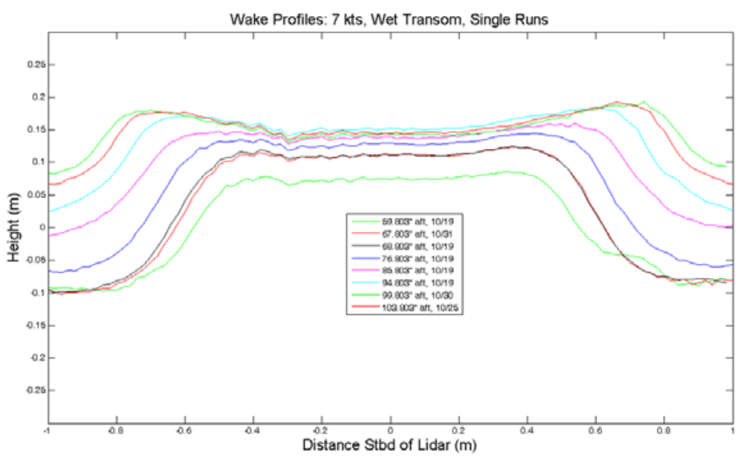
UNSTEADY FREE SURFACE
LIDAR Results



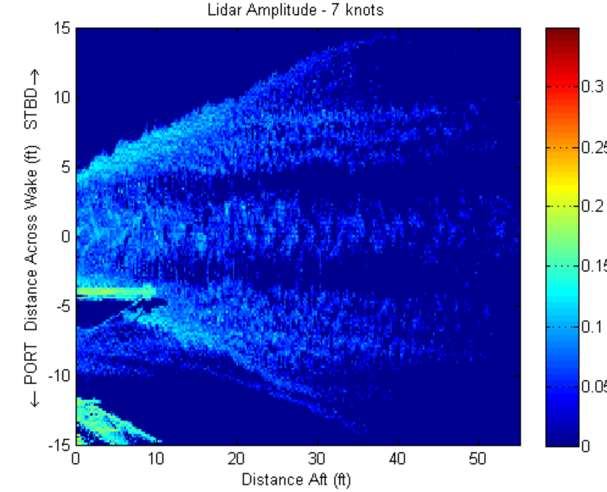
7 knots



8 knots



7 knots



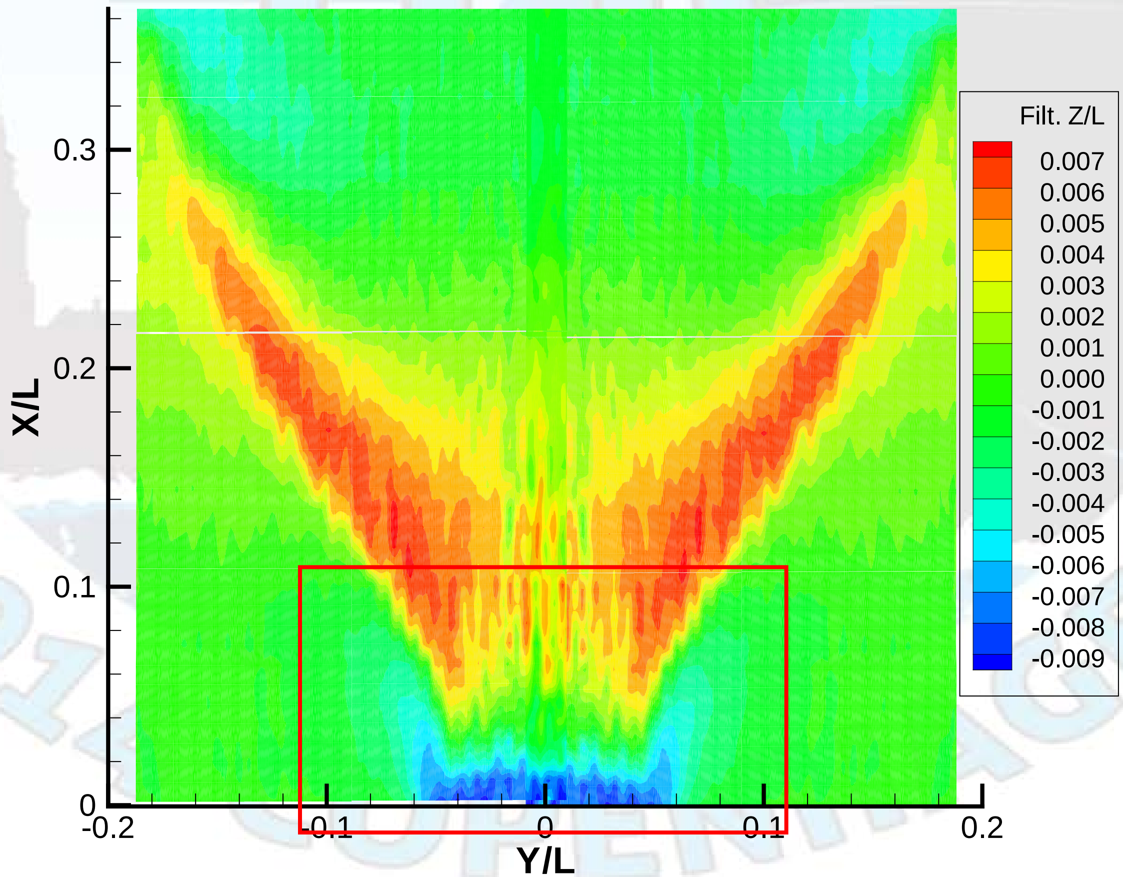
Lidar scanned at 3°/s

UNSTEADY FREE SURFACE

Model Stern Topography Results

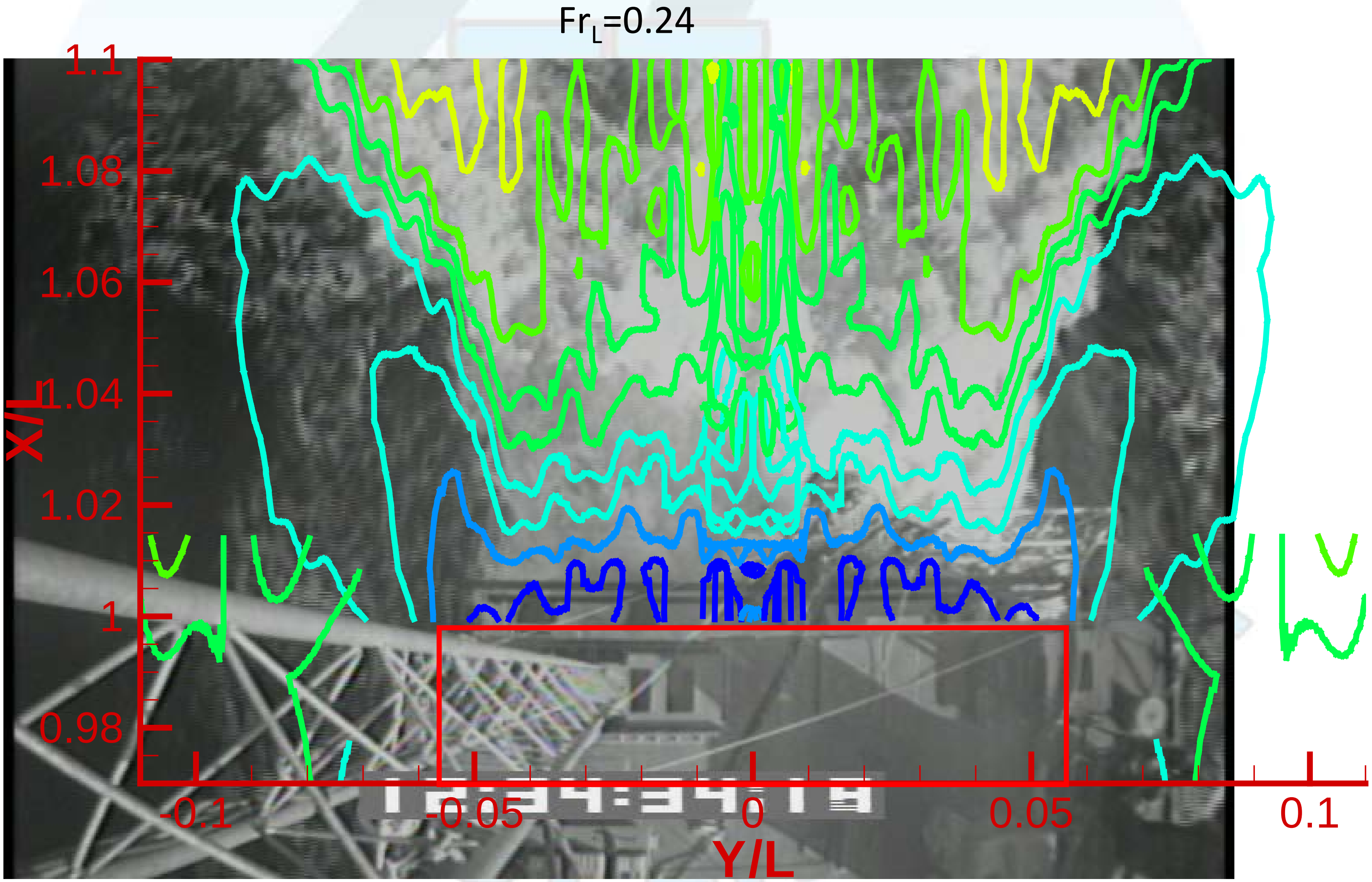
Model 5365

10.5 knots, Fr_L=0.24



UNSTEADY FREE SURFACE

Full vs. Model Scale



UNSTEADY FREE SURFACE

- The measurement and simulation of unsteady free surface flows remains an active area of research.
- Work in developing measurement techniques and fundamental understanding is to satisfy the long term need for better comprehension of the effect that these mechanisms have on added resistance.
- That is, our ability to use unsteady surface fluctuations and relate them back to resistance.

Task 7

7. MODEL MANUFACTURE

Task : Model Manufacture

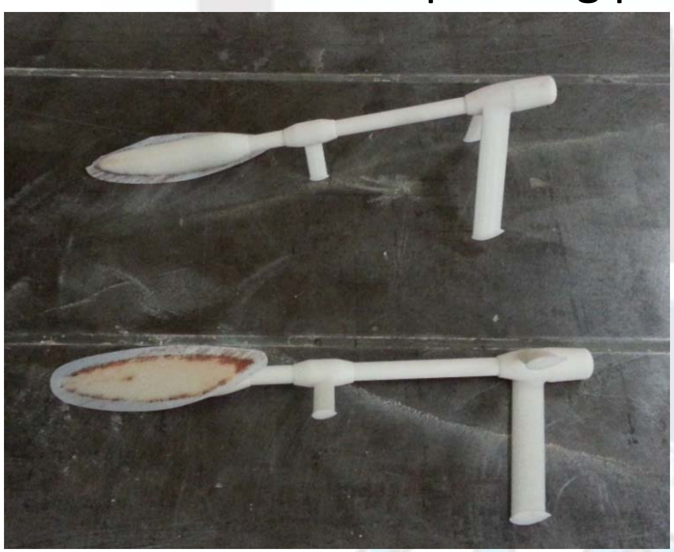
- The development of new manufacturing techniques that can provide a cost-effective way forward for investigation of parametric changes to local hull features or appendage arrangement will allow more effective use of towing tank testing for problems.

Rapid Prototyping Technology

- Rapid Prototyping Techniques
  - Stereo Lithography
  - Laser Sintering
  - Inkjet and 3D Printing
  - Masking Process
  - Fused Deposition Modeling
  - Laminated Object Manufacturing.

Potential Use in Model Production

- Rapid prototyping technology is quite expensive for model manufacturing purpose for today.
- But appendages such as shaft, barrel, rudder and strut could be produced with extremely high precision.
- Shaft-Barrel-Bracket System produced via 3D Printer and Installation to model after painting phase



Task 8

8. SIMULATION BASED DESIGN

Task 8: Simulation based design (SBD)

- The development in the computational power available and the relative maturity of the hydrodynamic analysis tools have significantly advanced simulation based design (SBD)
- Developments in:
  - geometry modelling and variation
  - global optimisation strategies
  - multi-objective optimisation
  - variable fidelity approaches
  - meta-models

SBD – Optimisation problem

- The optimisation problem is commonly formulated as a nonlinear programming (NLP) problem
- Studied cases are increasingly of multi-objective type (e.g. resistance and seakeeping, multi-speed optimisation)

$$\min_{\bar{x}} \mathbf{f}(\mathbf{x}, \mathbf{u}(\mathbf{x})), \;\; \mathbf{x} \in \mathrm{X} \subseteq \Re^{\mathrm{M}}$$

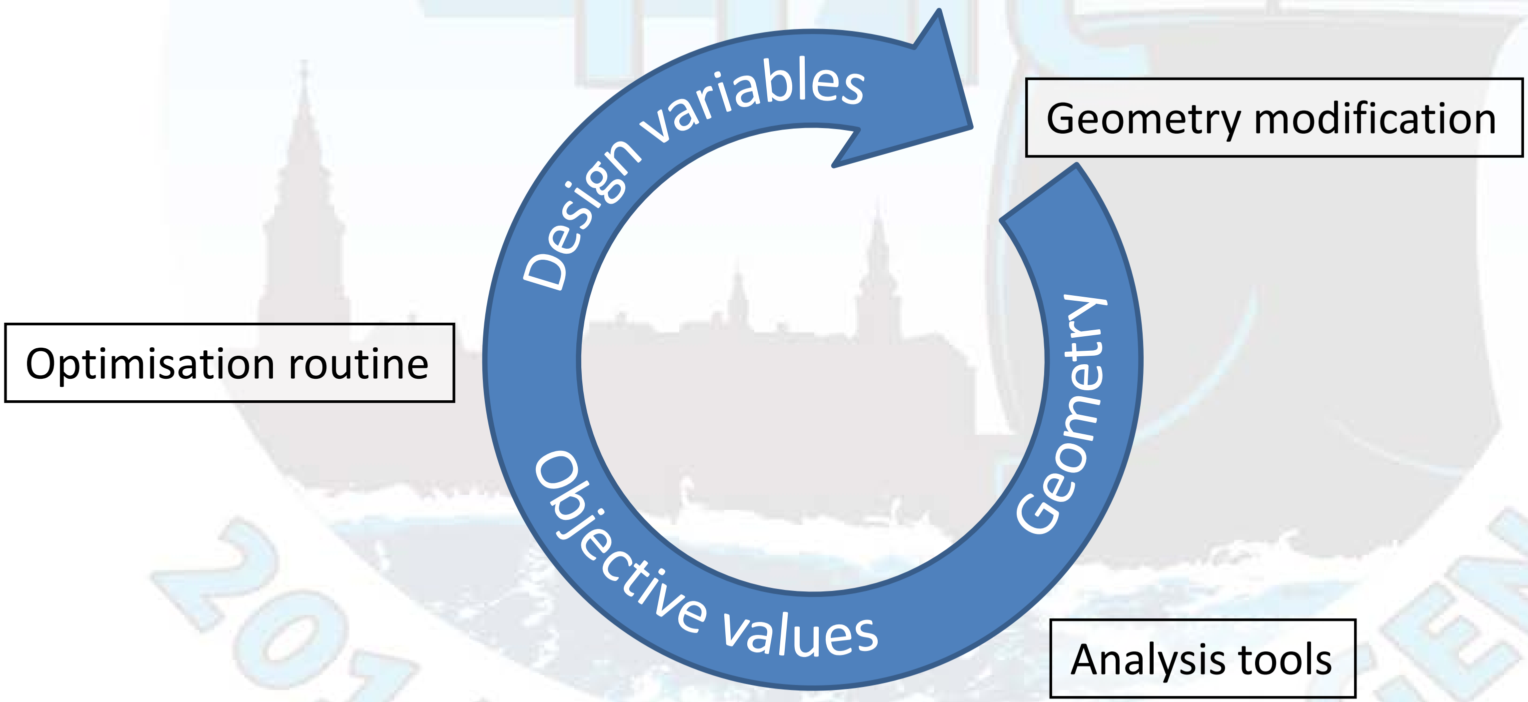
$$\begin{cases} h_j(\mathbf{x}) = 0, \quad j = 1, \ldots, p \\ g_j(\mathbf{x}) \le 0, \quad j = 1, \ldots, q \\ x_i^l \le x_i \le x_i^u \end{cases}$$

SBD- Elements of the problem

- <u>Objectives</u>: often multiple and conflicting; multi-disciplinary or multi-point; scalarisation vs. Pareto optimality; expensive to evaluate; multi-modal
- <u>Design variables</u>: define the search space; should be chosen carefully as the choice affects the computational expense and quality of the optimal solution; often subject to constraints (non-convex or discontinuous search space)
- <u>Operating conditions</u>: speed, loading, sea state, water depth; single or multiple operating points (the latter is the trend); operational profile
- <u>Stochasticity</u>: optimisation often deterministic, but real world problems stochastic; robust design optimisation (RDO); design optimised for the averaged conditions is not necessarily the real optimum of the stochastic problem

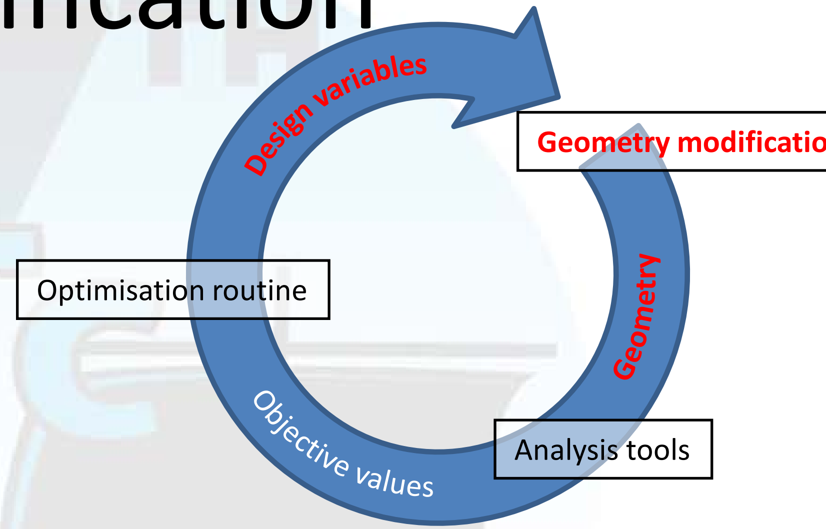
SBD – Design optimisation framework

- SBD toolbox consists of three elements:



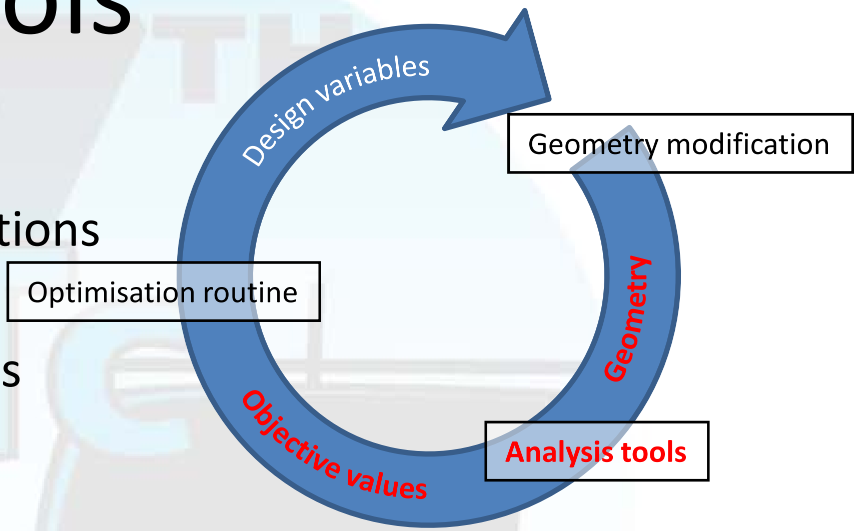
SBD – Geometry modification

- Input: design variables, output: modified geometry
- Several approaches proposed
  - Direct or indirect manipulation of hull surface points
  - Local or global modification of the geometry
- Two interesting (indirect) approaches
  - Geometry morphing: two or more parent hull forms are combined into one as a weighted sum of the parents; design variables are the weights
  - Free form deformation: the part of the hull to be modified enclosed in a parallelepiped which is deformed and the interior displacements are interpolated based on the displacement of a limited set of control points ; design variables are the control point displacements



Proper orthogonal decomposition has been used to significantly reduce the number of design variables while maintaining almost all of the geometric variability

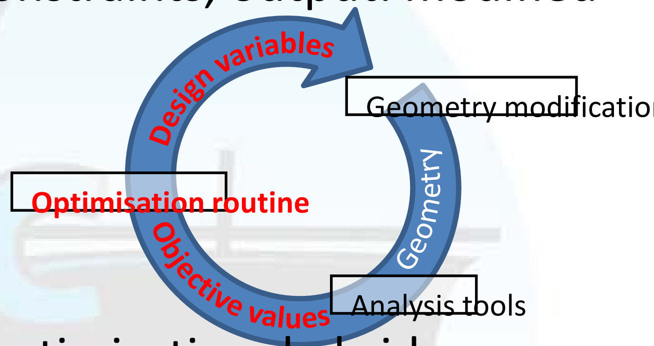
SBD – Analysis tools



- Input: modified geometry and operating conditions, output: values of objective functions and possible constraints
- The level of detail of the analysis tools varies depending on
  - number of design variables
  - number and type of objective functions
  - time and computational resources available
  - requirements on the accuracy
- The analysis tools in optimisation studies have ranged from design equations and regression lines (conceptual design) to RANS based tools (detail optimisation)
- In variable physics/fidelity based algorithms a combination of tools or solutions of different fidelity are used

SBD – Optimisation algorithms

- Input: values of the objective functions and constraints, output: modified design variables
- Different categories
  - Gradient based or gradient free
  - Local or global



- Trend has been towards global gradient free optimisation; hybrid algorithms combining the benefits of local and global algorithms have also been proposed
- Population based algorithms popular due to advances in parallel computing
  - Evolutionary algorithms (evolution strategies, genetic algorithm)
  - Particle swarm optimisation
- Computational expense can be reduced by using meta-models, variable physics/fidelity approach or a combination of these
  - Majority of evaluations is performed with low cost approach and the most accurate and most expensive method is used only when necessary (based on e.g. a trust region approach)

SBD – Verification and validation

- Simulated improvement should correspond to a real-life improvement with a sufficient confidence
- Extension of single run V&V procedures for systematic V&V in optimisation has been proposed
- Three steps:
  - Numerically verified: the simulated improvement is larger than the numerical uncertainty
  - Experimentally verified: the measured improvement is larger than the experimental uncertainty
  - Validated optimum: the difference between the simulated and measured improvement is less than the combined uncertainty of the simulation and measurement
- Only verifies and validates the trend; the values for the individual design can be verified and validated with the single run procedures

9. Recommendations

- Adopt the updated guideline 7.5-02-01-02 Testing and Extrapolation Methods, General Guidelines for Uncertainty Analysis in Resistance Towing Tank Tests
- Adopt the updated guideline 7.5-02-02-02.1 Testing and Extrapolation Methods, Example Uncertainty Analysis of Resistance Tests in Towing Tank which effectively replaces the dropped 7.5-02-02-02(2002, rev.01).
- Adopt the new guideline 7.5-02-02-02.2 Testing and Extrapolation Methods, Practical Guide: Uncertainty Analysis of Resistance Measurement in Routine Tests.

Recommendations con't

- Remove the procedure 7.5-02-02-03 Testing and Extrapolation Methods, Resistance, Uncertainty Analysis Spreadsheet for Resistance Measurements.
- Remove the procedure 7.5-02-02-04 Testing and Extrapolation Methods Resistance, Uncertainty Analysis Spreadsheet for Speed Measurements.
- Remove the procedure 7.5-02-02-05 Testing and Extrapolation Methods Resistance, Uncertainty Analysis Spreadsheet for Sinkage and Trim Measurements.
- Remove the procedure 7.5-02-02-06 Resistance uncertainty analysis spreadsheet for wave profile measurements.

10. Conclusions

- State-of-the-art
  - Increased need to do higher precision resistance measurements
  - Trim optimisation requires enhanced precision in resistance test e.g. <1%,
  - Capability to acquire more data during test motion e.g. wireless sensors, synchronised video and will generate better documentation for CFD validation,
  - Limited validation data, and preparation for the Tokyo 2015 CFD workshop will give validation for a new ship type.
  - Still a lack of high quality data for high performance craft e.g. planing/hydrofoil craft.

10 State of the art con’t

- For CFD mesh resolution is less of an issue, but still require greater appreciation of 'real' cost of such analysis esp.for unsteady flows
- Need for new R&D – surface roughness, wave breaking model construction/precision, aim to reduce uncertainty and gain better understanding

10 Procedures

- Decided to eliminate the spreadsheet as they were based on the AIAA standard and primarily for worldwide campaign
- Update to ISO GUM was applied as fairly straightforward and should be widely adopted in routine commercial tests. Examples given.
- Note that there is still no procedure for recording wave profile.
- The surface roughness guideline was not changed as it was deemed still appropriate

10 World wide campaign (WWC)

- WWC data should be made available via the new ITTC website along with searchable spreadsheet generated by the RC.
- An approach for inter tank bias comparison is suggested.
- A comparison is made with the corresponding data from the CFD analysis for the same hull (case 3) from Gothenburg 2010 and provided additional insight to both the CFD and bias study.
- For future WWC the double blind approach significantly reduced the usefulness of the exercise and due to extended time period there are likely to have been bias issues with changes to the models during the campaign.

10 tasks 5 to 7

- The challenge with surface roughness measurements is not that of the procedure applied but rather the capability/timescales of the instrumentation system applied.
- Detailed measurements of the unsteady free surface is still needed for better wave breaking models and validation.
- Model based manufacturing will rapidly evolve through proliferation of rapid prototyping technologies.
- The questions of whether large high fidelity physical models can be built from multiple pieces and how strength/stiffness are maintained remain to be answered.

10 Simulation based design SBD

- SBD evolving rapidly driven by reducing computational cost.
- Trend towards hybrid algorithms, which combine analysis methods of varying fidelity using rapid low cost methods to search for areas of greatest improvement.
- Careful setup of the design problem is required with improved geometry creation using morphing and freeform deformation
- Proper orthogonal decomposition reduces number of design variables and keeps geometric variability.
- As deterministic problems start to mature, it is expected that the stochastic nature of the design problems (e.g. variable environment in terms of seastate/wind, operational profile) will gain more attention.

11 Possible tasks for next RC

(i) Develop a new procedure for wave profile measurement and wave resistance analysis.
(ii) Unsteady free surface dynamics is still an active area for research – and there remains a long term need for better comprehension of added resistance.
(iii) Resolve differences between ISO 4287 and widely used BMT roughness measurement system.
(iv) Propose an approach for tanks to reduce/manage their uncertainty as a follow on from the Worldwide Campaign.
(v) Sensitivity study for which areas of the ship should you be measuring/modifying roughness

Any Questions?

University of Southampton’s new 138m x 6m x 3.5m towing and wave tank to officially open in spring 2015.
ALL WECOME