Technical Committee on Seakeeping

2017-2021

Chairman: Pepijn de Jong

Members: B. Bouscasse, F. Gerhardt, O.A. Hermundstad,
T. Katayama, C. Kent, M. Minoura, B.W. Nam, Y.L. Young

Committee Members

a) Benjamin Bouscasse, ECN, France

b) Frederick Gerhardt, SSPA, Sweden

c) Ole Andreas Hermundstad, SINTEF Ocean, Norway

d) Toru Katayama, Osaka Prefecture University, Japan

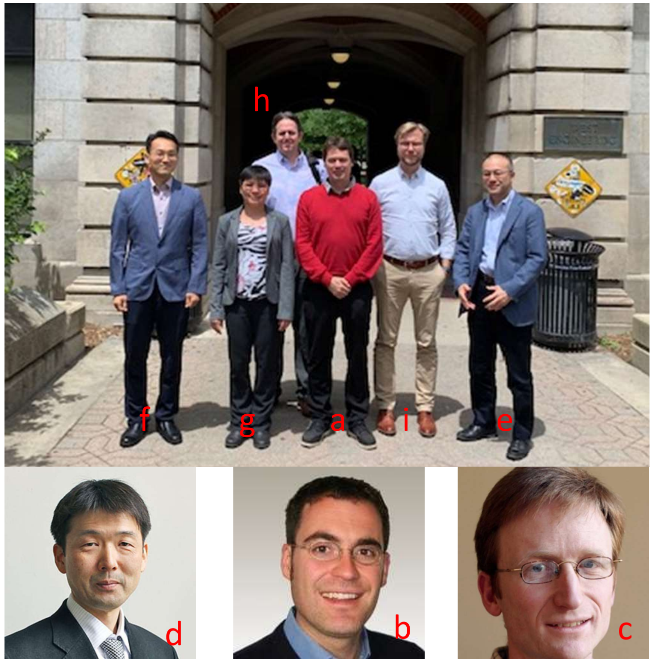
e) Munehiko Minoura, Osaka University, Japan

f) Bo-Woo Nam, Seoul National University, Korea

g) Yin Lu (Julie) Young, University of Michigan, USA

h) Christopher Kent (Secretary), NSSWC-DC, USA

i) Pepijn de Jong (Chairman), MARIN, The Netherlands



Meetings

- Committee Meetings
  - MARIN, Wageningen, Netherlands, January 2018
  - Osaka University, Osaka, Japan, December 2018
  - University of Michigan, Ann Arbor, USA, June 2019

- Video Tele Conferences
  - Following the onset of the COVID-10 Pandemic
  - Between February 2020 and April 2021
  - About 10 meetings of 1 to 2 hours each
  - Were an effective way to proceed the work of the committee
  - Face-to-face meetings before that made sure the committee members knew each other sufficiently well

Terms of Reference 29th Term

General

1. Update the State of Art review
2. Review and revise ITTC Procedures relevant for Seakeeping

12. Survey and/or collect benchmark data for ship structural hydroelasticity in waves and for added resistance in waves tests
13. Continue the collaboration with ISSC committees, including Loads and Responses and Environment Committees

Specific Procedures Updates

3. Update 7.5-02-07-02.5 *Verification and Validation of Linear and Weakly Non-linear Seakeeping Computer Codes* to include the verification and validation of ship hydroelasticity codes (link with ISSC)

8. Update 7.5-02-07-02.3 *Experiments on Rarely Occurring Events* to include the measurement and analysis of impulsive loads, peaks in pressures and accelerations

Terms of Reference 29th Term

Added Resistance

4. Update 7.5-02-07-02.1 Seakeeping Experiments
    1. Measurement of added resistance and uncertainty thereof
    2. Ensure consistency with 7.5-02-07-02.2 and 7.5-02-07-02.8
5. Update 7.5-02- 07-02.8 *Calculation of the weather factor f_w for decrease of ship speed in waves*
    1. To match the terminology in the EEDI guidelines
    2. Submit to MEPC 72 (Spring, 2018). Focus on large vessels, state limitation for small vessels
6. Expand Recommended Procedure 7.5-02- 07-02.8 *Calculation of the weather factor fw for decrease of ship speed in waves* to include the uncertainty associated with each method
7. Update 7.5-02-07-02.2 *Prediction of Power Increase in Irregular Waves from Model Tests* should be modified to make it more comprehensible for the wider community outside of the ITTC

Terms of Reference 29th Term

Model conditioning and (dynamic) stability

9. Liaise with SIW Committee on the updates to the guideline 7.5-02-07-04.3 *Prediction of the occurrence and magnitude of parametric rolling*
10. Develop a procedure for undertaking inclining tests at full scale include estimates of the measurement uncertainty. Liaise with the Stability in Waves Committee, as required
11. Develop a procedure for conditioning a model for seakeeping tests, e.g. CG position, GM, moments of inertia. Include in the procedure estimates for measurement uncertainty

Terms of Reference 29th Term

High Speed Marine Vehicles (HSMV)

14. Undertake a complete review of the procedures related to HSMV and update according to recent advances in testing techniques, in particular,
    1. Update the seakeeping related HSMV procedures:
        - 7.5-02-05-04 Seakeeping tests
        - 7.5-02-05-06 Structural loads
        - 7.5-02-05-07 Dynamic instability
    2. Develop a new procedure for motion control of HSMV during seakeeping tests.
    3. Use as a basis the reports of the various committees to undertake a review the state-of–the-art in seakeeping of HSMV

Terms of Reference: adaptations

- Very large scope of work
  - In consultation with AC/EC a number of adaptations were done

- Development of procedure for full scale inclining experiments
  - Was transferred to the Stability in Waves Committee
  - SKC wishes to express its gratitude to SIW and EC/AC

- Uncertainty of Added Resistance:
  - In a very broad sense, touching many procedures: experimental and numerical
  - Still lack of consensus of which method to prefer (in the context of EEDI and f_w)
  - Detailed discussion was included in the Final Report on experiments and numerical methods

- High Speed Marine Vehicles
  - New procedure on HSMV Control in model tests: added as discussion in the Final Report

Highlights

- 12 Procedures received updates, some of them extensive:
  - 7.5-02-07-02.1: model conditioning was added
  - 7.5-02-07-02.1/2/8: consistency was substantially improved
  - 7.5-02-07-02.5: V&V of hydroelastic codes was substantially extended
  - 7.5-02-07-02.8: submitted to MEPC 72 (spring of 2018)
- State-of-Art review
  - High Speed Marine Vehicles was included
- Two additional discussion sections were added to Final Report:
  - Uncertainty of added resistance in model experiments and in numerical predictions
  - HSMV Control Issues in model tests
- Collaboration:
  - ISSC: 4th ITTC-ISSC Joint Workshop, global loads procedure
  - Stability in Waves Committee correspondence, feedback and procedure reviews
- Benchmarking

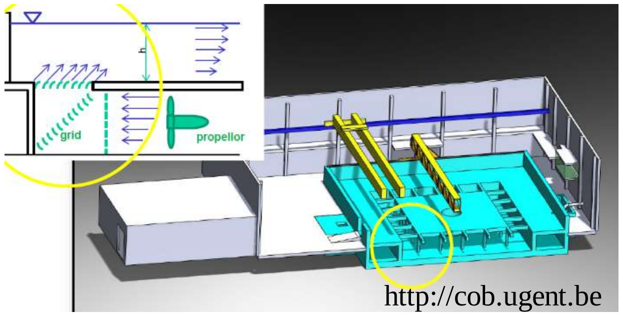
State of Art review

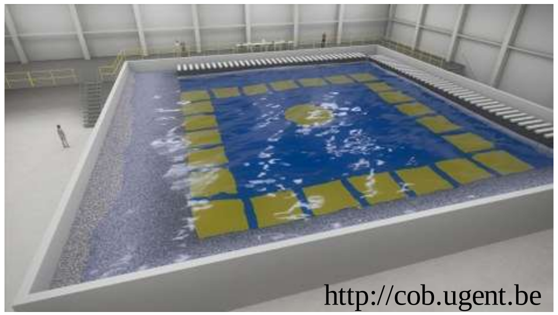
State of Art review

Key area	Members
New experimental facilities	**FG**
Experimental techniques (detailed flow measurements)	**FG**
Numerical methods/Potential flow methods (non-CFD) (FD and TD motions and loads)	**OAH** / BN
Rarely occurring events, slamming, green water, …	**PJ** / CK / OAH
Sloshing	**BN** / BB
Hydroelasticity	**JY** / OAH
Added resistance and power/speed	**MM** / JY
CFD applications	**BB** / BN
HSMV	**TK** / PJ

New Experimental Facilities

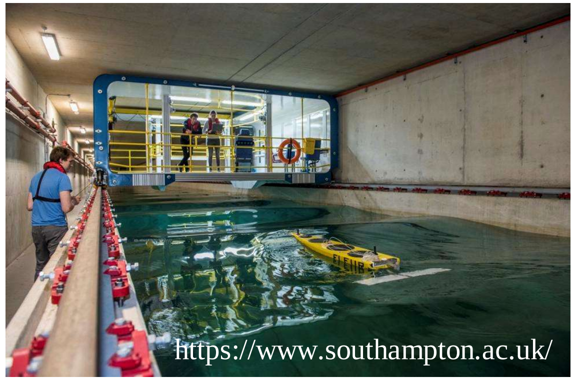
- Flanders Maritime Laboratory
  - Coastal and Ocean Basin 30x30x1.4/4.0m
    - Focused on waves/wind/currents on coastal defenses and blue energy applications
  - Shallow water Towing Tank 174x20x1m
    - Ship behavior in shallow and restricted waterways
  - Operational by 2021





New Experimental Facilities

- Korea Research Institute of Ships and Ocean Engineering (KRISO)
  - Deep Water Offshore Basin 100x50x15/50m (world biggest)
  - Generation of wind, waves and current
  - Successfully commissioned in 2020
- Technology Centre for Offshore and Marine Singapore (TCOMS)
  - Large deep water basin with a 50m put
  - Under construction, to be opened in 2021
- University of Southampton
  - New towing tank 138x6m
  - Straight and oblique waves up to 0.7m
  - Became operational in 2020
  - Sports engineering investigations reported



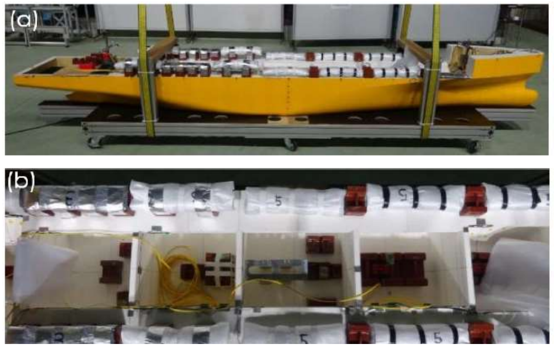
Experimental Techniques

- Measurement of added resistance
  - Accurate measurement is as challenging and important topic
  - Small difference between two large values
  - High demands for quality of experiments
  - Understanding of uncertainties is increasing (Park et al. 2019 for instance) and needs further attention

- Instrumentation:
  - Measurement quality of electrical resistance-type wave gauges (Tukker et al., 2019)
  - Pressure measurement
    - Zeraatgar et al. (2019) recommend sampling rates for impacts
    - Fukushima et al. (2019) use Fiber Bragg Grating based sensors to simultaneously measure the pressure at 146 points

Experimental Techniques

- Hydroelastic ship models:
  - 8th International Conference on Hydroelasticity in Marine Technology (2018)
  - Trend towards non-segmented models without backbone with correctly scaled stiffness
  - Made possible with careful model design and advanced building techniques

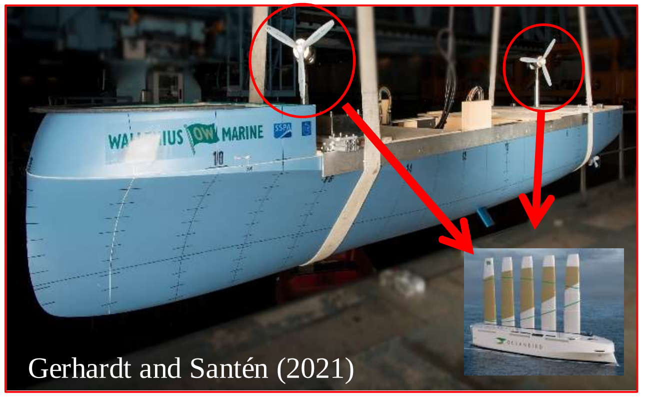


Houtani et al. (2018)

Experimental Techniques

- Seakeeping of Sail-Assisted ships
  - Emerging trend in the quest for more sustainable shipping
  - Several alternative methods are investigated:
    - “Wind Tunnel” under the towing carriage
    - Using ropes and winches to replicate sail forces
    - “Hybrid approach” by using RPM controller azimuthing wind fans
  - Need for developing guidance on how to perform such model tests


Eggers and Kisjes (2019)

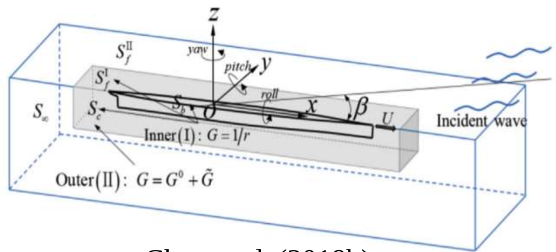


Gerhardt and Santén (2021)

Numerical Methods

- CFD (Navier-Stokes solvers) still not practical for routine seakeeping analyses
- Potential theory:
  - Boundary methods (BEM): still by far the most used: 2D (strip) and 3D
  - Field methods: interesting work on finite-different methods (Amini-Afshar and Bingham)

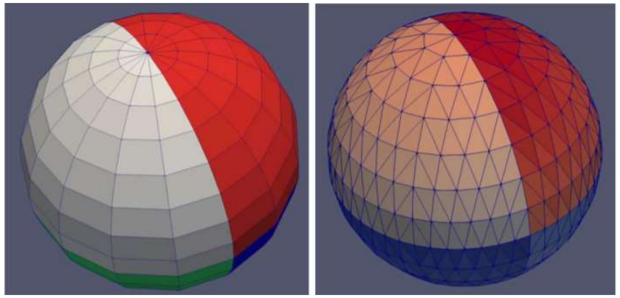
  - Green Function Methods (GFM)
    - Zero-speed GFM (pulsating source): Well established
    - Forward-speed GFM (translating-pulsating source): Complicated
  - Rankine Panel Methods (RPM)
    - Must also discretize the free surface
    - Easier to include forward speed effects and nonlinearities than GFM
  - Multi-domain (hybrid) methods
    - RPM in inner domain. GFM in outer domain
    - Gaining more popularity
  - Treatment of forward speed: uniform or double body, flat water or steady wave system



Chen et al. (2018b)

Numerical Methods

- Nonlinearities
  - Nonlinear Froude-Krylov and hydrostatics
    - Important for hull girder load effects, less for heave-pitch motions
- Acceleration techniques:
  - Sparsification of dense matrices (BEM)
    - Multipole expansion, pre-corrected FFT
  - Faster influence matrix computation:
    - De-singularisation and mixed order methods
  - Improved modelling techniques (Zangle et al. 2020)
    - E.g. triangular B-splines (Zangle et al. 2020)



Zangle et al. (2020)

- Not all studies conclude that the more complex methods compare better
- Trends:
    - Added resistance (higher order methods)
    - Coupled seakeeping and maneouvering: Time-domain simulations
    - More activity on CFD-methods than on high-fidelity potential/BEM methods

Rarely Occurring Events

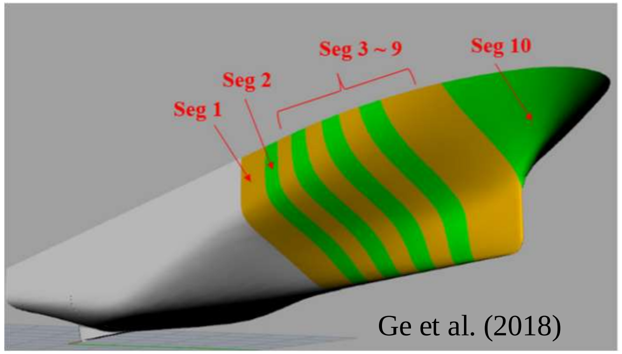
- Can be categorized into three aspects:
  1. Slamming of a ship (bow, bottom, stern) into the waves
  2. Green water events: water flowing onto the deck, possibly followed by impact
  3. Emergence events of propellers or other equipment (appendages, sonars), sometimes associated with ventilation

- Impact and green water very similar in approach (combination of ship motions and impact)

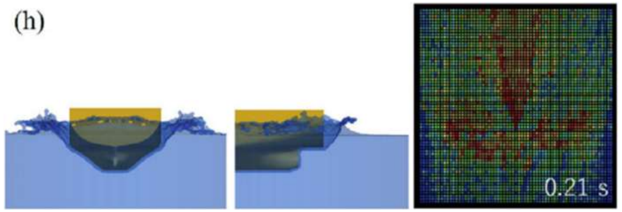
- Not included here:
  - Rarely occurring events associated with dynamic stability in waves: SIW committee
  - Impacts of high speed marine vehicles:
    - **Not rare** and included in HSMV topic
    - Still there is an overlap with 'normal' slamming

Rarely Occurring Events

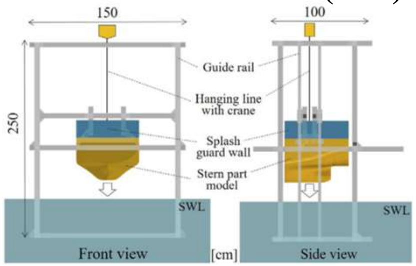
- Increased focus on oblique impact
  - Multiple sources report **larger** impact loads than in head seas
  - Highlights the need to carefully considering wave heading
- Some studies consider stern impact
- Most computational approaches employ multi-fidelity levels
  - Standard and efficient 2D and 3D potential flow methods:
    - Identify slam and/or green water events
    - Long duration time traces
  - Higher fidelity methods focusing on individual impacts (water entry problem/ dam break problem):
    - Shift from analytical/empirical 2D Wagner and Von Karman based approaches
    - Towards advanced CFD methods and SPH (2D and 3D)
    - Effect of compressibility and air-pockets are often included
    - In many cases combined with hydroelastic structural assessment



Ge et al. (2018)



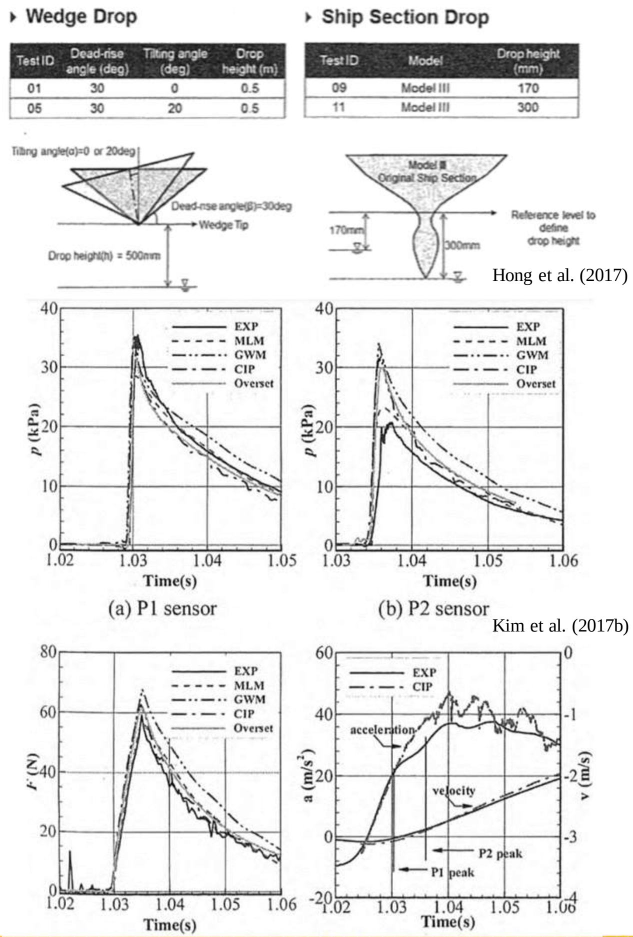
Mutsuda et al. (2018)



Rarely Occurring Events

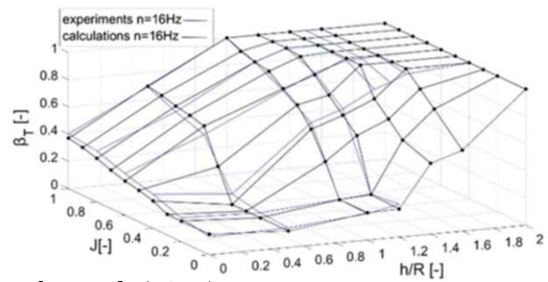
- With more advanced computational tools: increased focus on validation, especially on water entry
- ISOPE 2016: comparative study by IHC (Hong et al., 2017)
  - 13 Institutions participated, 20 different approaches:
    - BEM (Generalized Wagner or Modified Logvinovitch)
    - CFD based on FVM, FEM and FDM
    - Langrangian methods (SPH and MPS)
  - Four experimental cases: wedge and ship section

  - Overall CFD quite promising, but increased spread for:
    - Asymmetry and realistic ship section (air pockets)
  - CFD results very sensitive to grid generation and prone to human error
    - Highlights the need for proper grid convergence studies
    - Use of result filtering should be used with care and properly explained



Rarely Occurring Events

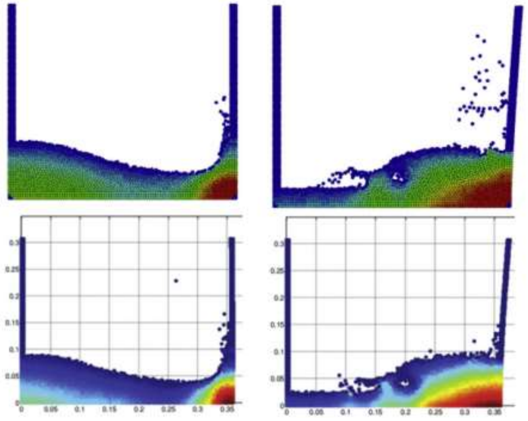
- Research on emergence mainly focused on the effects of ventilation on performance of propellers and lifting surfaces (foils, struts)
- Detailed experiments and CFD computations on to predict propeller and foil performance in different flow regimes
- Propeller ventilation important topic:
  - Leads to a significant reduction of thrust and torque
  - Large RPM variations to maintain trust or involuntary loss of speed and heading
  - This can have a direct impact on safe navigation in waves, keeping steerageway
  - Other consequences include:
    - hydro-elastic propeller loading and deformation

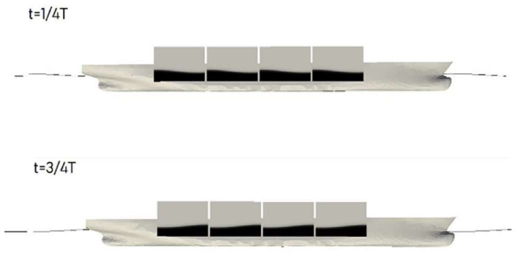


Kozlowska et al. (2017)

Sloshing

- Assessment of sloshing (impact) loads important issue in the design of LNG carriers (and FPSOs)
  - So far mostly based on model tests
  - Focus on considering the effect of gas-liquid density ratio and bubbles on sloshing impacts
- Large body of numerical research to study fluid-structure interaction inside sloshing tanks and the effect on ship motions
- To capture the highly nonlinear and complex phenomena new techniques based on machine learning from experiments are being investigated to predict sloshing load severity


Zhang et al. (2018)



Lyu et al. (2019)

Hydroelasticity

- Experimental and numerical results indicate the importance of flow-induced vibrations on the dynamic loads and stresses
  - Significant dynamic load amplification can occur near resonant conditions, accelerating fatigue
- Added mass, modal frequencies and damping change with operating conditions
  - Confined water, speed, wave heading, submergence/draft
  - These must be considered to avoid unexpected dynamic load amplification
- For large container vessels: 2-way coupling FSI models seem necessary
- Fully coupled CFD-FEM calculations of a vibrating vessel in waves is still not practical
  - Need to advance our understanding of hydroelastic effects
  - Model-scale experiments are challenged by scaling effects
  - Full-scale measurements are challenged by the ability to control the loads and motions
- More experiments are needed to validate the numerical solutions that are still in need of further improvement

Added Resistance and Power in Waves

- CFD has shown that the assumed quadratic relation added resistance with wave height is not satisfied in short steep waves
  - Effects of viscosity
  - Nonlinear interaction between fluid and hull shape (i.e. bow waterline intersection variations)

- Oblique wave conditions:
  - Before less researched (less suitable facilities), but nowadays more data available
  - Shows that added resistance in oblique waves can be **higher** than in head waves
  - Highlights the need to also for added resistance consider the heading
  - Viscous effects of more importance in oblique conditions (for instance roll damping, manoeuvring forces)
  - This makes CFD a promising tool to complement basin tests

Added Resistance and Power in Waves

- Added power in waves:
  - Scale effects found in added power coefficient due to
    - Reduction of advance coefficient at model scale
    - Relatively higher contribution of viscous effects
  - More understanding needed for hull-propeller-rudder interactions and scale effects

- Calculation methods:
  - CFD based prediction has become more reliable over the past few years
  - Potential flow codes often show under-estimation for the short-wave region and over-prediction at resonance
    - Rankine Panel Methods significant improvement over more traditional strip theory and panel methods
  - Semi-empirical prediction methods have evolved and cover a broader range of ship types and wave lengths
    - Useful when studying many design variations in relation to EEDI

CFD Applications in Seakeeping

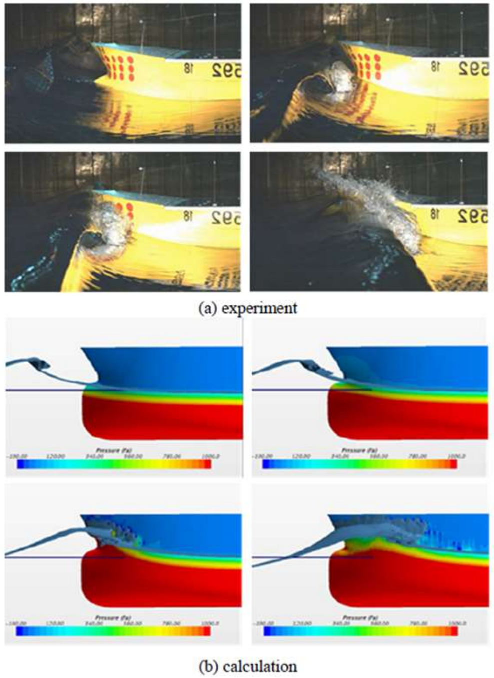
- CFD use keeps increasing
  - Over 50 publications identified by the committee (+ those in other sections)
  - Content mostly about engineering application of CFD
  - CFD solvers are both open source and commercial built on similar methodologies

- CFD Models
  - Most common:
    - Navier-Stokes equations + Turbulence model + Volume of Fluid
    - Finite Volume Method discretization, Implicit/semi-implicit solvers
  - Other formulations/methods/discretizations have competitive performances
  - Allow flexibility in imposing initial and boundary conditions
  - Natural treatment of nonlinear problems

CFD Applications in Seakeeping

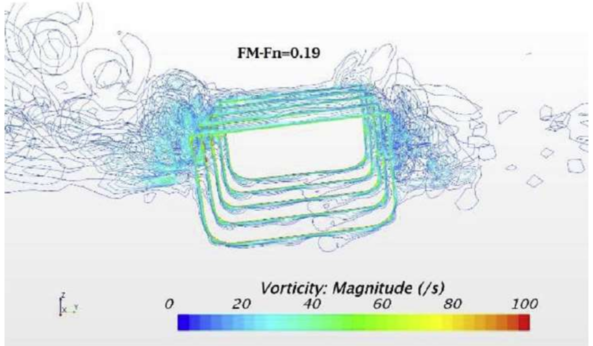
- Applications
  - Often at a crossover of traditional seakeeping applications
    - Added resistance and forces on semi captive models
    - Role of shape and appendages in performance
    - Self propulsion and manoeuvring in waves
    - Green water and extreme motions
    - Hydrodynamic coefficients and roll damping
    - Fluid-Structure interaction
- Objectives of studies
  - Verification and Validation
  - Estimation of added value with respect to alternative traditional solutions
  - Very nonlinear problems (steep waves, viscous effects, breaking waves, ...)
  - To evolve the design methodology and accommodate for the computational cost

CFD Appl.

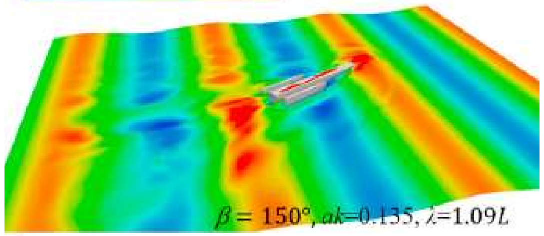


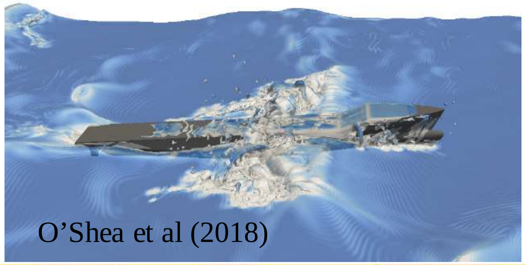
Hong et al (2019)

Kianejad et al (2019)

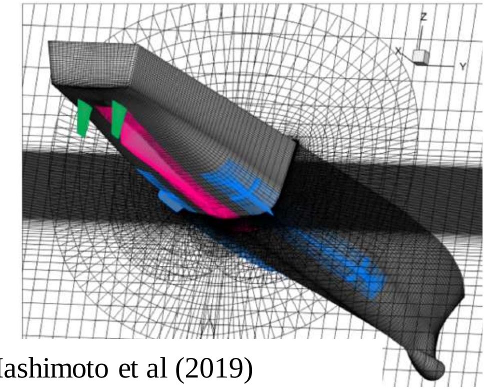


Gong et al (2019)

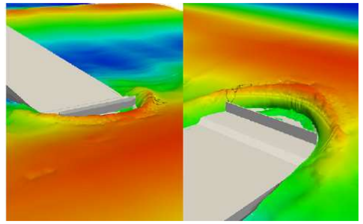




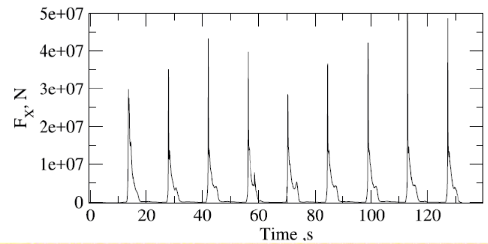
O'Shea et al (2018)



Hashimoto et al (2019)

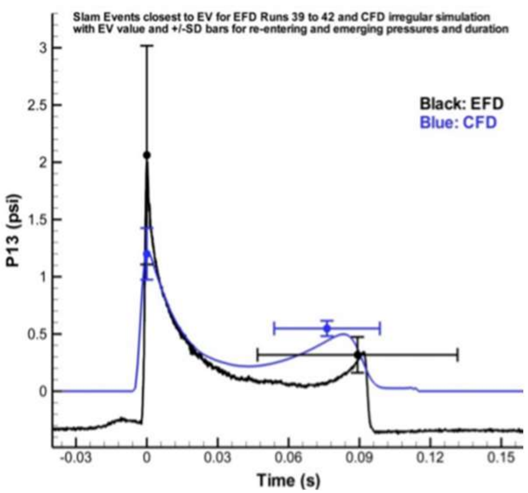


Gatin et al (2019)

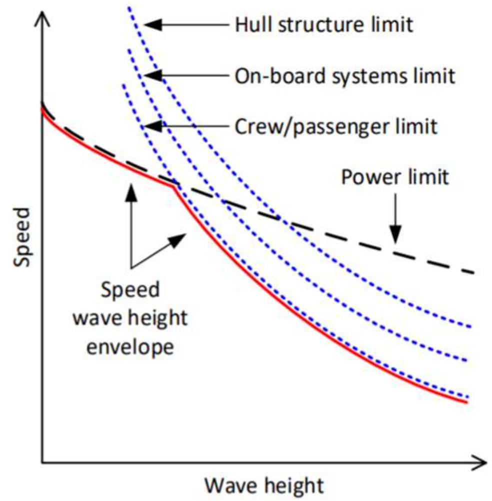


Seakeeping of High Speed Marine Vehicles

- Associated with very dynamic behaviour related to dynamic stability and slamming impacts
- High speed craft in waves are subjected to significant and frequent impacts with large effects not only on the structural integrity but also on human performance and human safety



Judge et al. (2020)

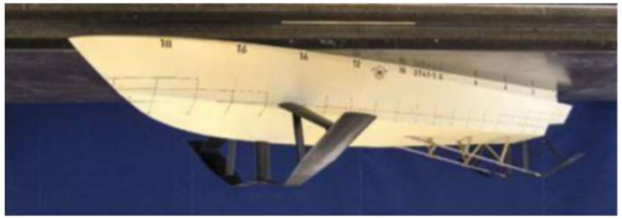


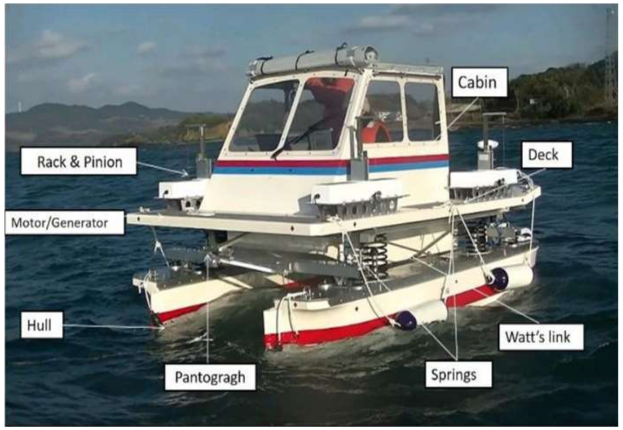
Rosen et al. (2018)

Seakeeping of High Speed Marine Vehicles

- Although research mostly focused on monohulls and multihulls, growing interest in hydrofoiling craft and foil assisted craft
- Ride control systems not only for improving passenger comfort but also used to actively reduce slamming

AlaviMehr et al. (2019)

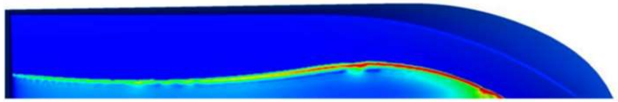

Morace and Ruggiero (2018)



Han et al. (2018)

Seakeeping of High Speed Marine Vehicles

- Calculation methods:
  - Traditionally based on 2D+t methods
  - Nonlinear panel methods have gained significant popularity
  - CFD is gained some ground, but hindered by computational burden for practical applications
  - Much effort in validating by means of model tests



Diez et al. (2020)

Bonci et al. (2017b)

- Semi-empirical methods used by class for assessment of vertical accelerations were scrutinized, raising important questions of the associated safety levels

Special Topics

Uncertainty of Added Resistance

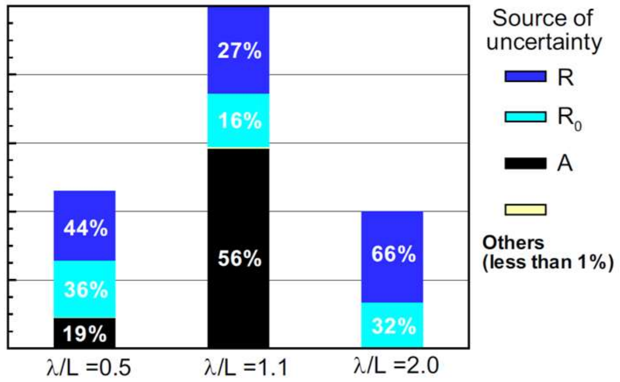
- Added Resistance in Waves key component in determining weather factor f_w in EEDI
- Current procedures leave open many options to determine added resistance:
- These fall roughly into two groups:
  - Model tests
  - Numerical calculations
- Within each group still multiple options exist, each with a different level of uncertainty

Uncertainty of Added Resistance – Model Tests

- Added resistance determined by subtraction of two 'large' values of two separate model tests:
  Total resistance in waves – Total resistance in calm water
- This is the main cause of uncertainty, as the total uncertainty is affected by:
  - The uncertainty of the two measurements each combined
  - 'Interpolation' error of the speed (are both measurements performed at the same speed?)
- Variability in the wave generation is a major factor affecting added resistance
  - Statistical variability of irregular waves and repeatability of wave generation
- Various choices can be made in the model tests:
  - Test setup (semi-captive versus soft-moored (or similar) versus free running)
  - Regular versus irregular waves
  - Capability to deal with various headings
- A balance is sought between realism in the representation of the vessel behavior and minimization of the uncertainty

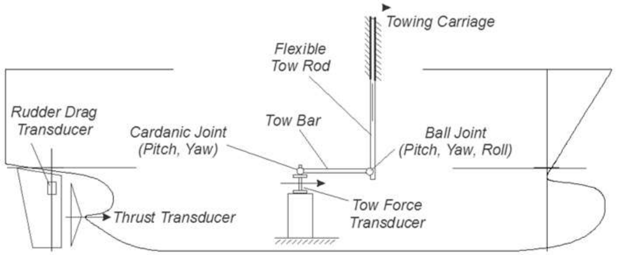
Uncertainty of Added Resistance – Model Tests

- Sources of uncertainty in model tests (Park et al. 2015):
  - Mainly subtraction of two large numbers
  - Also wave amplitude large effect on uncertainty



Park et al. (2015)

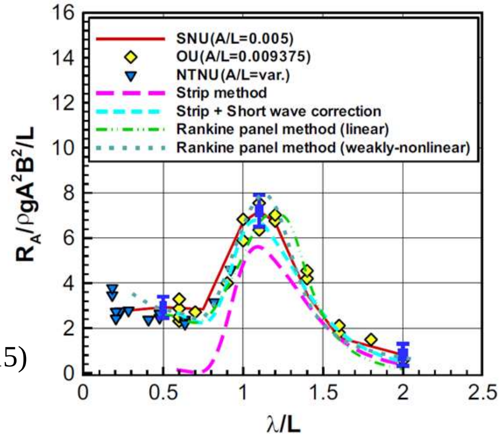
- Model tests setups:
  - Semi-captive
    - Measure total resistance on model fixed in surge
  - Soft-moored
    - Allow first order surge motions
  - Free running
    - Measure thrust
  - Hybrid:
    - Controlled speed, free motions



Crepier et al. (2018)

Uncertainty of Added Resistance - Numerical

- Various methods are in use, ranging from:
  - Empirical (correction) methods
  - Strip theory based potential flow
  - Panel method based potential flow
    - Green function methods
    - Rankine Panel Methods
  - CFD

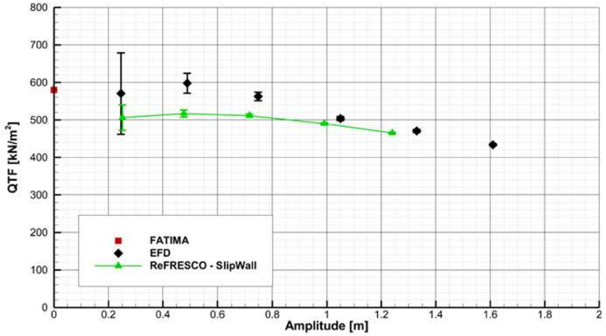


Park et al. (2015)

- Empirical methods are 'as good as what was put in'. As time progresses they cover more ship types and operational conditions and seem a reasonable approach in the early design stage
- The simpler potential flow methods (linear strip theory and green function methods) usually under-predict added resistance in short waves and over-predict at the peak
  - Often are combined with empirical short wave corrections\
  - This gives sometimes reasonable results, but not all the time: not very reliable

Uncertainty of Added Resistance

- At this moment, for modest sea states:
  - Rankine Panel Methods that account for steady flow interactions offer a reasonable balance between calculation time and accuracy
  - Provided that the quadratic assumption wave height – added resistance holds



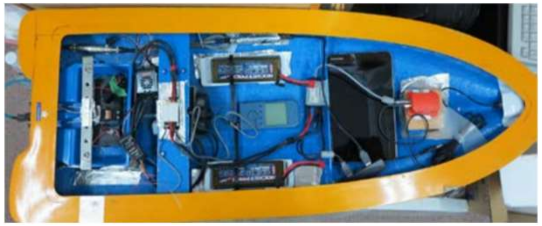
- For short and steep sea states and breaking waves:
  - Model experiments or complex CFD seem the best options to obtain reasonable predictions of added resistance

- Achieving sufficiently accurate predictions of added resistance requires careful attention to the details of the computations or experiments, as well as significant computational resources for CFD

Control of HSMV

- Model tests are often used for HSMV
- Froude's law of similarity:
  - Leads to small and light models
  - Can be difficult to build accurately (including weight and weight distribution)
  - New manufacturing techniques help (CRP, 3D printing)
- When model control is important:
  - Typically small scale self-propelled, self-steered models are needed (cable connections can affect boat motions, and/or carriage not able to reach sufficient high speeds in XY plane)
  - Made possible by new battery tech, and miniaturized computing devices
- Small scale also causes issues with control time delays becoming unacceptably large:
  - Undesired time delays and phase shifts in control actions

Van Walree and Thomas (2017)



Katayama et al. (2014)

Control of HSMV

- Reynolds scale effects on lift and drag need to carefully considered
  - Overloaded model scale propellers (Reynolds scale effect) may affect steering loads in the slipstream
  - Lift generation of appendages can be affected as well
    - Careful turbulence stimulation important
    - Consider the local Reynolds number of each foil (at least 5 to $7.5*10^5$ recommended by some authors)
    - Consider using adapted foil sections at model scale to correct lift: higher lift sections can be used as cavitation is no limitation at model scale
    - Mainly steady flow affect, not apparent in unsteady part of the lift (i.e. shift of lift curve slope)
- Scale affects related to surface tension, spray formation and ventilation may need to be considered
- Fluid-structure interactions of lifting surfaces may required also dynamic similitude (especially for hydro-foils and foil assisted ships, and applying modern flexible materials at full scale (CRP)

Benchmarking

A standardized problem or test that serves as a basis for evaluation or comparison

- The 19th SKC has performed additional work on benchmarking
- Definitions and criteria were retrieved from 25th ITTC Report:
  - Verification of experimental procedures
  - Validation of numerical methods
  - Reproducible, both numerically and experimentally
    - Ship/model condition (hull form, model scale, weight (distribution), hydrostatics,.)
    - Sailing conditions (speed and heading)
    - Wave conditions (wave amplitude, wave period, spectrum, spreading,…)
    - Test details (arrangement, control, run duration, facility parameters,…)
  - Data should be fit for the intended purpose
  - Should include uncertainty assessment
- A review was made of all benchmarks suggested in Seakeeping related ITTC procedures
- CFD seems to require more detailed experimental flow data

Benchmark

Overview table (included as appendix)

		Benchmark set-up and information						Quantity benchmarked							Mentioned in					Criteria				
Origin	Comments	Model	Froude conditions	Wave direction	Wave conditions	Description	Litterature	Motions	Loads	Added Res/ Added thrust	Added Mass/Damping Exc forces	Bending Moment	Green Water	Slamming	Seak Exp 021	Power Increase in IW 022	Rarely Occuring Events 023	Sloshing 026	fw factor 028	Ship/model Condition	Ship speed/heading	Waves	Arrangement	Presentation of data
		Wigley					Journée (1992)																	
75-02-07-021 (Seak Exp)	Very important step but Large disappointment in conclusion and discussions, candidate for removal	S60 Cb=0.6	Fr = 0, 0.18 ,0.21 ,0.24 ,0.27 and 0.30		Lpp/H = 36, 48, 60, 72 ; Lambda / Lpp = 0.75, 1.0, 1.25, 1.5 pp	Seagoing Quality of Ships. . A model of the Todd-Forest Series 60 with *C* B=0.60. Results from 7 tanks are presented.	7th ITTC, 1955, pp.247-293	x							x									
Other	Wave cuts for model in circulating channel comparison with Gerritsma	S60 (Cb=0.6 and 0.8)					Maury et al (2003)																	
75-02-07-021 (Seak Exp)		Series 60 with Cb=0.60 and Cb 0.7	Fr =0, 0.1 0.17, 0.2, 0.25	also oblique		Comparative Tests of a Ship Model in Regular Waves (several studies)	11th ITTC, 1966, pp.411-426	x		x					x									
75-02-07-021 (Seak Exp)	Not particularly interesting in 2019 perhaps, candidate for removal	Fibre-glass model of the S.S. Cairndhu			RW, IW, TW	Experiments on a ship model in waves using different test techniques. Also prediction by K. Kroukovsky's theory calculating added mass and damping coefficients by Grim.	(11th ITTC, 1966, pp.332-342)				x				x									
75-02-07-021 (Seak Exp)		Destroyer H.M. "Groningen"	Fr = 0.15, 0.25, 0.35, 0.45, 0.55		L/lambda= 0.5, 0.555,0.625, 0.714, 0.833,1,1.25, 1.67, 2 (H/L=1/40)	Full Scale Destroyer Motion Tests in Head Seas Comparison among motion response obtained from full scale tests, model experiments and computer calculations	11th ITTC, 1966, pp.342-350	x							x									
75-02-07-021 (Seak Exp)		S-175	Fr = 0.275	some oblique	RW	Analysis of the S-175 Comparative Study	17th ITTC, 1984, pp.503-511					x			x									
75-02-07-021 (Seak Exp)		S-175	Fr =0.275		RW IW	Comparison of results from tests at 12 establishments in irregular waves. Absolute and relative motions	18th ITTC, 1987, pp.415-427	x		x					x									
75-02-07-023 (Rarely Occuring Event)		S-175	Fr = 0.275		IW (ITTC Hs=7.9m, T0 = 14.8)	Rare Events	19th ITTC 1990, pp.434-442	x					x				x							
75-02-07-023 (Rarely Occuring Event)		S-175					Hamoudi et al (1998)						x				x							
75-02-07-021 (Seak Exp)		S-175				The ITTC Database of Seakeeping Experiments	20th ITTC,1993, pp.449-453								x									
[illegible]		[illegible]				[illegible]	[illegible]																	

Benchmarking

- Observations and Conclusions
  - 25th ITTC definitions and criteria still relevant
  - CFD methods might require improvements due to inherently more detailed flow information
  - Classification per hull form instead of by experiment may be more useful
  - Proposed path forward:
    - Review criteria
    - Review quantities that are included
    - Add missing benchmarks
    - Fill benchmarking table
    - Decision on obsolete benchmarks
    - Propose new distribution of benchmarks on procedures and websites

Procedures

Procedure 7.2-02-07-02.1

Seakeeping Experiments

- ToR #4: extend to include measurement of added resistance (and uncertainty thereof)
- ToR #4: maintain consistency with 7.2-02-07-02.2 and 7.2-02-07-02.8
- ToR #11: develop procedure for model conditioning for seakeeping tests
- Updates (substantial):
  1. Section on added resistance model tests was moved from 7.5-02-07-02.2 to this procedure and extended
  2. All three procedures (1, 2 and 8) have been checked for consistency and formulations for wave energy density spectra have been brought in-line with 7.5-02-07-01
  3. Recommendations for model conditioning have been added, including a new section on the ballasting procedure
  4. Recommendations for pre-simulations for selection of test conditions have been added
  5. Measurement of global wave loads brought in-line with 7.5-02-07-02.6
  6. Remarks on wave generation and measurement have been added

Procedure 7.2-02-07-02.2

Prediction of Power Increase in Irregular Waves from Model Tests

- ToR #7: make more comprehensible for wider audience outside of ITTC
- ToR #4: maintain consistency with 7.2-02-07-02.1 and 7.2-02-07-02.8
- Updates (substantial):
  1. Section on added resistance model tests was moved to 7.5-02-07-02.1 and referred to from this procedure
  2. All three procedures (1, 2 and 8) have been checked for consistency and formulations for wave energy density spectra have been brought in-line with 7.5-02-07-01
  3. Updates were done to clarify this procedure for a wider audience and maintain consistency with the ITTC Symbols list
  4. An error was fixed in the formula to compute added power (HP versus Watt)

Procedure 7.2-02-07-02.3

Experiments on Rarely Occurring Events

- ToR #8: include measurement and analysis of impulsive loads and max. accelerations
- Updates:
  1. Details were added on the measurement and recording of impacts and green water events
     1. Effect of air-pocket on the impact loads
     2. References to useful background literature were added that contain further details
     3. Suggestions were included to properly document the means used to record impact pressures
  2. Corrections were made to inconsistent suggestions of run duration
  3. Outdated usage of 'wets per ship model length' for wetting event occurrence rate was removed

Procedure 7.2-02.07.02.5

V&V of Linear and Weakly Nonlinear Seakeeping Computer Codes

- ToR #3: Include V&V of hydroelasticity codes in response to comments from ISSC
- Updates (substantial):
  1. This procedure was revised substantially to minimize redundancies and to use consistent terminology
  2. Improvements were made to the language used to improve clarity and readability
  3. Procedure focuses on potential flow theory, in the future possibly new procedure for V&V of CFD
  4. The section on hydroelastic codes was substantially improved by joint ISSC/ITTC SKC members
  5. Remarks on appropriate verification and validation procedures were introduced in the procedure

Procedure 7.2-02.07.02.6

Global Loads Seakeeping Procedure

- ToR: no specific ToR related to this procedure
- Updates:
  1. Minor editorial revisions to improve readability
  2. More details were added on the usage of elastic segmented models
     1. Internal rigid structures with instrumented elastic joints
     2. Offer advantages in tuning for specific natural periods of two-node bending modes
     3. Important for slamming induced whipping responses

Procedure 7.2-02.07.02.7

Sloshing Model Tests

- ToR: no specific ToR related to this procedure
- Updates:
  1. Procedure was newly introduced during previous ITTC term
  2. Minor updates:
     1. A remark on thermal shock issues of pressure transducers was added
     2. Language revisions
     3. Updated figure for improved readability

Procedure 7.2-02-07-02.8

Calc. of the Weather Factor f_w for Decr. of Ship Speed in Wind and Waves

- ToR #4: maintain consistency with 7.2-02-07-02.1 and 7.2-02-07-02.2
- ToR #5: bring in line with EEDI to submit to MEPC 72 (2018), large vs smaller ships
- ToR #6: include uncertainty associated with each method
- Updates 1 for MEPC 72:
  1. Based on discussion during the 38th ITTC Full Conference
  2. Statement on applicability for large vessels, need for additional work for smaller ships and indication of this size limit was added (about 150m length)
  3. Substantial updates to terminology and symbols to be consistent with EEDI guidelines
  4. References to benchmarks were added
- Updates 2:
  1. Minor additional revisions aimed at maintaining consistency with 7.5-02-07-02.1 and 7.5-02-07-02.2
  2. A discussion on uncertainty of the various methods was added to the Final Report

Procedure 7.5-02-05-04

HSMV Seakeeping Tests

- ToR #14: undertake complete review of the HSMV seakeeping procedures and update according to recent advances
- ToR #14: develop a new procedure for motion control of HSMV
- Updates:
    1. Most mature procedure of the three HSMV procedures
    2. Substantial revisions done to modernize the procedure:
        1. Model construction, materials used and manufacturing tolerances
        2. Removal of outdated sections on run duration based on linear wave statistics
        3. Removal of side-by-side comparison testing
        4. Removal of superfluous discussion on details of specific wave and motion measurement systems
        5. Removal of recommendations on the use of linear RAOs
- A discussion on motion control issues of high speed craft has been added to the Final Report

Procedure 7.5-02-05-06

HSMV Structural Loads

- ToR #14: undertake complete review of the HSMV seakeeping procedures and update according to recent advances
- Updates:
  1. This procedure was found to be of a lower level of maturity
  2. The purpose of the procedure was updated and better clarified
  3. Language and references were improved
  4. The updates were done with a focus on the link with the related procedure 7.5-02-07.6 for non-HSMV
  5. The unrealistically high recommended sampling rate of 100kHz for impacts was reduced to 10-20kHz
  6. The section on the parameters to be taken into account was expanded

Procedure 7.5-02-05-07

HSMV Dynamic Instability Tests

- ToR #14: undertake complete review of the HSMV seakeeping procedures and update according to recent advances
- Updates:
  1. This procedure was reviewed and found to be inadequate
  2. The introduction and stated purpose were found to be not appropriate
  3. Dynamic instability behaviour types should be more adequately defined and consistently treated
  4. The procedure is not clear on whether it treats with instability in calm water or in waves, or both
  5. The descriptions on the experiments to be performed were found to be inconsistent and to only cover planing monohulls

- Due to the high workload of the SKC activity on this procedure deferred to a future committee, preferably a SC on HSMV
- In the meantime the procedure should be **withdrawn** from the ITTC Recommended Procedures

Recommendations and Future Work

Recommendations

- Adopt the updated procedures:
  - 7.5-02-07-02.1 Seakeeping Experiments
  - 7.5-02-07-02.2 Prediction of Power Increase in Irregular Waves from Model Tests
  - 7.5-02-07-02.3 Experiments on Rarely Occurring Events
  - 7.5-02-07-02.5 Verification and Validation of Linear and Weakly Non-linear Seakeeping Computer Codes
  - 7.5-02-07-02.6 Global Loads Seakeeping Procedure
  - 7.5-02-07-02.7 Sloshing Model Tests
  - 7.5-02-07-02.8 Calc. of the Weather Factor fw for Decr. of Ship Speed in Wind and Waves
  - 7.5-02-05-04 HSMV Seakeeping Tests
  - 7.5-02-05-06 HSMV Structural Loads
- Withdraw 7.5-02-05-07 HSMV Dynamic Instability Tests from the ITTC Recommended Procedures pending complete revision by a possible future Specialist Committee

Proposals for Future Work

- Verification and Validation for CFD Seakeeping Applications
  - CFD (including mesh free methods) methods are becoming more and more commonplace for seakeeping problems
  - Clear need for guidance on verification and validation for seakeeping applications
  - New procedure? (next to the existing 7.5-02-07-02.5)

- Weather Factor for Small ships (< ~150m)
  - Current procedure specifies 'representative wave conditions' that are not suitable
  - 'Voluntary speed reduction' to avoid excessive motions and loads: effect on f_w
  - Further work is needed to understand and quantify this issue further
  - Option could be to suggest reduced wave environments (e.g. IMO Minimum Power Requirements)

Proposals for Future Work

- HSMV
  - Need for updated procedure on HSMV Dynamic Instability tests
  - Comprehensive review and revision of all related procedures for HSMV
    - Seakeeping, manoeuvring, dynamic stability and powering
  - Draft a procedure for motion control of HSMV during model tests based on Section 3.3 of the 29th SKC
  - Specialist Committee on HSMV?

- Seakeeping Benchmark Campaign
  - A new benchmark experimental campaign is highly recommend with a focus on the characterization of the uncertainty in the measurement of added resistance
  - Candidate vessels include KCS and KVLCC2
  - Careful definition of test requirements and recording of test conditions
  - Circulation of model over facilities
  - Important aspect in the f_w discussion

Proposals for Future Work

- Real-Time On-Board Data Processing
  - Identify the need for ITTC recommendations for the acquisition and analysis in real-time of data, for instance obtained on board of autonomous systems

- Wind Resistance
  - Accurate and consistent determination of both f_w and minimum power require realistic determination of the wind resistance
  - Wind resistance not at same level of detail as added wave resistance
  - Need seems to be widely spread over multiple committees, not only related to EEDI issues:
    - Effect of wind loads on manoeuvres and dynamic stability, calm water resistance and wind loads on offshore structures

Proposals for Future Work

- Seakeeping Assessment of Wind Assisted Ships
  - Develop guidelines for model tests with wind assisted ships
  - This particular application has gained significant attention
  - There seems a wide variety in approaches by various institutes
  - Valuable to bring together these experiences in a single comprehensive guideline

Thank You!