26th ITTC
Propulsion Committee
(2009 – 2011)

Rio de Janeiro, Brazil

28 August – 03 September 2011

Structure of presentation

- Members, Meetings
- Tasks (terms of reference)
- Report presentation
- Conclusions
- Recommendations to the 27th ITTC

- More emphasis on EFD results

Committee Members

- Dr. **Suak-Ho Van**, MOERI, Korea (Chairman)
- Dr. **Scott D. Black**, NSWCCD, U.S.A. (Secretary)
- Prof. **Jun Ando**, Kyushu University, Japan
- **Valery O. Borusevich**, KSRI, Russia
- Prof. **Emin Korkut**, Technical University of Istanbul, Turkey
- Dr. **Anton Minchev**, FORCE Technology, Denmark
- Dr. **Didier Fréchou**, DGA Hydrodynamics, France
- **Rainer Grabert**, SVA, Germany
- Prof. **Chen-Jun Yang**, Shanghai Jiao Tong University, China

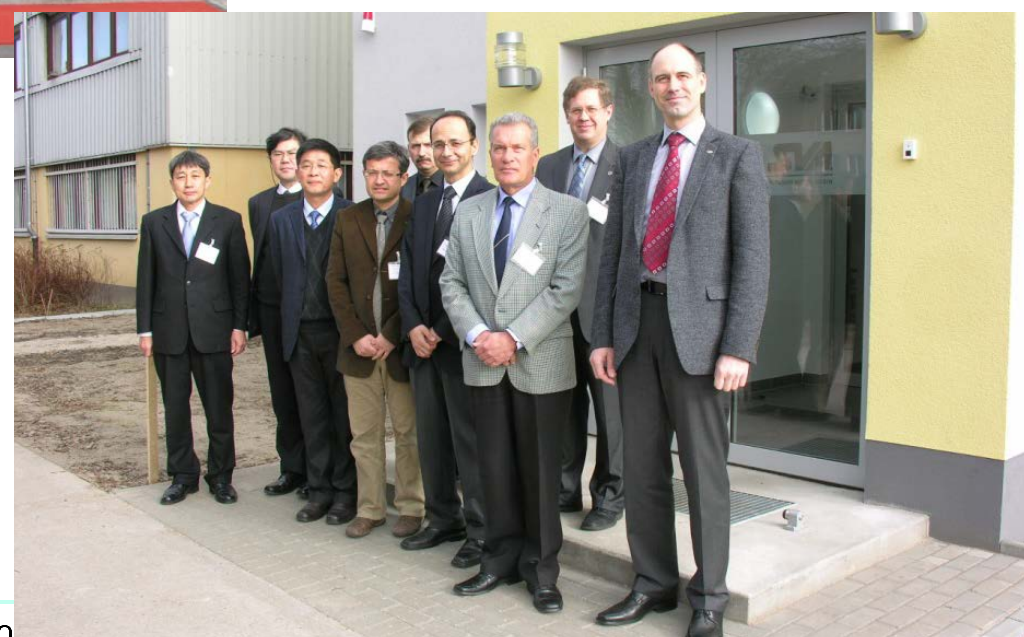
- Krylov Shipbuilding Research Institute, Bassin d’essais des carenes, Schiffbau-Versuchsanstalt Potsdam GmbH

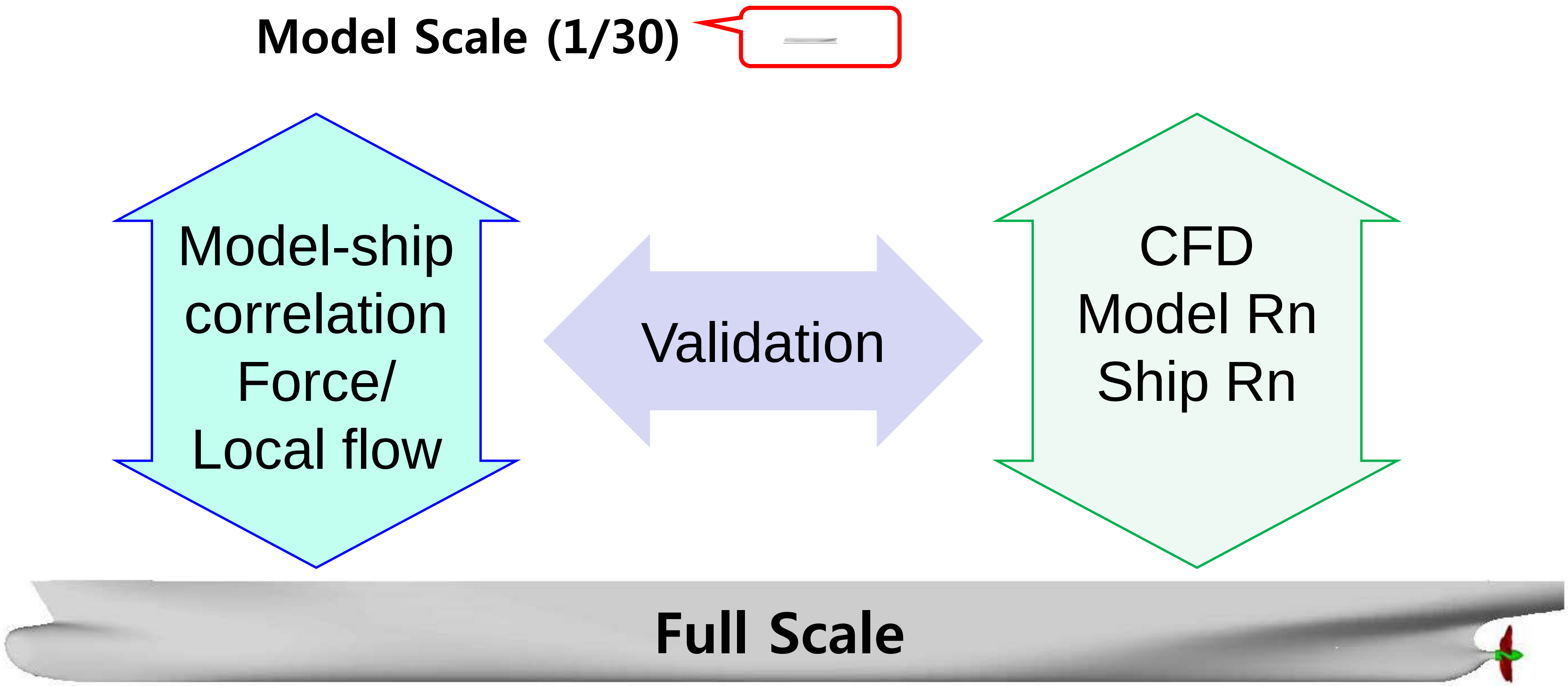
Committee Meetings

1. **MOERI**, Korea, 11-13 March 2009 (8)
2. **DGA**, France, 4-6 November 2009 (9)
3. **NSWC**, USA, 5-7 May 2010 (7)
4. **SVA,** Germany, 9-11 February, 2011 (9)

Meeting at MOERI in 2009

Meeting at SVA in 2011




Model Scale (1/30)
Model-ship
correlation
Force/
Local flow
Validation
CFD
Model Rn
Ship Rn
Full Scale

Tasks (1/3)

1. Update State of the Art
   (a) Impact of New Technologies
   (b) New experimental techniques and scaling
   (c) New benchmark data
   (d) Computational methods for predictions and scaling
   (e) New experimental and computational method for cavitation prediction
   (f) Identify the need for R&D for improving model experiments, numerical modelling and full-scale measurements

Tasks (2/3)

2. Review ITTC Recommended Procedures relevant to propulsion

(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, Procedure 7.5-02-05-03.3 "Waterjets - Uncertainty Analysis Example for Propulsion Test" to bring it into line with the ISO approach adopted by the ITTC,

(d) Include procedure for testing of bollard pull in Recommended Procedure 7.5-02-03-01.1

Tasks (3/3)

3. Identify primary sources of propulsion uncertainty
4. Review 25th ITTC Powering Performance specialist committee recommendations
5. Investigate improving Podded propulsion procedures
6. Review changes in propellers regulations for ice operations.

General Remarks

- **Report: each chapter/section to Task**
- **The task 2(c) moved to Specialist Committee on High Speed Crafts**
- ***Procedures relevant to propulsion* were confirmed.**

- Committee wants to focus on the Sections on the conventional propulsion and not to include the Sections on Cavitation, Ice, and High Speed vehicles

- **Related with the tasks 2(a), (b)**

- the questionnaire was distributed

- need for new procedures from the member organizations

- **Ice Task**

- Jorma Kämäräinen (Finnish Transport Safety Agency)

- Mary Williams (IOT)

- **Scarce of full scale data**

Major International Conferences
(sources reviewed)

- RINA Marine CFD 2008 (Mar. 2008, UK),
- 19th IAHR International Symposium on Ice (IAHR'08 July 2008, Vancouver Canada),
- 8th International Conference on HydroDynamics, (ICHD'08 2008, Nantes, France),
- 27th Symposium on Naval Hydrodynamics (Oct. 2008, Korea),
- 8th International Symposium on Particle Image Velocimetry (Aug. 2009, Australia),
- First International Symposium on Marine Propulsors - SMP'09 (June 2009, Norway),
- 7th International Symposium on Cavitation (CAV2009 Aug. 2009, U.S.A.),
- 1st International Conference on Advanced Model Measurement Technology for the EU Maritime Industry (AMT'09 Sept. 2009, France),
- SNAME Propellers/Shafting'09 (Sep. 2009, U.S.A.),
- 10th International Conference on Fast Sea Transportation (FAST2009 Oct. 2009, Greece),
- 12th Numerical Towing Tank Symposium (Oct. 2009, Italy),
- 6th International Workshop on Ship Hydrodynamics (IWSH'2010 Jan. 2010, Harbin, China),
- 2010 International Propulsion Symposium (Apr. 2010, Japan),
- PRADS 2010 (Sept. 2010, Brazil),
- 28th Symposium on Naval Hydrodynamics (Oct. 2010, U.S.A.),
- 9th International Conference on Hydrodynamics (ICHD'10 Oct. 2010 Shanghai, China),
- 2nd International Conference on Advanced Model Measurement Technology for the EU Maritime Industry (AMT'11 April 2011).

EEDI

- Energy Efficiency Design Index of the International Maritime Organization
  - Compares ship efficiency to an average performance of ships launched between 1995-2005
  - Stimulates research and development of new and old energy saving concepts to reduce CO_2 emission.
    - Using modern computational and experimental methods, some previously marginal devices have been demonstrated to yield efficiency improvements.
    - Some of these devices could require updated or new procedures to ensure consistent testing and scaling between organizations.

Potential Impact of New Technologies on the ITTC

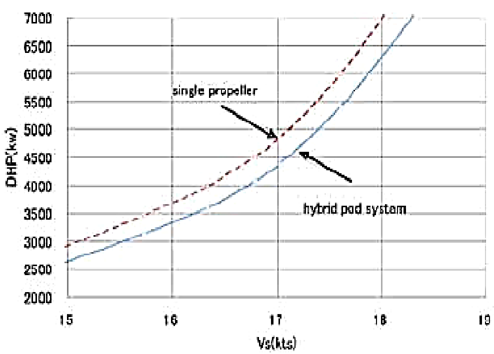
2.1.1 AzimuthingThrusters (hybrid)

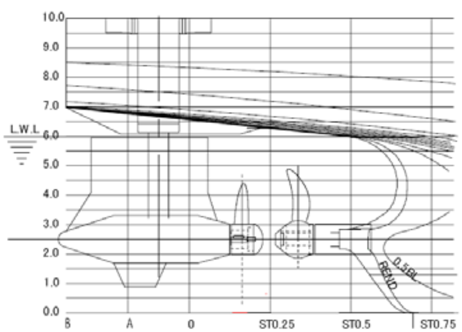
2.1.2 Alternative Material Propellers

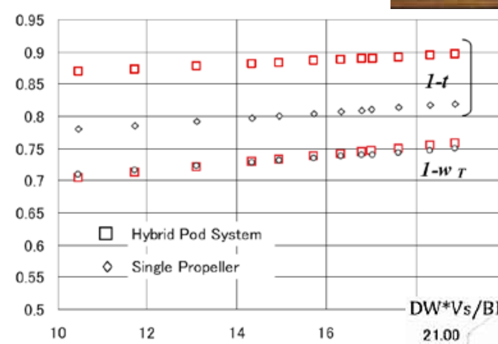
2.1.3 Other Novel Propulsors

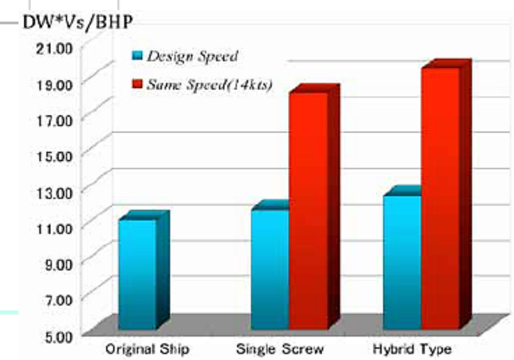
Hybrid CRP

- Hybrid contra-rotating pod propulsion
- POW, Resistance & Self-propulsion test(container ship)
  - Sasaki(2009)





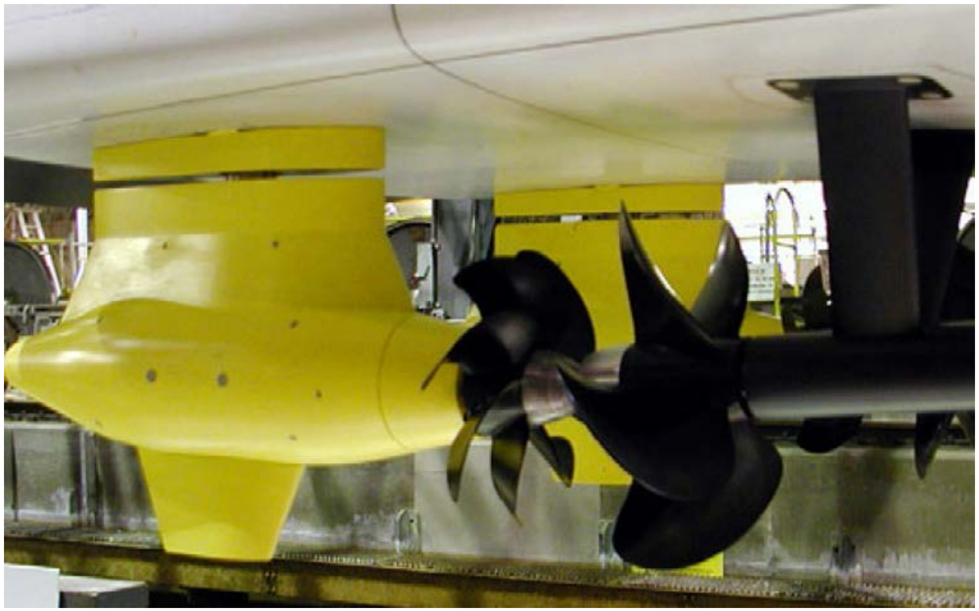


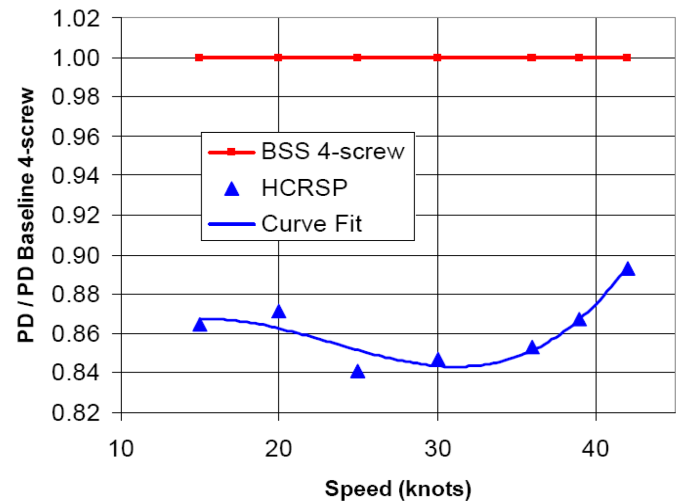


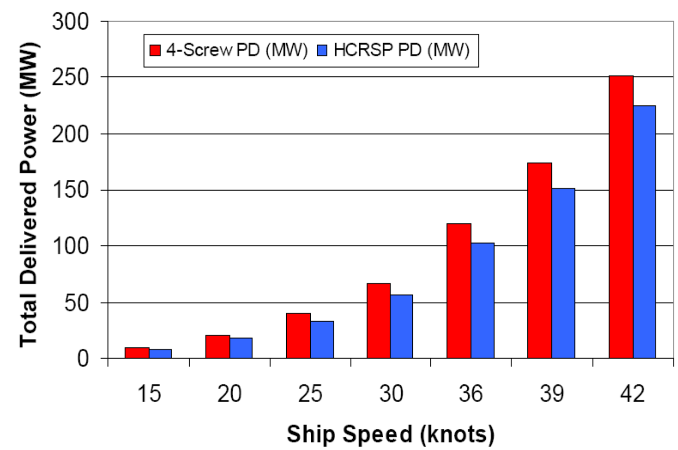
Azimuthing thrusters

- Hybrid contra-rotating pod propulsion
  - Of interest for efficiency and maneuvering benefits
  - Open water, resistance and powering testing
    - 4-screw / 2-screw / axial-waterjet / mixed-flow waterjet / hybrid contra-rotating testing by Cusanelli (2009)
  - System engineering single screw containership study by Shimamoto, Takeda, and Miyake (2010)

BSS(4) vs. HCRSP(2)







14.7% @36knots, 13.3% @39knots

- BSS: Baseline shaft & strut
- HCRSP: Hybrid contra-rotating shaft-pod

Alternative Material Propellers

- Increased interests in composite propellers
- Advantages over conventional materials propellers
  - Light weight
  - Potential cost savings (acquisition & maintenance)
  - High strength and stiffness
  - Tailorability
- Major Issues
  - Cavitation erosion
  - Structural integrity
  - Impact resistance
  - Repairability

Yagatogi et al. IPS 2010

Propulsion related concerns

- Hydroelasticity strongly affects performance
  - Open water performance is dependent on dimensional loading

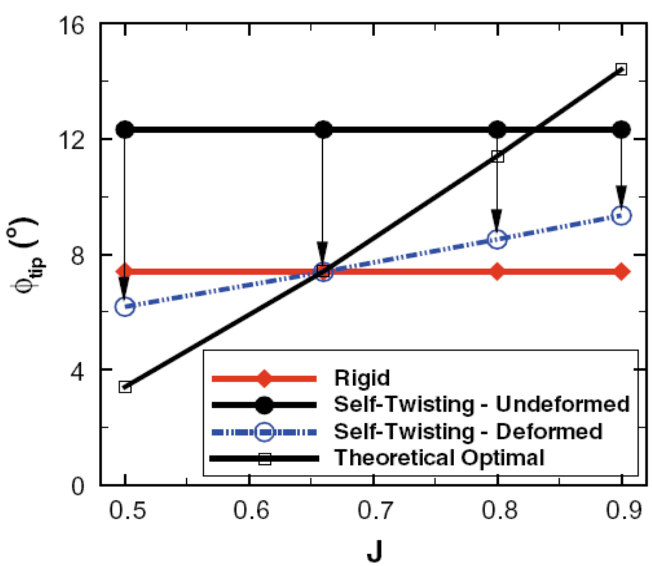
- Material properties and behavior do not scale with traditional hydrodynamics
  - Unsteady response at small scale may not represent full scale

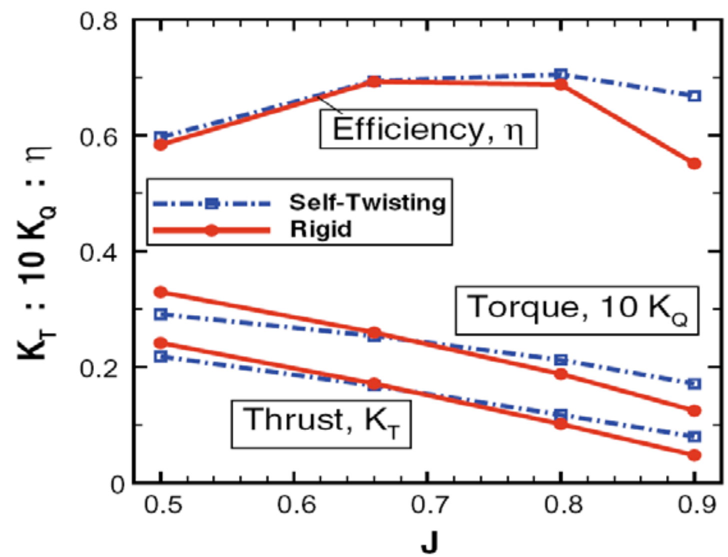
- Issue of fluid-structure interaction
  - Miller *et al.* (2010) : OpenFOAM RANS + FEA
  - Young *et al.* (2010) : Panel Method + FEA

Optimization & performance

- Composite marine propeller (self-twisting)
- Reliability-based design and optimization methodology

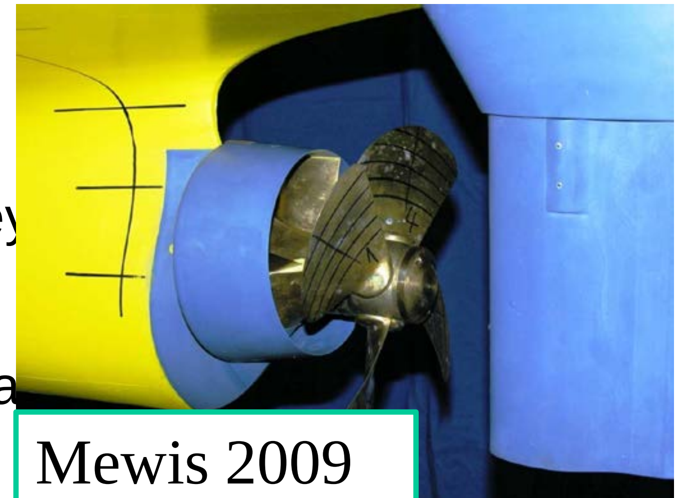
- Young, *et al*. (2010).



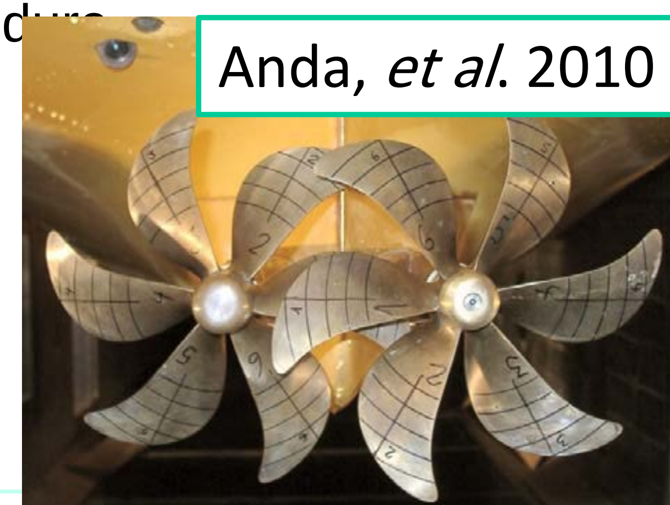


Efficiency Improvements

- Inflow duct/stators
  - Scaling effect issues with low Rey
- Overlapping Propellers
  - Challenges traditional powering a
- Rudder bulbs
  - Affects ITTC wake scaling procedure



Mewis 2009



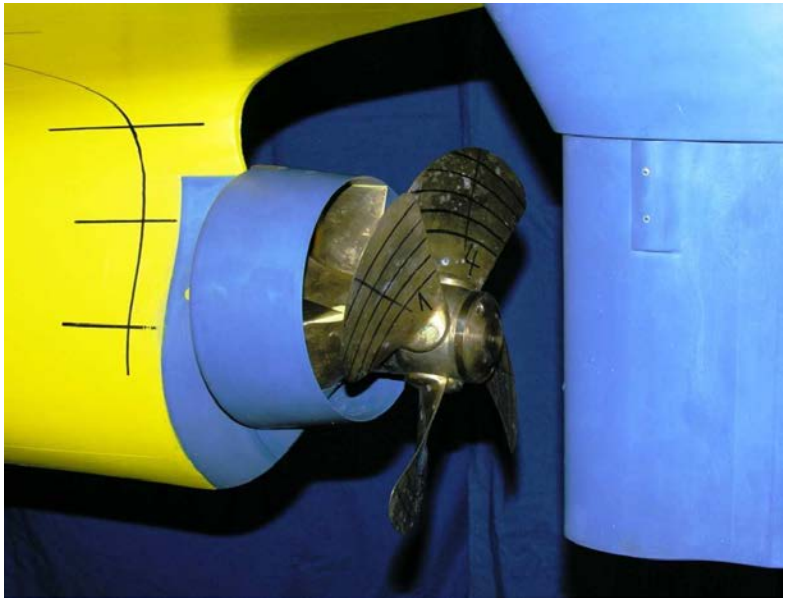
Anda, *et al*. 2010

Oh *et al*. 2010

Mewis pre-swirl Duct

- Full form, thrust coefficient >1.0
- Speed less than 20knots
- 7% reduction in required power

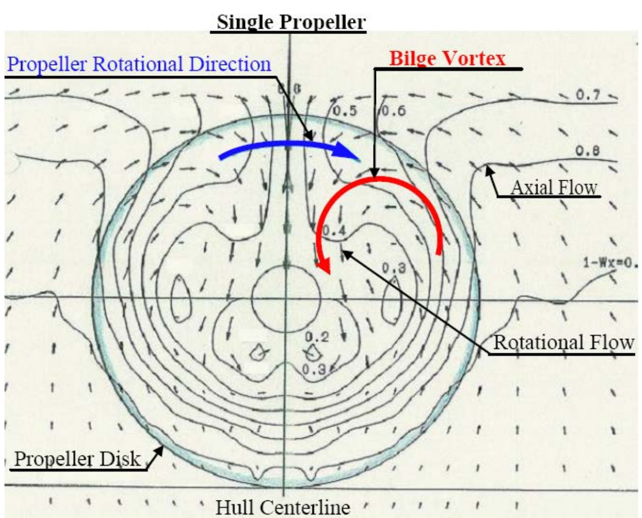
  - Mewis (2009)

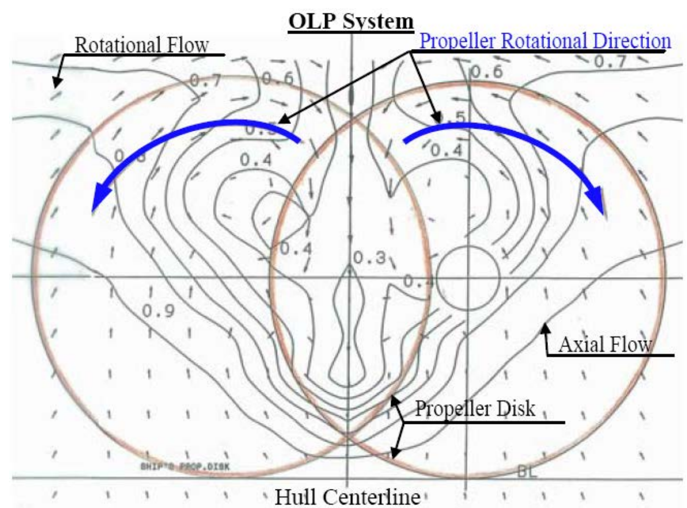


Overlapping Propellers

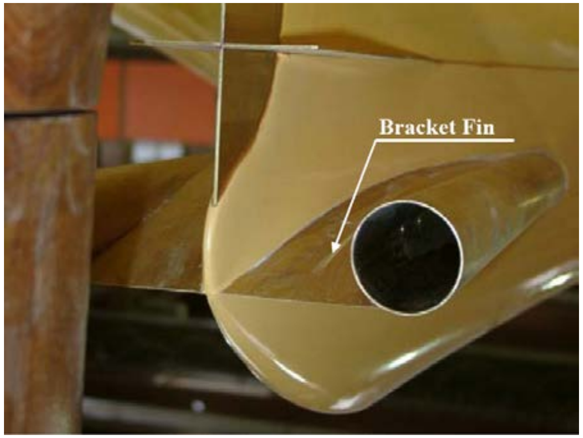
- LNG carrier
- Bracket fin
- Wake improved Fin

- Masaki Anda(2010)

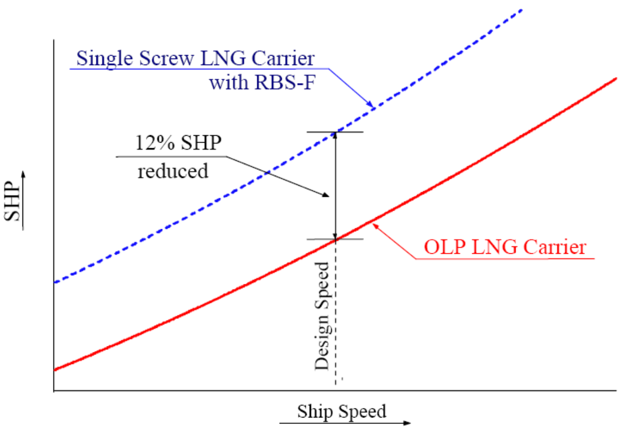


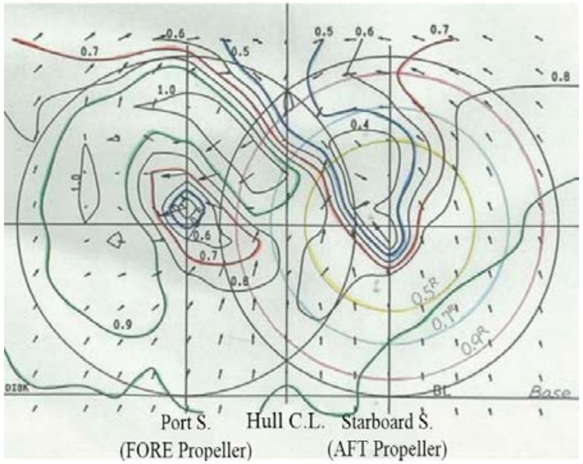


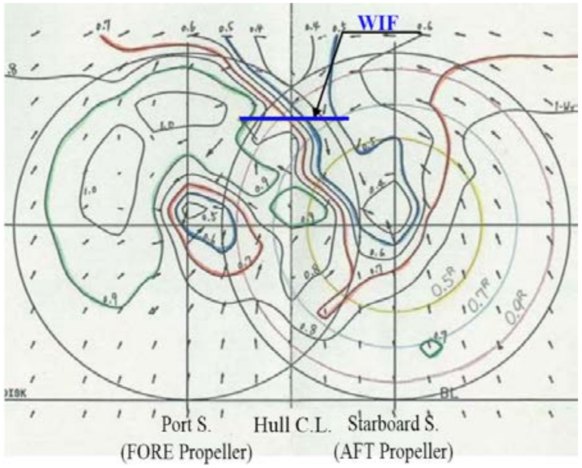
continued

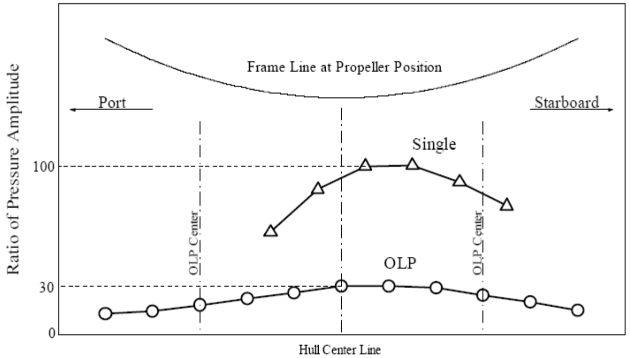

Bracket Fin


Wake Improved Fin


Single Screw LNG Carrier
with RBS-F
12% SHP
reduced
OLP LNG Carrier
SHP
Design Speed
Ship Speed


Port S.
Hull C.L.
Starboard S.
(FORE Propeller)
(AFT Propeller)

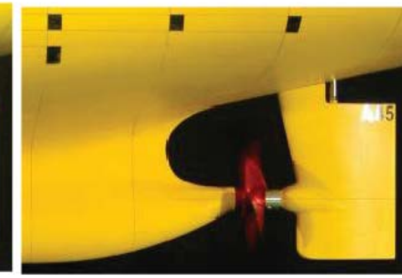

WIF
Port S.
Hull C.L.
Starboard S.
(FORE Propeller)
(AFT Propeller)


Frame Line at Propeller Position
Port
Starboard
Single
OLP
OLP Center
Ratio of Pressure Amplitude
100
30
0
Hull Center Line

Rudder Bulb

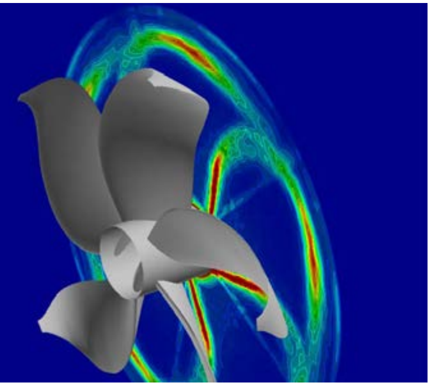
Prediction Method	With Rudder Bulb	
	ITTC 1978	Modified
Δw_{TM}	0.019↑	
Δt	0.010↑	
$\Delta \eta_R$	0.012↑	
Δw_{TS}	0.014↑	0.019↑
$\Delta \eta_D$	1.4%↑	**2.0%↑**

- Oh *et al*. (2010)



Other Works

- Hsin et al.(2010) : Kappel & CLT
- Yamasaki, et al. (2009) : hydrodynamic load
- Lee et al.(2010) : Wide Chord Tip
- Inukai (2010) : IHI Marine United Inc.
  - CRP electric propulsion, wake gain
  - 10% power reduction, chemical
- Karafiath et al.(2009) : Sea train



Example of a 4 Unit Seatrain with Notch Transom Design in Last Unit

Example of a 3 Unit Seatrain with Full Transom Design in Last Unit

New Experimental Techniques and Extrapolation Methods

2.2 Full scale measurement

2.2.1 PIV Measurements

2.2.2 Tomography PIV and Holography Techniques for 3D Flows Investigations

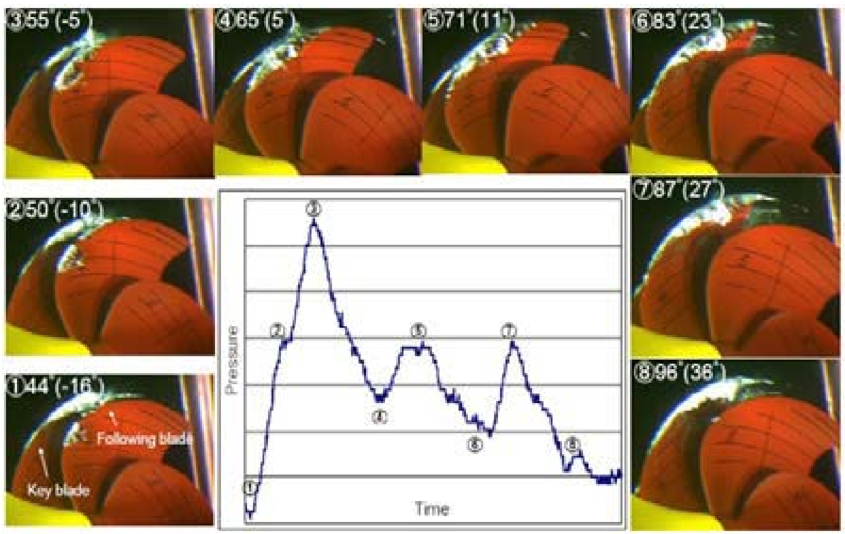
2.2.3 Manufacture of Model Propellers by Rapid Prototyping (RPT)

2.2.4 Lateral Forces and Non-Stationary Measurement on Propellers

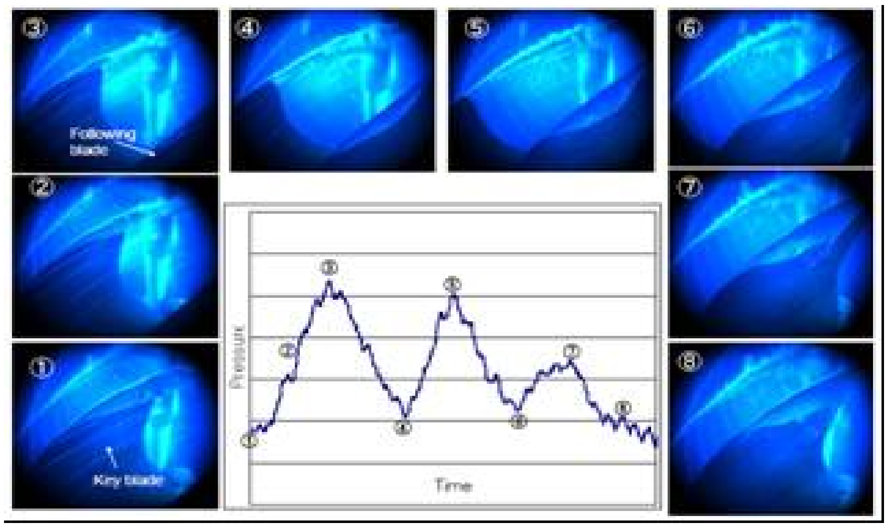
2.2.5 Wireless Communication

New experimental techniques for propulsor cavitation

- High speed camera synchronized with hull pressure signal for propeller cavitation observation at model scale and full scale



Model scale

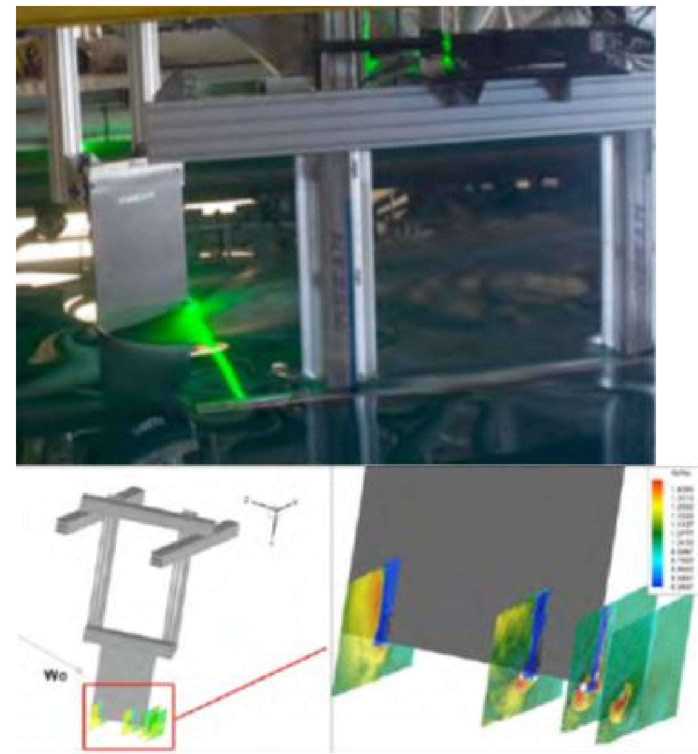


Full scale

Relation between cavitation and pressure fluctuation signal of a six blades propeller on a container ship (Hoshino, *et al.* 2010)

New experimental techniques for propulsor flow measurements

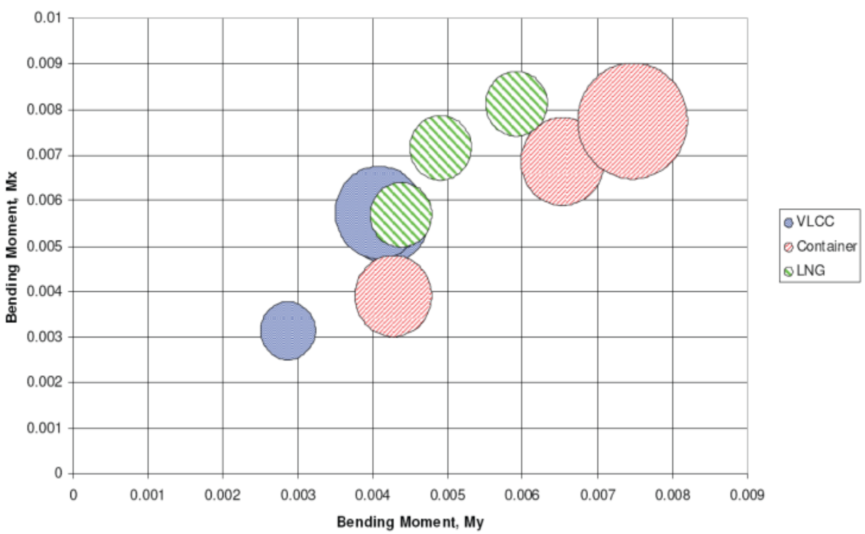
- Extensive use of the PIV (Particle Image Velocimetry) technique for detailed 3D flow investigations on propeller wake, propeller inflow
- Propulsion testing in towing tank : Felli, et al. (2009); Nakaie, et al. (2009); Nagaya, et al. (2011); Kim, et al. (2011); Di Felice, et al. (2011).
- Beside the large amount of applications of PIV in the naval hydrodynamics studies, the PIV European community (Borleteau et al (2009) launched a benchmarking test on a plate to assess the overall uncertainties of the PIV technique.



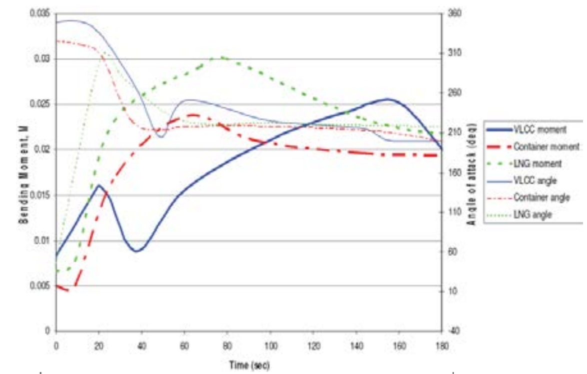
Lateral forces measurements on propellers

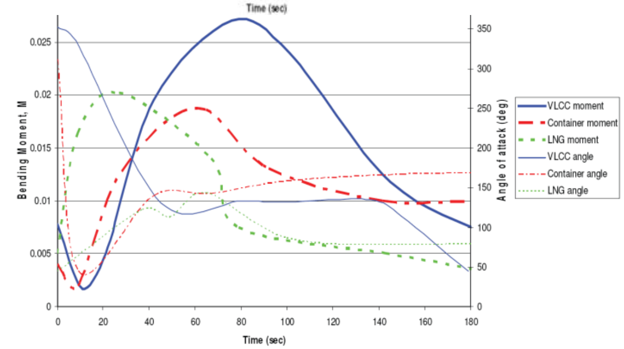
- Need to evaluate lateral forces to quantify the propellers forces on the shaft bearing interaction

- Vartdal *et al.* (2009)



Bending moment amplitude ON VLLC, Container and LNG





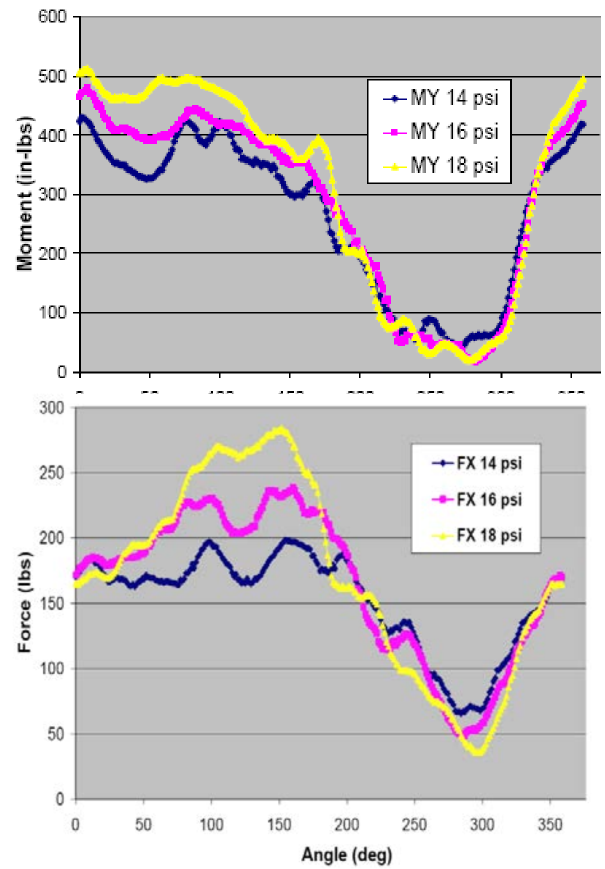
Dynamic blade loading measurements

- Improvement for the prediction of alternating blade loading under operation condition

- In-hub dynamometer+slip ring housing

- Jessup *et al.* (2009)

In-hub blade dynamometer



Tomography PIV and Holography Techniques for 3D Flows Investigations

- Thomas, *et al*. (2009) and Atkinson, *et al*. (2009)
- Investigate the performances of PIV techniques for the measurement of the three components of the velocity in a whole volume
- Tomographic particle image velocimetry (Tomo-PIV) and Holography referring to a paper of Arroyo and Hinsch (2008)
- These techniques are mainly applied to academic flows
- May be applied in the future to investigate the 3 components velocities in the flow volume around propulsors or in the inflow of the propulsor disk.

Manufacture of Model Propellers by Rapid Prototyping (RPT)

- **Propeller with sintered metal powder**
- After the RPT manufacturing, a suitable surface finishing and polishing has to be done. (resin & painting)
- Mechanical strength : low force & torque only
- new materials (PROTOFIBER) ABS assembly by carbon fibres inside

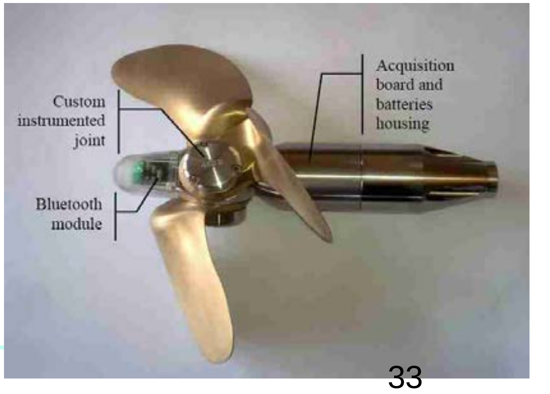
  - Bazzi and Benedetti (2009)

Wireless Communication

- Sensors in ship models and amplifiers on land is becoming quite mature. Free running model tests offer complementary information from captive model tests.

- The model-ship can be free of restraints and unnecessary external forces and interference can be removed in free running tests.

- Kimber *et al*. (2009) : control the submarine model free running
- La Gala *et al*. (2011): Torque measurement for CPP

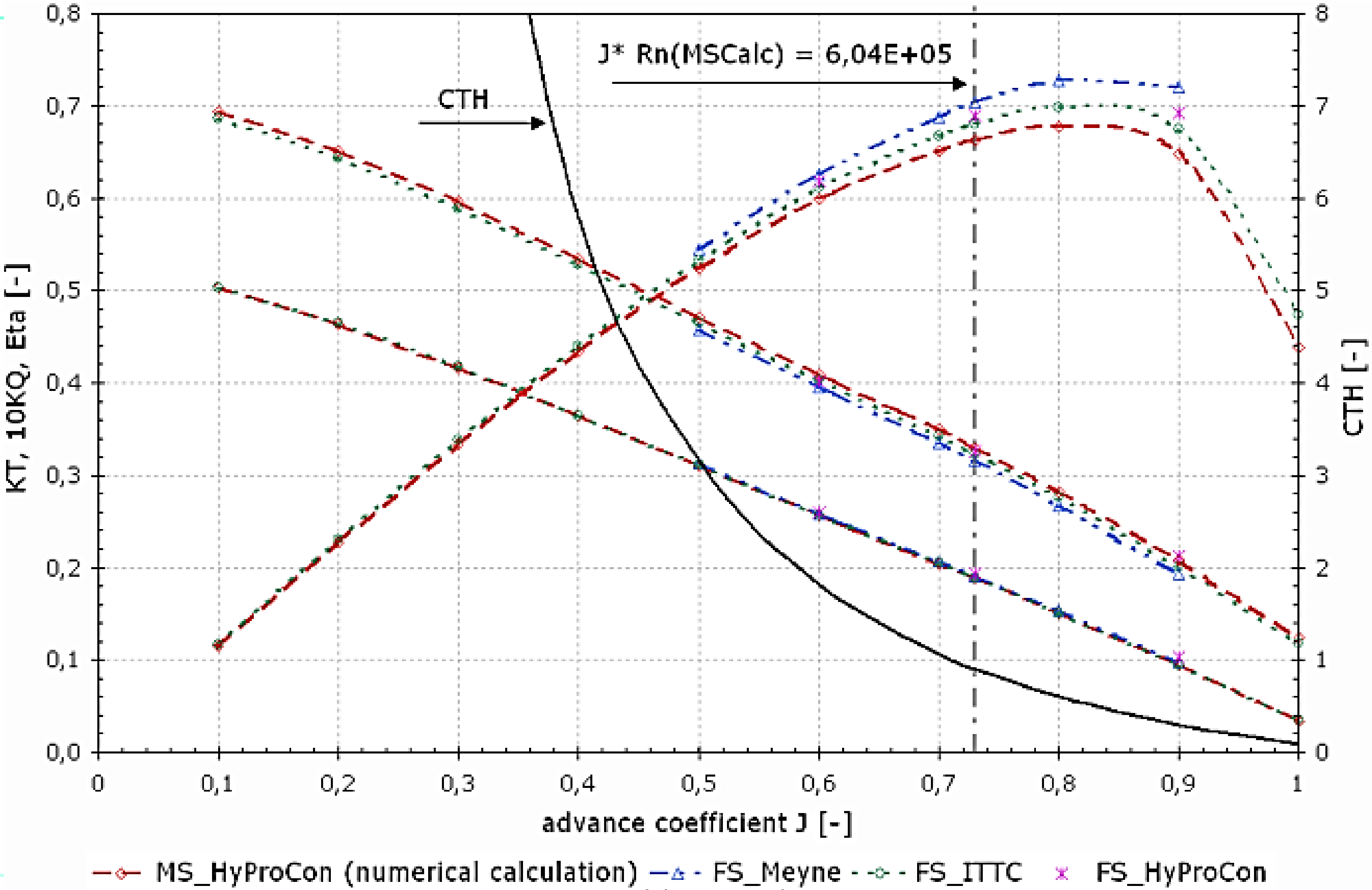


Extrapolation and Scaling

- Recent CFD calculations at model and full scale indicate that 1978 scaling procedure for propellers and wake fraction may need adjustment for propellers with
  - Highly skew
  - Wide tip chords
  - Tip loaded (Kappel / CLT)
  - Ducted propellers

    - Kawamura & Omori (2009)
    - Oh, *et al.* (2010): Rudder bulb, wake scaling
    - Hsin et al (2010): torque scaling
    - Lee, *et al*. (2010)
    - Krasilnikov, *et al*. (2009)
    - Müller, *et al*. (2009)
    - Mertes and Heinke (2008)

Müller, *et al.*, 2009



Mertes & Heinke (2008)

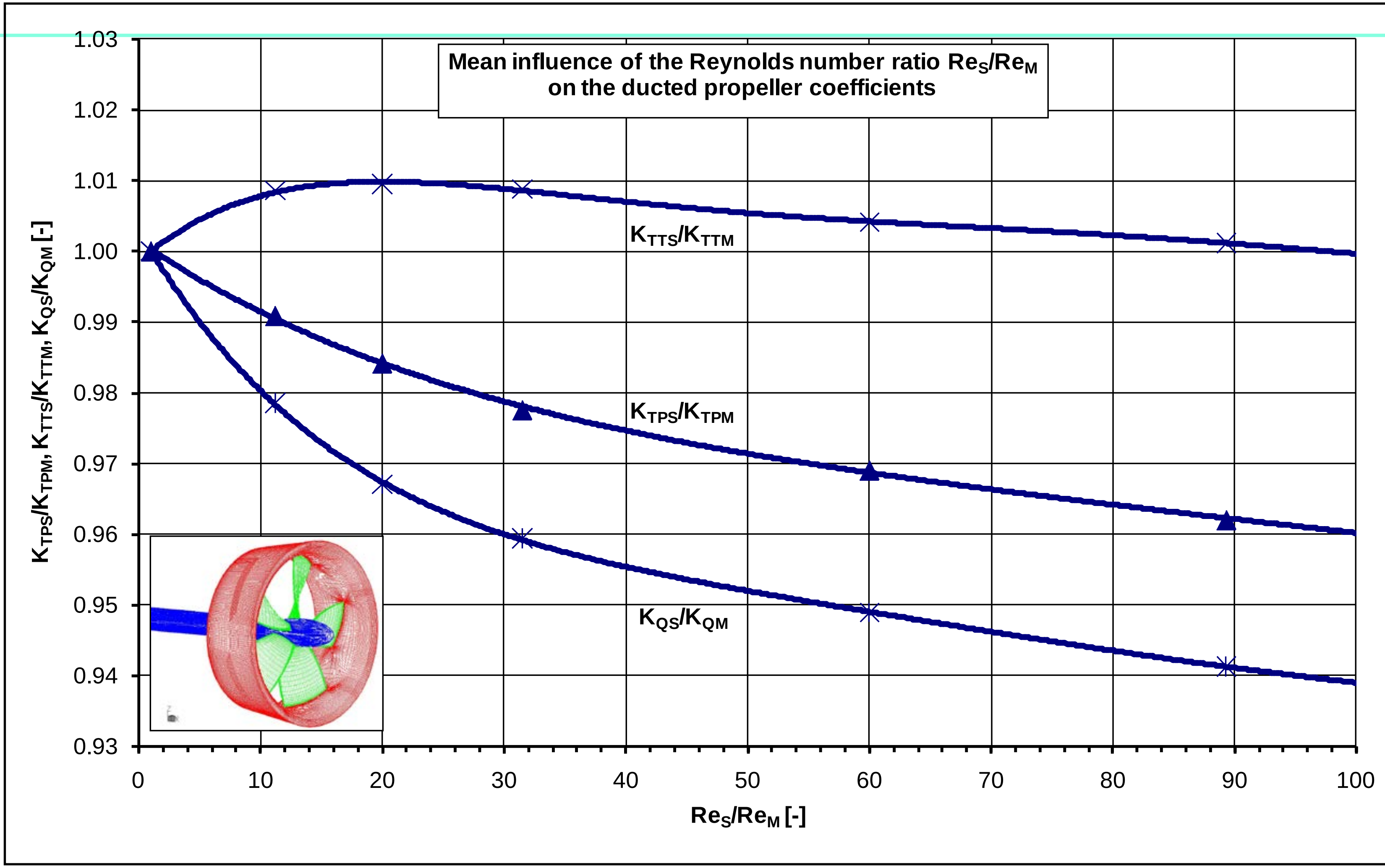


ABB case

- Propeller: same
- Propeller open water: 5.9%

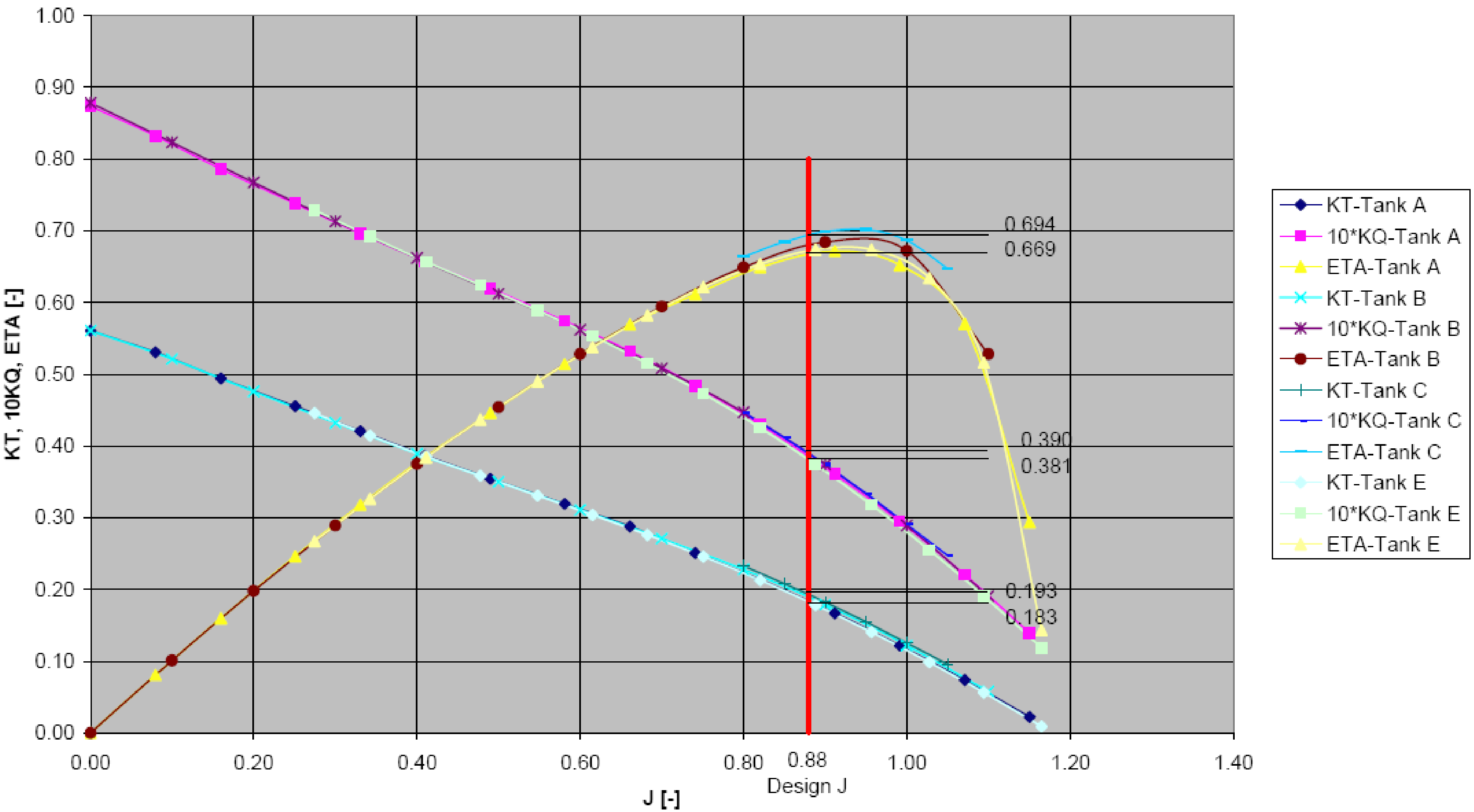
New Benchmark data

- **Comparison of Experimental Predictions of Open Water Performance Characteristics of a Podded Propeller**

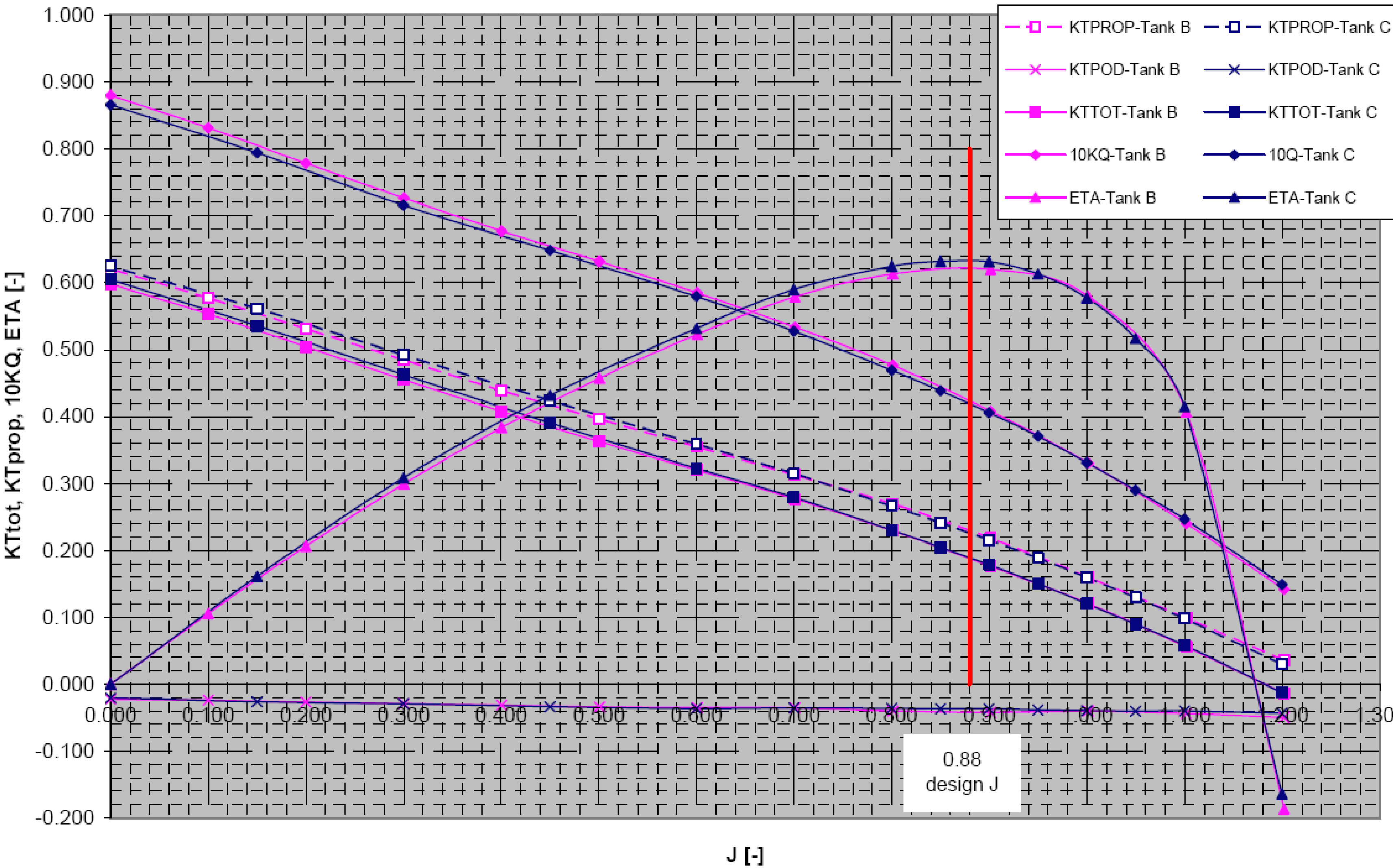
  - J. Richards et al.(2011), AMT11

- ITTC procedure(7.5-02-03-02.1, 7.5-02-03-01.3)
- All tests are done according to the same standardized procedures, defining main test parameters,
- All tests are to be carried out using the same propeller model
  - manufactured according to the documentation
  - additional elements of the measuring test stand (as caps, fairing cone): standardization and manufacturing
- All tests (where it is applicable) are to be done with the same propulsor body (the housing model)

JRP4

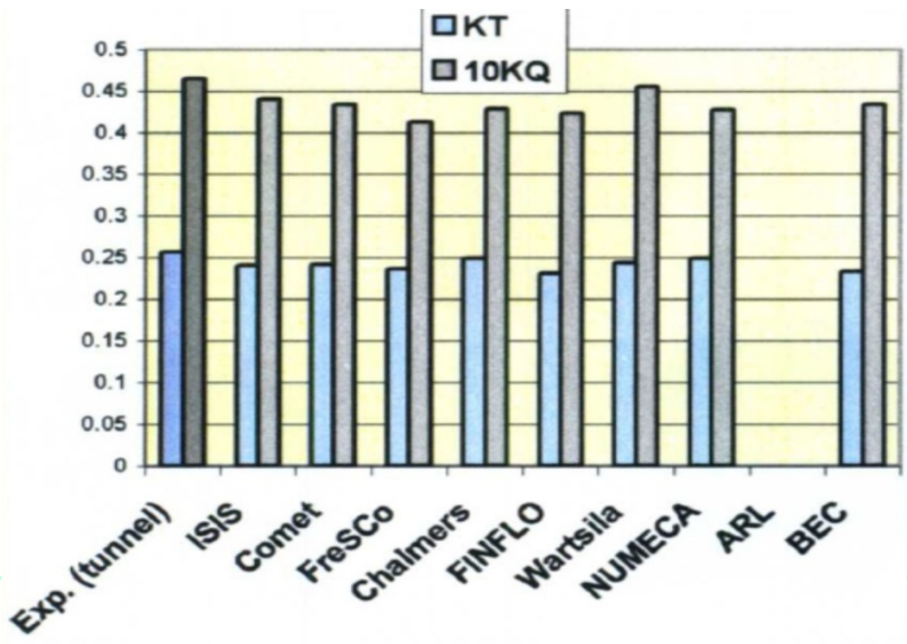

1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
KT, 10KQ, ETA [-]
0.00
0.20
0.40
0.60
0.80
0.88
Design J
1.00
1.20
1.40
J [-]
0.694
0.669
0.390
0.381
0.193
0.183
KT-Tank A
10*KQ-Tank A
ETA-Tank A
KT-Tank B
10*KQ-Tank B
ETA-Tank B
KT-Tank C
10*KQ-Tank C
ETA-Tank C
KT-Tank E
10*KQ-Tank E
ETA-Tank E

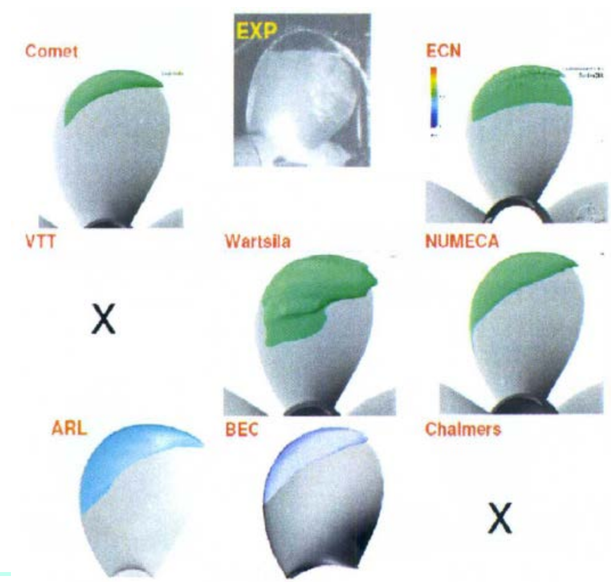
JRP4


KTPROP-Tank B
KTPROP-Tank C
KTPOD-Tank B
KTPOD-Tank C
KTTOT-Tank B
KTTOT-Tank C
10KQ-Tank B
10Q-Tank C
ETA-Tank B
ETA-Tank C
KTtot, KTprop, 10KQ, ETA [-]
J [-]
0.88
design J
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300

Non cavitating and Cavitating, in uniform flow

- VIRTUE Workshop 2008
- J=0.71, Cv=0.5
  - Streckwall and Salvatore (2008)





Benchmark data: CFD

- G2010 Workshop on Numerical Ship Hydrodynamics
- KCS, KVLCC2, DTMB5415
- 1980, 1990, 1994, 2000, 2005, 2010

Mean error and standard deviation of self-propulsion predictions

	K_T	K_Q	n	$R_{T(SP)}$-T
Mean error	**0.6%D**	**-2.6%D**	**0.4%D**	**-7.8%D**
Standard deviation	**7%D**	**6%D**	**3.1%D**	**8.7%D**

- Larsson and Zou (2010)

G2010 test cases

Number	Hull	Attitude	Measured quantity
1.1a	KVLCC2	FX_0	Mean velocity, Reynolds stresses (Postech WT)
1.1b		FX_0	Wave pattern (MOERI)
1.2a		FX_0	Resistance (MOERI)
1.2b		$FR_{z\,\theta}$	Resistance, sinkage and trim (MOERI)
1.4a		$FR_{z\,\theta}$	Pitch, heave, added resistance (INSEAN)
1.4b		$FR_{z\,\theta}$	Pitch, heave, added resistance (NTNU)
1.4c		$FR_{x\,z\,\theta}$	Surge, Pitch, heave, added resistance (Osaka Univ)
2.1	KCS	FX_0	Wave pattern (MOERI)
2.2a		FX_0	Resistance (MOERI)
2.2b		$FR_{z\,\theta}$	Resistance, sinkage and trim (MOERI)
2.3a		FX_0	**Self propulsion** (thrust, torque, propulsive factors, mean velocity), local flow (NMRI)
2.3b		$FR_{z\,\theta}$	**Self propulsion (thrust, torque, RPM)**, sinkage and trim (FORCE)
2.4		$FR_{z\,\theta}$	(Surge), Pitch, heave, added resistance (FORCE)
3.1a	DTMB 5415	$Fx_{\sigma,\tau}$	Mean velocity, resistance, wave pattern (INSEAN)
3.1b		$FX_{\sigma,\tau}$	Mean velocity, resistance, wave pattern, Reynolds stresses (IIHR)
3.2		$FR_{z\,\theta}$	Resistance, sinkage and trim (INSEAN)
3.5		$FX_{\sigma,\tau}$	Wave diffraction, Mean velocity (IIHR)
3.6		FR_{φ}	Roll decay (IIHR)

CFD application for propulsion prediction and scaling

2.5.1 Hull-Propulsor-Rudder Interactions

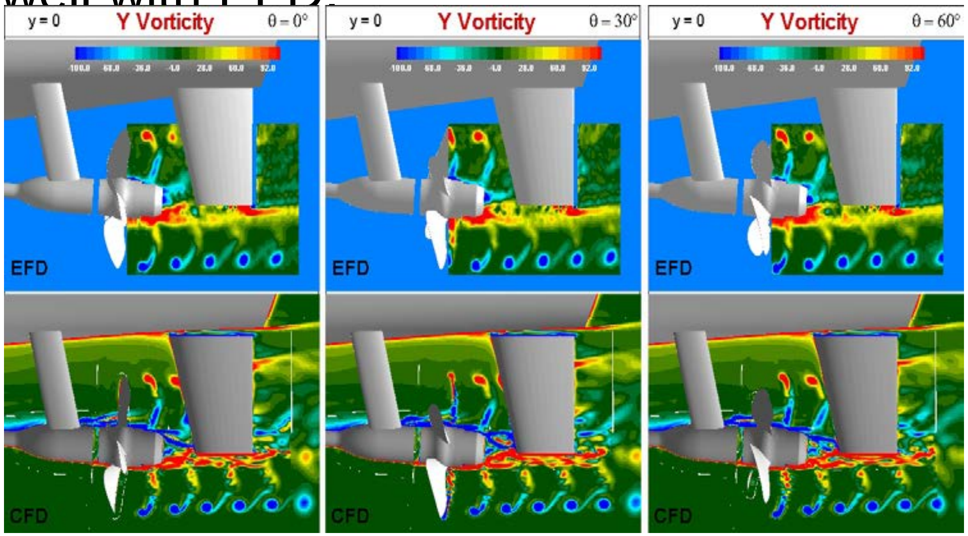
2.5.2 Propulsor/Hull Optimization

2.5.3 Multi-Component Propulsors

2.5.4 Crashback

Hull-Propulsor-Rudder Interactions

- The flow around a fully appended hull with twin propellers was simulated using an in-house FVM code with dynamic overlapping grids and Spalart and Allmaras one-equation turbulence model, and compared with EFD data obtained from LDV measurements. *(Muscari, et al., 2010)*
- Propeller tip vortex interacting with the rudder was correctly captured by CFD and agreed well with EFD.
- The axial velocities simulated with both fine and coarse grids were quite close to those measured, while the transversal vorticity was over-predicted, especially with the fine grid.



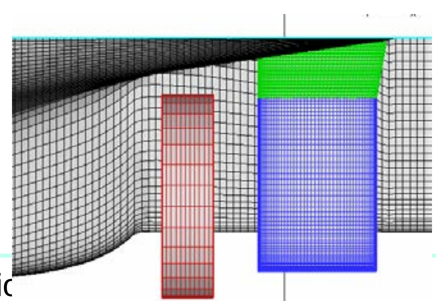
Hull-Propulsor-Rudder Interactions

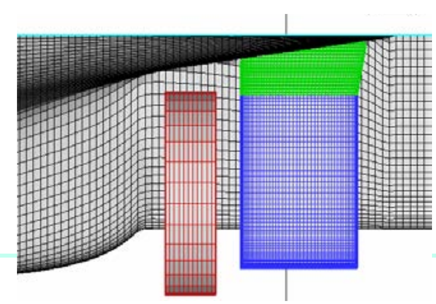
- For automatic optimization of hull-propeller-rudder interaction, the flow around hull and rudder was computed by steady RANS method with an algebraic stress turbulence model and a lifting-line based body force propeller model, using an in-house CFD code. *(Han, et al., 2008)*
- Using OpenFOAM and LES, propeller-hull interactions were studied for the fully appended DARPA AFF8 submarine hull and the INSEAN E1619 propeller at model scale. The Deformation and Regeneration (D&R) method *(Liefvendahl, et al., 2007)* was employed in unsteady flow simulations. *(Alin, et al., 2010)*
- Fine grids were found necessary for capturing the features of wake flow induced by the trailing vortices, although coarse grids are also acceptable when the open water performance is of interest. *(Liefvendahl, et al., 2010)*

Hull-propulsor-rudder Interaction

	Hull/propeller	Hull/prop/rudder 11		Hull/prop/rudder11np	
	Cal	Cal	Exp	Cal	Exp
R(N)	71.5	72.55	71.07	73.38	73.07
T(N)	57.38	58.32	61.93	59.02	63.89
Q(N.m)	1.89	1.9	1.896	1.92	1.942
Pd (Watt)	127.23	128.2	127.73	129.26	130.81
Pe (Watt)	80.04	79.8	84.04	79.55	83.98
Fd(N)	14.12	14.26	9.14	14.4	9.18
t	0.182	0.197	0.204	0.209	0.229
w	0.35	**0.336**	**0.339**	**0.35**	**0.349**
η_O	0.488	0.512	0.535	0.498	0.527
η_r	1.024	1.007	1.02	1.017	1.028
η_h	1.258	1.21	1.205	1.217	1.185
η_d	0.629	0.622	0.658	0.615	0.642

Han, *et al.*,(2008)





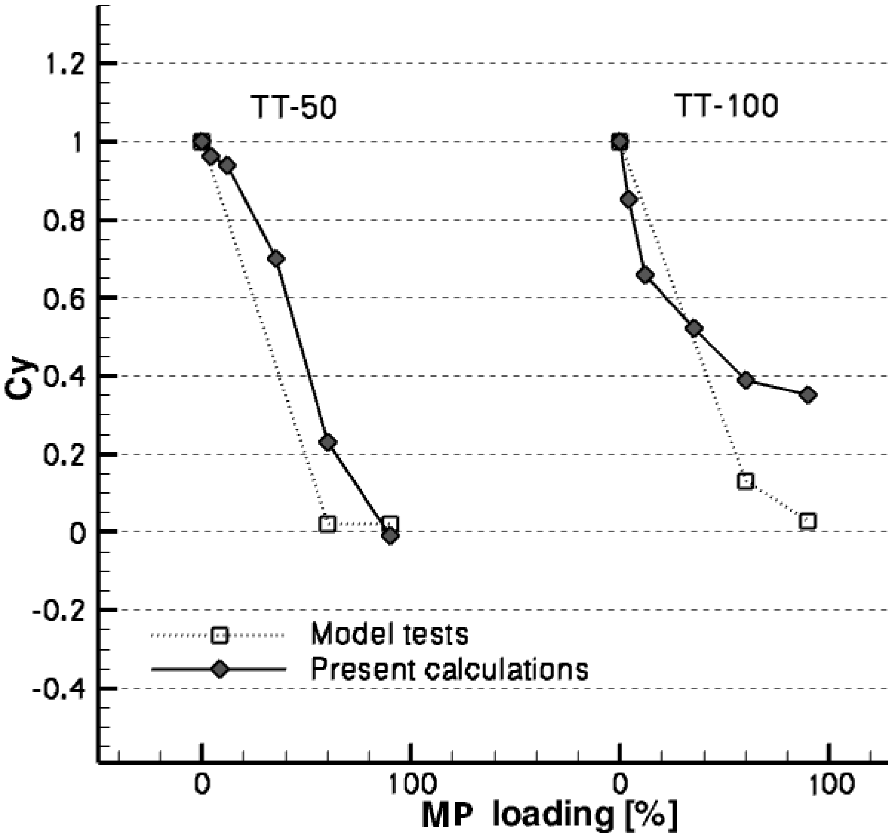
Propulsor/Hull Optimization

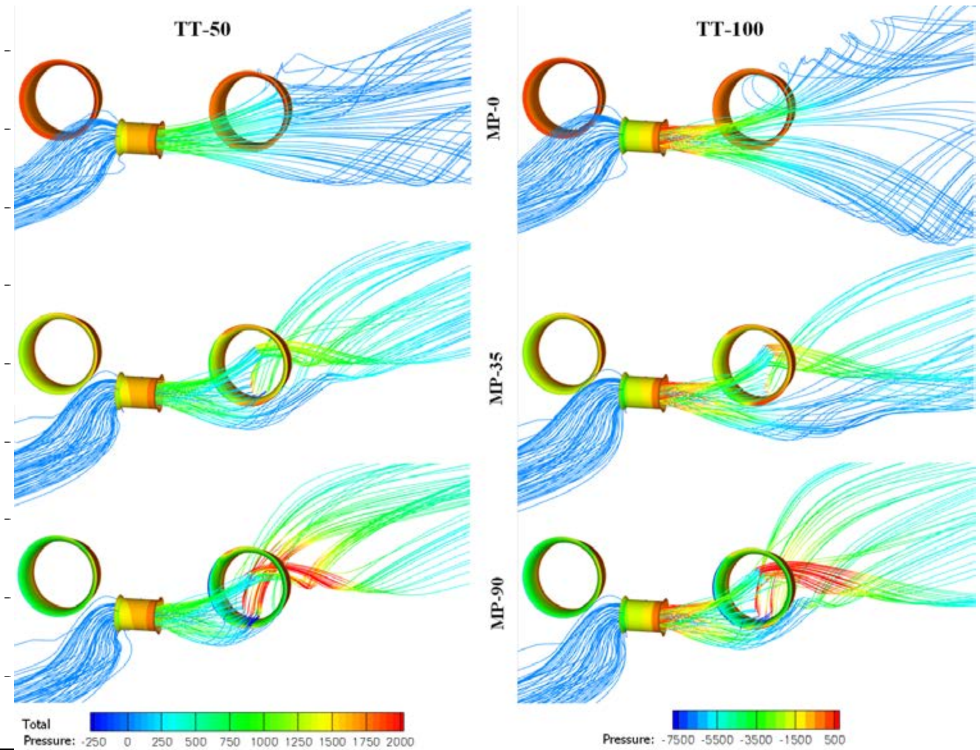
- Hull form optimization to minimize resistance and improve wake quality
  - Van de Ploeg and Raven, 2010
- Hull form optimization and utilization of various energy saving propulsor devices
  - Hollenbach and Reinholz, 2010
- Optimization of hull form and propulsor for a waterjet propelled monohull and catamaran
  - Bow hull form and WJ inlet, JHSS design
  - Peri, et al., 2010

Multi-component propulsors

- Sánchez-Caja, *et al.* (2009): ducted Prop.+rudder
- Taketani, *et al.* (2009) : ducted prop., bollard pull
- Sileo, *et al.* (2009) : MP+TT for AHTS
- Minchev, *et al.* (2009) : Alpha high thrust nozzle
- Liu (2009) : potential, CRP, steady & unsteady
- Fujisawa, *et al.* (2010): Fluent, CRP
- Zhang, *et al.* (2008) : Fluent, Podded propulsor
- ……

Main propulsor vs Tunnel thruster





- Sileo, *et al.* (2009)

EFD and CFD Methods Applicable to the Prediction of Cavitation

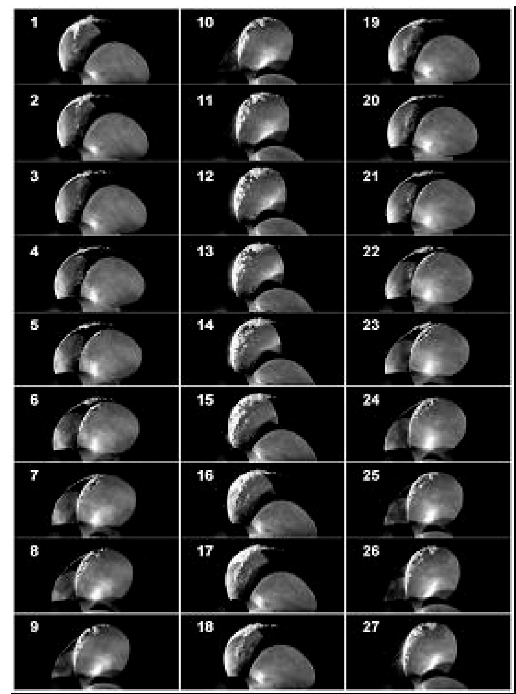
2.6.1 New Experimental Cavitation Prediction Methods

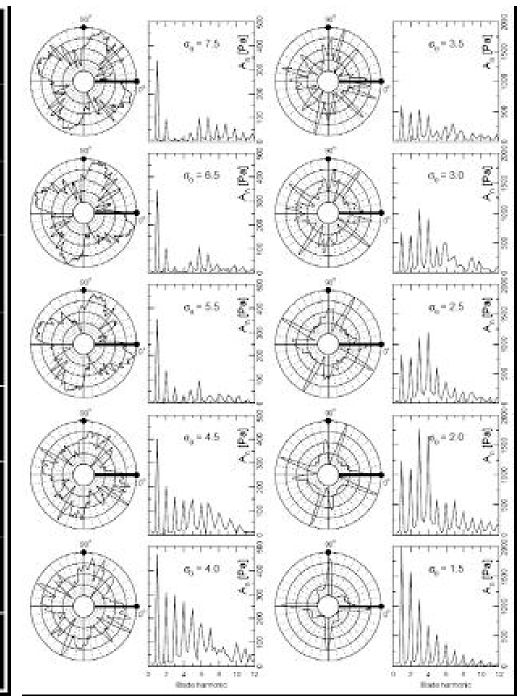
2.6.2 New CFD Prediction Techniques for Cavitation

New experimental techniques for propulsor cavitation

- High speed camera synchronized with hull pressure signal for propeller cavitation observation
- Provide detailed insight into cavitation phenomena (typically what kind of cavitation structure is causing the highest pressure pulses)

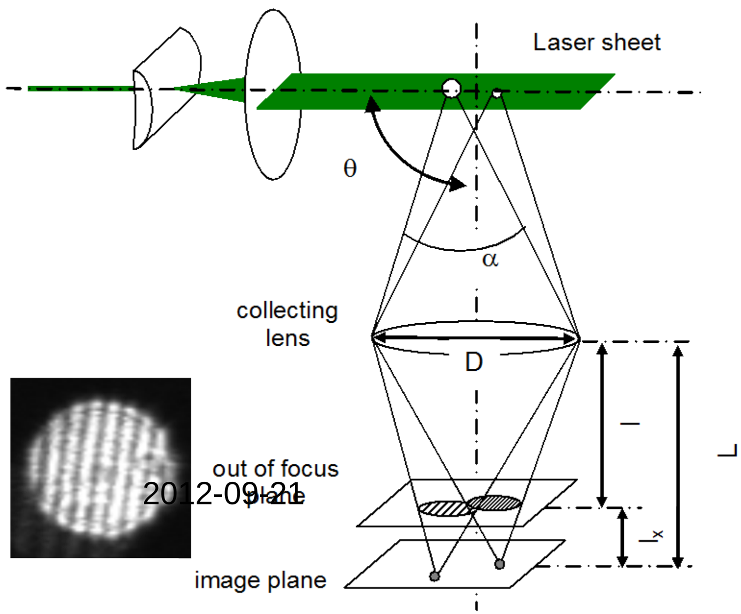
- Pereira et al. (2009)





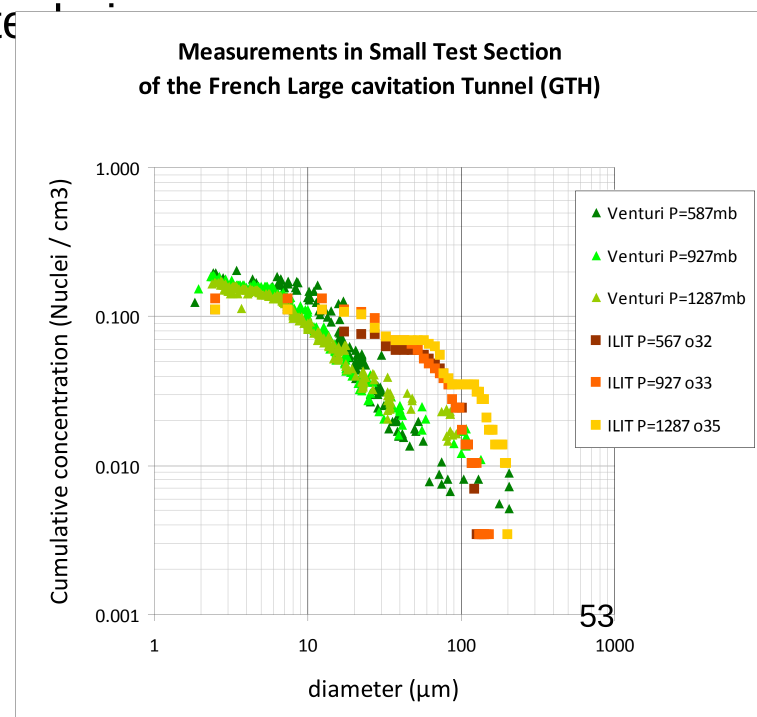
New experimental techniques for propulsor cavitation

- Cavitation Nuclei contents in cavitation tunnel have been proved to be essential for cavitation inception prediction (21st ITTC Cavitation committee).
- New optical measurement techniques have been developed using the ILI Technique using the similar equipment as PIV te



Interferometric Laser Imaging Technique (Mées et al, 2010)

⇔ Defocused Image of micro bubbles illuminated by a Laser sheet



Nuclei Content comparison with Venturi method

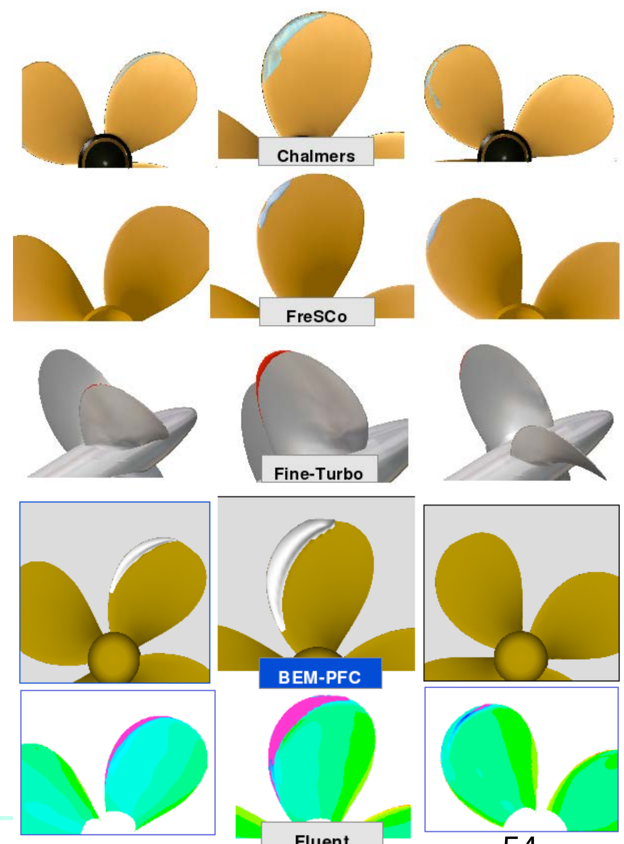
New CFD prediction techniques for cavitation

Summary of results on cavitating propeller modeling from the VIRTUE 2008 Rome workshop (Salvatore, *et al.*, 2009)

- Seven models were employed for a benchmark analysis of the INSEAN E779A propeller model in uniform and non-uniform inflow conditions

Code (organization)	*Grid size wet/cav*	*Time- step / angular step*	*CPU effort*
OpenFoam (Chalmers)	4.6 M	1.1E-6 s / 0.012 deg	
FreSCO (HSVA)	2.4 / 3.1 M	4.55E-5 s / 0.5 deg	3 days (8-proc)
Fine-Turbo (NUMECA)	3.0 / 11.4 M	2.28E-4 s / 2.5 deg	3 days (24-proc)
Fluent 6.3 (SSPA)	0.8 / 2.3 M	4.55E-4 s / 5 deg	
FINFLO (VTT)	1.7 / 5.9 M	4.55E-5 s / 0.5 deg	4 days (16-proc)
M-Uncle (ARL-PU)	3.7 / 7.3M	2.28E-5 s / 0.25 deg	0.6 days (192 proc)
BEM-PFC (INSEAN)	*surface*	2.5 deg	6 hours

- The errors in predicted thrust and torque fall within a range of -10% ~ +8%
- Qualitative agreement of predicted and experimental cavity extent was confirmed
- Further study of turbulence model, cavitation model, grid resolution, numerical dissipation, and especially the modeling of non-uniform inflow, are found necessary



CFD prediction techniques for cavitation

- Effect of grid resolution on cavity geometry prediction
  - Sipilä, *et al.* (2009)
- Cavity geometry prediction by commercial CFD codes
  - Liu, *et al.* (2008)
  - Kimura, *et al.* (2009)
  - Sato, *et al.* (2009)
  - Ji, *et al.* (2010)
  - Hasuike, *et al.* (2009)
  - Yamasaki, *et al.* (2009)
- Potential flow modeling of cavitation
  - Kanemaru, *et al.* (2008, 2009a, 2009b)
  - Baltazar, *et al.* (2010)
- Two-phase flow, OpenFOAM
  - Kim (2009)

R&D Needs in Propulsion

- **Model Experiments**
- Uncertainty and Calibration standards for PIV measurements
- Improved tractor pod (alone) test standards
- Wake scaling improvements
- Scaling and tripping procedures for low Reynolds number appendages with full scale correlation

- **Full Scale Measurements**
- Methods to measure the interaction of drag reduction techniques
- Improve accuracy of thrust dynamometers and side-force measurements
- More public domain data is needed for validation, particularly for pods.

R&D Needs in Propulsion

- **Numerical Modelling**
- Numerical uncertainties from different mesh resolutions, turbulence models and numerical discretization schemes
- Full scale propulsion prediction
- More benchmark data

- **For cavitation**
  - Grid resolution and numerical dissipation at the cavity/fluid interface
  - Turbulence and cavitation models
  - Modelling of a non-homogeneous inflows

REVIEW PROCEDURES RELEVANT TO PROPULSION (+ UNCERTAINTY ANALYSIS)

3.1 Identify the Need for New Procedures and Outline the Purpose and Content of Them

3.2 Survey by Questionnaire

3.2.1 Summary of the Responses

3.2.3 Conclusion and Recommendation

ITTC Recommended Procedures relevant to propulsion

7.5-02-03	Propulsion		
7.5-02-03-01.1	**Propulsion Test**	✓	**Bollard pull, Trawl pull**
7.5-02-03-01.2	**U. A. Example for Propulsion Test**	✓	**Corrections**
7.5-02-03-01.3	***Podded Propulsor Tests and Extrapolation**	✓	**Not accepted**
7.5-02-03-01.4	**1978 ITTC Performance Prediction Method**	✓	**Corrections**
7.5-02-03-01.5G	*Predicting Powering Margins	X	
7.5-02-03-02.1	**Open Water Test**	✓	
7.5-02-03-02.2	**U. A. Example for Open Water Test**	✓	**Corrections**
7.5-02-03-02.3	Guide for Use of LDV	X	
7.5-02-03-02.4	**Nominal Wake Measurement by 5-Hole Pitot Tube**	✓	**Modification**

Questionnaire survey

- the hybrid propulsion systems require specific model testing and full scale powering prediction procedures
- types of hybrid propulsors tested, frequency of testing, testing method (variable loading/ variable speed approach), power sub-division between multiple propulsors, optimization of pod/azimuthing thruster angle and propeller direction of rotation,
- availability of in-house hybrid propulsion testing procedure and willingness to share it within the ITTC community.
- The second group of questions concerned the derivation of propulsive factors (wake fraction, thrust deduction and relative rotative efficiency) as well as their scaling procedures.
- Finally, existence of full scale trial data from hybrid propulsion systems and willingness to share this information were inquired.

Questionnaire Response

- 14 out of 55 (7countries)
- 11 hybrid propulsion test (3 no experience)

CL conv. propeller + wing pods/thrusters/Z-drives	7
CL pod/thruster unit + wing conv. propellers	4
CRP concept - conv. propeller/pod combination	8
Water jet(s) combined with conv. propellers/pods	4
Forward/Aft propulsion systems (typically double-ended ferries)	8

Procedure, method

Separate resistance, propeller open water and propulsion tests	11
pod/thruster housing: appendage	4
pod/thruster housing: propulsor	7
Both stock and design propellers	11
Constant ship speed/variable propeller loading	6
Variable ship speed/corresponding propeller loading	2
Combination of both	3

By a pre-testing selection of the azimuthing angle in line with local streamlines (found from RANSE CFD analysis, for example)	2
By sweeping a pre-defined discrete range of azimuthing angles in a resistance test set-up (resistance test)	1
By sweeping a pre-defined discrete range of azimuthing angles in a propulsion test set-up (propulsion test)	6
Combination of the above	5
Thrust identity Q:1, No:1	9
Effective Wake scaling(1978 ITTC)	7
Combination of both	3

Procedures

Do you have a dedicated in-house propulsion testing procedure for hybrid propulsion systems?	6
If you have such a procedure(s) would you are willing to share the comparison with the rest of the ITTC?	2
Do you consider it necessary that ITTC works out and proposes a recommended standard procedure for propulsion testing of hybrid propulsion systems? (NO : 3)	8
Do you have ship trials data to compare to your standard hybrid propulsors powering prediction method?	4
If you have ship trials data comparison to model predictions, are you willing to share the comparison with the rest of the ITTC?	**1**

Questionnaire summary

- Based on above survey, the Committee can conclude that the hybrid propulsor testing is not very frequent and is still in its pre-mature phase of development. The general conception is that institutions dealing with this subject are **NOT** very much willing to share their expertise in this field, but at the same time, it is feasible for the ITTC to develop and propose standardized testing procedure.

- Double-ended ferries
- Triple screws with different diameter
- Centerline propeller with wing pods
- Hybrid contra-rotating propellers

Propellers for Ice going ships

Comment on the impact of developments of propellers for ice going ships in the view of the increasing operations in ice covered waters and changes in regulations

Regulations and Rules reviewed

- “Requirements (UR I, UR K) concerning Polar Class (2007)” by International Association of Classification Societies (IACS)
- “FINNISH-SWEDISH ICE CLASS RULES 2010” by Finnish-Swedish Maritime Administration (FMA)
- Canadian Maritime Association

Changes in Regulations

- **Current changes in IACS UR (2007) and FSICR (2010) for ice class propellers are related to propeller strength calculations and partly to pod strength**
  - FEM-based analysis instead of simplified cantilever beam method
  - The propeller design ice loads instead of ice torque
  - Rules changes are the result of extensive research activities such as: analyses of service history of propeller damages, load measurements on full scale trials, laboratory investigations and numerical simulation.

- Lee et al. (2007)

Further rule's corrections could be implemented to improve assessment accuracy.

Changes in Rules and UR

- **UR simplified cantilever beam model applied for blade edge strength calculations could overestimate the stress a lot compared to FEM analysis**
- 3D effect of the blade geometry should be considered in the edge strength assessment,
- Plastic FEM analysis is appropriate for ice propeller strength assessment.
- Compared to ice load, hydrodynamic load is small but could be dominated source for fatigue failure.

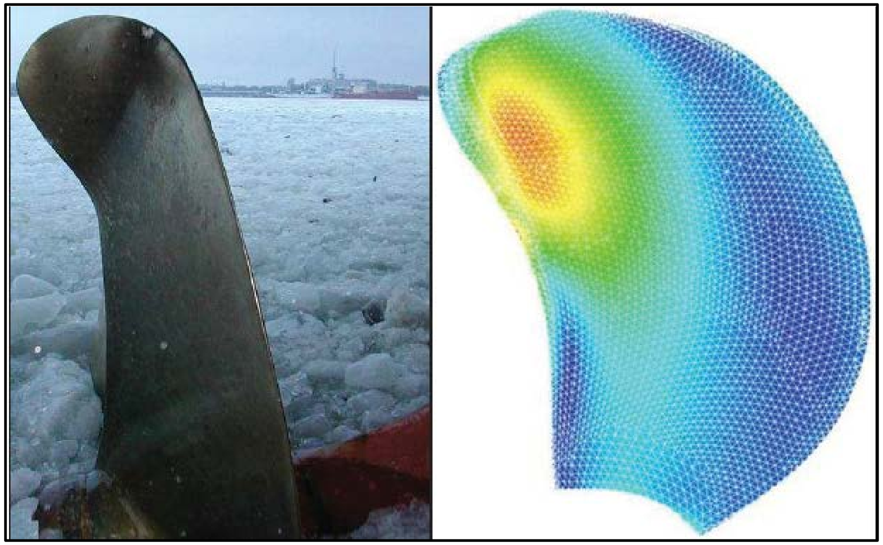
Location	Leading edge S.F. based on FEM σ	Leading edge S.F. based on URI3 σ > 4.08	Trailing edge S.F. based on FEM σ	Trailing edge S.F. based on URI3 σ > 2.08
0.5R	20.66	10.37	7.283	2.76
0.6R	9.49	5.19	3.68	1.61
0.7R	7.15	2.94	2.50	1.12
0.8R	7.68	1.75	2.09	0.75
0.9R	8.47	1.22	0.78	0.27
Tip*	21.70	2.69		

* S.F. > 8.33 for tip

- Lee *et al.* (2007)

Ice load distributions and Strength assessment

- Ice load distributions derived from loads models by rules
- Strength assessment of essential propeller components, such as blades, hub and pitch mechanism, in propulsion line requested accordingly to recently introduced rules
- Rules require deep analysis of both propeller and shafting system.
- Need to cover whole scope



- Norhamo *et al.* (2009)

No clear indications found in new procedures requirements caused by changes in rules of IACS UR, FSICR, and rules of CMA.

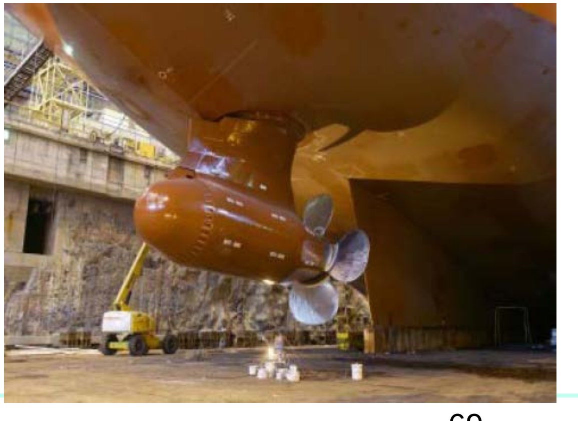
Specific ice class rules for azimuthing thrusters are necessary

- **Since 2010, FSMA initiated R&D project AZIRULE. AHRAVUO project (completed in 2009) followed to determine ice load scenarios and load cases for azimuthing thrusters and its propellers to be included in ice class rules. The task is targeted on 2013.**

- **FMA response to committee inquiry**
- **Test procedures for hybrid propulsion system for ice going ships**
- **Load calculation model for Azipod propellers**

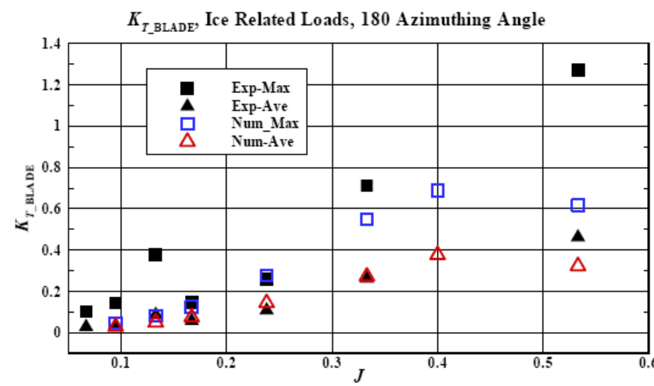
  - Full scale measurements of global and local ice load and shaft line fatigue loads to identify Azipod ice loading scenarios and develop optimum criteria for ice classed Azipod units

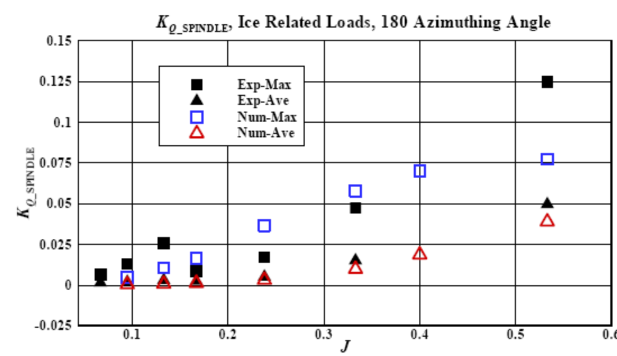
    \- Hänninen et al. (2007)



Model tests and numerical predictions for propeller-ice interaction in NRC/IOT

- With an azimuthing podded propulsor model in the ice tank,
- Propeller performance in ice load
- For tractor mode, Steady milling condition assumed
- Empirical model for ice loads developed and implemented into panel code
- The 3-D unsteady panel method (PMARC) used for numerical calculation (Wang et al. 2009)





- Unsteady time-domain, multiple body panel method model verified and compared with experimental results for pack and pre-sawn ice(Liu et al. 2008)

Recommendation to 27th ITTC

1. Procedure Review / Update

(a) Review the procedures dealing with cavitation and propulsion in ice

(b) Continue looking for full scale pod data. Refine pod procedure as full scale data becomes available, this may allow the CFD section to be removed.

(c) The current propulsion procedure needs to address thrust loss due to cavitation

(d) Review the results of the 26th wake scaling specialist committee to potentially update cavitation scaling procedures

(e) Look for full scale data to improve correlation/extrapolation procedures.

(f) Examine existing procedures and assess where CFD results can be introduced in the propulsion process to reduce or eliminate some model testing

Recommendation to 27th ITTC

(g) Consider updating the 1978 (friction line, form factor, wake scaling) methd especially for twin propellers

i. Examine wake fraction scaling for twin screw ships

Ii Examine propeller scaling procedure to ensure it is applicable for skewed propellers and propellers with long chord tips (WCT, Kappel, CLT) based on modern CFD and full scale data.

(h) Find full scale correlation data that will allow the Predicting Powering Margins guideline (7.5-02-03-01.5) to have a roughness correction to be added to section 4.2.2. Also monitor whether the EEDI may influence on margins in the future.

Recommendation to 27th ITTC

2. New Procedures

(a) The Committee recommends that the next ITTC Propulsion Committee initiates the development of practical initial guidelines for hybrid propulsor testing, which at later stage to be further developed as a standard procedure.

3. Technologies to monitor

(a) Recommend ice propulsion issues be monitored in the future. Should any significant issues develop, then a specialist committee on ice should be formed since most propulsion committee members are not knowledgeable on ice related issues.

Recommendation to 27th ITTC

(b) The reduction of green house gases from ship (marine transportation) becomes more and more significant to cooperate the global warming problem. It is worthy to review the technologies (hydrodynamic issues) for enhancement of the powering performance, such as speed reduction, energy saving devices, hull form and propeller design, etc

(c) Monitor status of CFD to perform full scale powering, resistance, cavitation and wake simulations and their correlation with full scale data.

4.Scaling for propulsors

(a) Scaling effects of low Reynolds number preswirl vanes, wake-influencing ducts and boss-cap fins performance.

Recommendation to the Conference

- The Committee recommends the Conference to adopt the changes to the following procedures:
- *7.5-02-03-01.1 Propulsion Test*
- *7.5-02-03-01.2 Uncertainty Analysis Example for Propulsion Test*
- *7.5-02-03-01.4 1978 ITTC Performance Prediction Method*
- *7.5-02-03-02.2 Uncertainty Analysis, Example for Open Water Test*
- *7.5-02-03-02.4 Nominal Wake Measurement by a 5-Hole Pitot Tube*

- **REFERENCES**

Thanks