The Specialist Committee on Manoeuvring in Waves

2017-2021

Chairman : H. Yasukawa (Hiroshima University)
Members : M. Tello Ruíz (HSVA, formerly: Ghent University and Flanders Research Hydraulics)
E. Milanov (BSHC)
Y.-J. Sung (Hyundai Heavy Industries)
Y. Kim (KIOST)
X. Gu (Shanghai Jiao Tong University)
W. Duan (Harbin Engineering University)
M. Steinwand (SVA Potsdam, left in 2019)

1. INTRODUCTION
Meeting

1. BSHC, Varna, Bulgaria, February 2018
2. Shanghai Jiao Tong University, China, October 2018
3. Ghent University and Flanders Research Hydraulics, Antwerp, Belgium, May 2019
4. Hiroshima University, Japan, January 2020

1. INTRODUCTION
Tasks (1)

1. Define the overall framework for what manoeuvring in waves means. (*section 2*)
2. Present the state of the art based on a comprehensive literature review. (*section 3*)
3. Create a guideline for benchmark tests on manoeuvring in waves. Consideration should be given to the generation of data for the validation of numerical tools. (*Publication of the new guideline was postponed*)
4. Investigate the methodology needed to combine experimental tests and numerical tools. (*section 3*)
5. Investigate new manoeuvres to assess minimum power requirements (e.g. return to head waves). (*section 4*)

1. INTRODUCTION
Tasks (2)

6. Address the issues brought about from IMO-MEPC71 and following meetings concerning the minimum power requirements, including issues on manoeuvrability under adverse weather. (*section 4*)
7. Validate the Level 2 – Simplified Assessment Method of the 2013 Interim Guidelines (MEPC.1/Circ.850). (*section 4*)
8. Liaise with IMO and/or IACS to address manoeuvring in waves. (*section 5*)
9. Liaise with the Manoeuvring Committee, the Seakeeping Committee and the Stability in Waves committee. (*section 5*)
10. Establish a mathematical model for manoeuvring in waves. (*section 3*)

Originally, we planned to add the results of the SIMMAN workshop, but we did not mention it because it was postponed due to the influence of the Corona-virus.

2.1 Overview on the Ship Maneuvering in Waves

State-of-the-Art Update

- New free-running model tests in regular & irregular waves - benchmark data
- New captive model test for measuring wave drift force and yaw moment
- Further development of numerical methods for predicting the ship maneuverability in waves
- Investigations on ship sailing performance in combined wave & wind action
- New studies on shallow water maneuvering in waves
- Investigations on additional aspects of maneuvering in adverse conditions
- Studies on criteria and standard indices, related to the maneuvering in waves

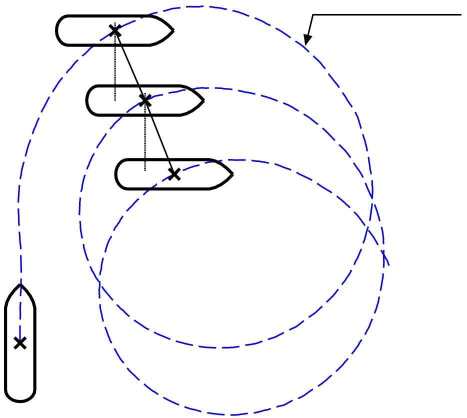
2.2 Indices Representing Maneuvering in Waves (1)

	straight moving	small/medium rudder angle	large rudder angle
calm water	propulsive peformance	10/10 or 20/20 zig-zag maneuvers	35deg turning
waves	steady sailing performace		
indices in waves	check helm, drift angle, speed drop, etc.	overshoot angles	advance, tactical dia., drifting distance, drifting direction

2.2 Indices Representing Maneuvering in Waves (2)

Turning motion in waves

- Trajectory distortion indices (Ueno, 2003)



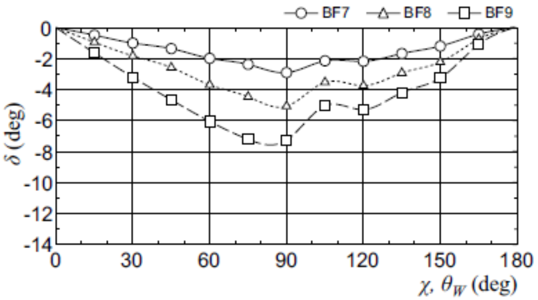
Drifting distance H_D

Drifting direction (angle) μ_D

2.2 Indices Representing Maneuvering in Waves (3)

Steady sailing performance

- Check helms values to maintain course within defined limits



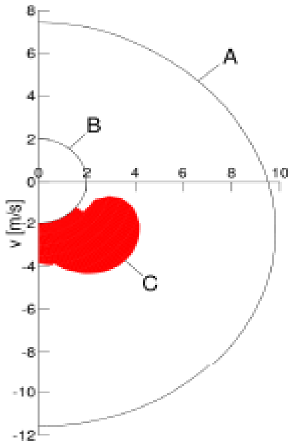
- Directional stability, analytical criteria based on characteristic equation coefficients of linearized yaw motion ODE's

$$\boxed{Re(z) < 0}$$

2.2 Indices Representing Maneuvering in Waves (4)

Criteria, related to the EEDI requirements

□ SHOPERA procedure of course-keeping ability assessment - converged solution of coupled ODE system (Shigunov and Papanikolaou 2015)



A - power $P = P_{AV}$

B - speed

C - rudder critical area

3. STATE-OF-THE ART OF PREDICTION METHODS OF SHIP MANOEUVRING IN WAVE

3.1 Experimental Methods

3.2 Numerical methods

3.3 Steady Sailing Performance and Manoeuvring Limit in Wind and Waves

3.4 Wave Effect on Ship Manoeuvring in Shallow Water

3.5 Additional Aspect of Manoeuvring Simulation in Waves

3.1 Experimental Methods summary

3.1.1 Free running tests in waves

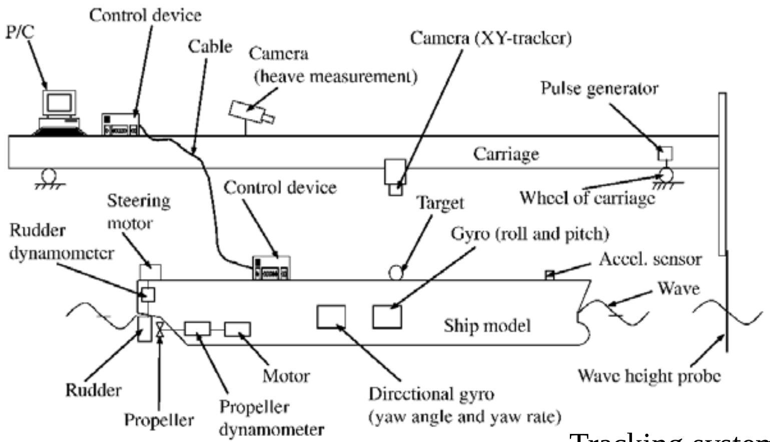
- General : Measurement system, Free running test equipment
- Free running test results in regular waves : Many papers and results
- Free running test results in irregular waves : Some papers and results about KVLCC2 and KCS
- Free running test results in wind and waves: Limited papers and results

3.1.2 Captive model tests in waves

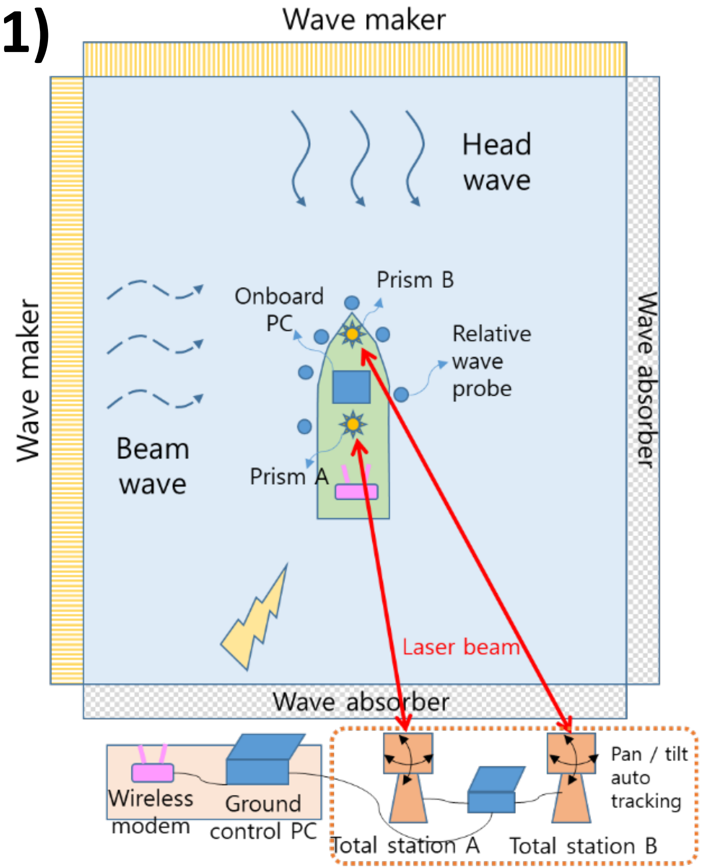
- General : Static straight test, Oblique test, Steady circular motion test
- Ship motions and measured forces in waves : Oblique test results
- Mean wave drift forces : Steady circular motion test results

3.1.1 Free running tests in waves (1)

- In 1980 Hirano carried out free running tests in waves.
- Since 2000 many papers and results have been published.
  - Ueno 2003, Yasukawa 2009 2015, Sanada 2013, Kim 2019, Hasnan 2020 etc.
- Tracking system and total station system for position measurement

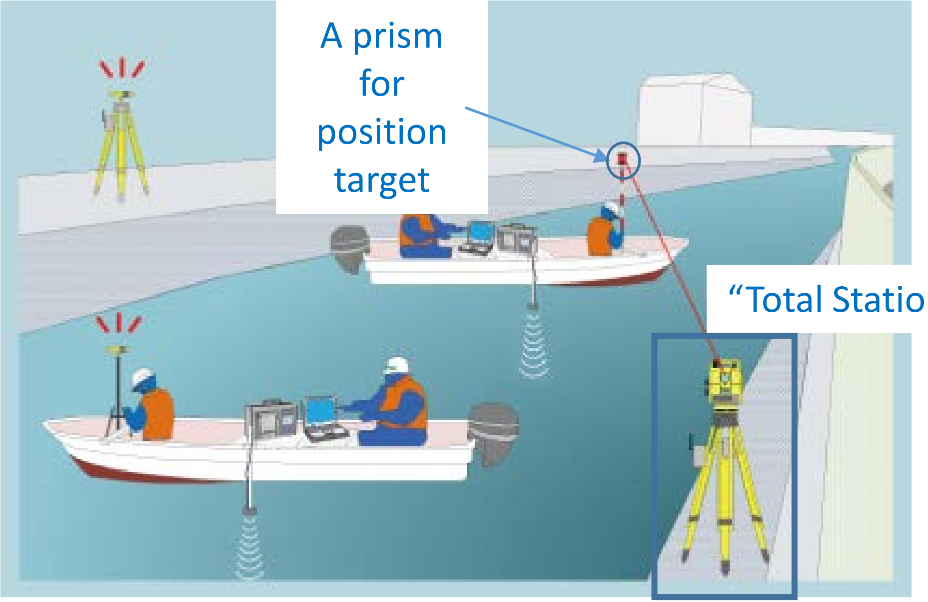


Tracking system (Yasukawa 2009)



Total station system (Kim 2019)

Total Station system
for 3D position measurement in the tests

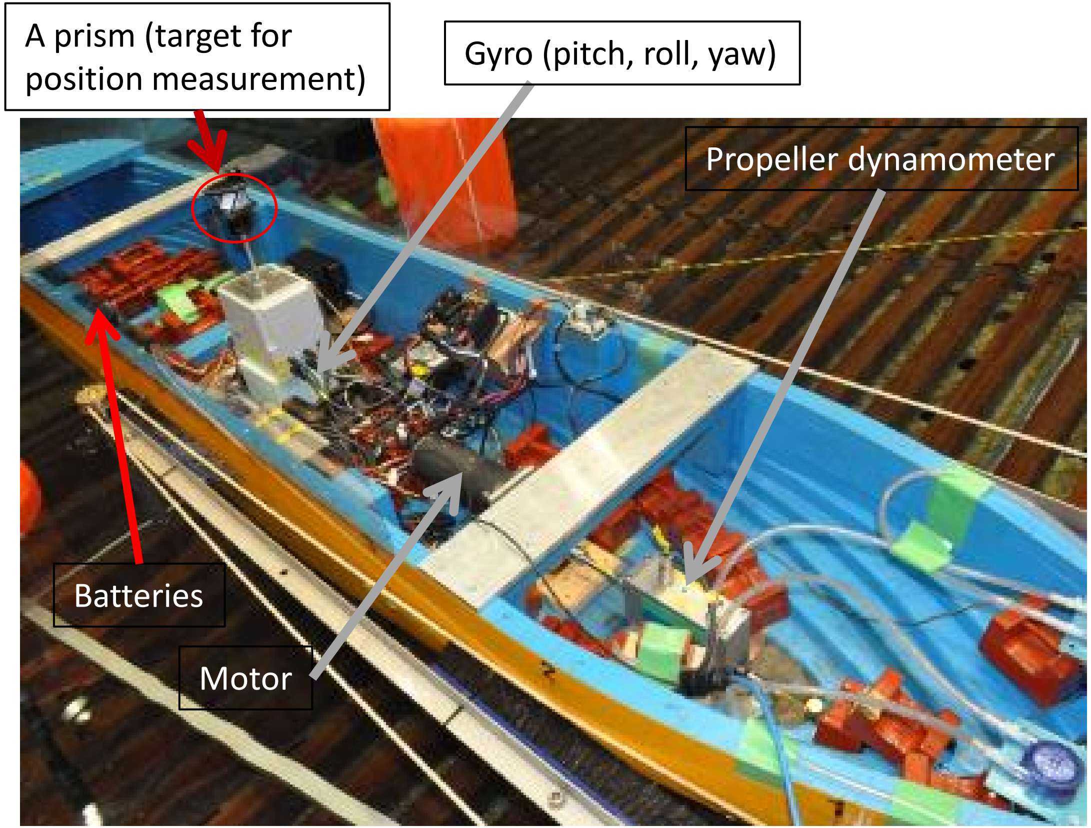


http://tamaya-technics.com/measure/

- Originally, the Total Station system comes from civil engineering field.
- The Total Station can truck the ship model automatically from the square tank side.

A camera in "Total Station"

A fully free-running model



- 3D position of a prism equipped to the ship model is measured by **Total Station**.

3.1.1 Free running tests in waves (2)

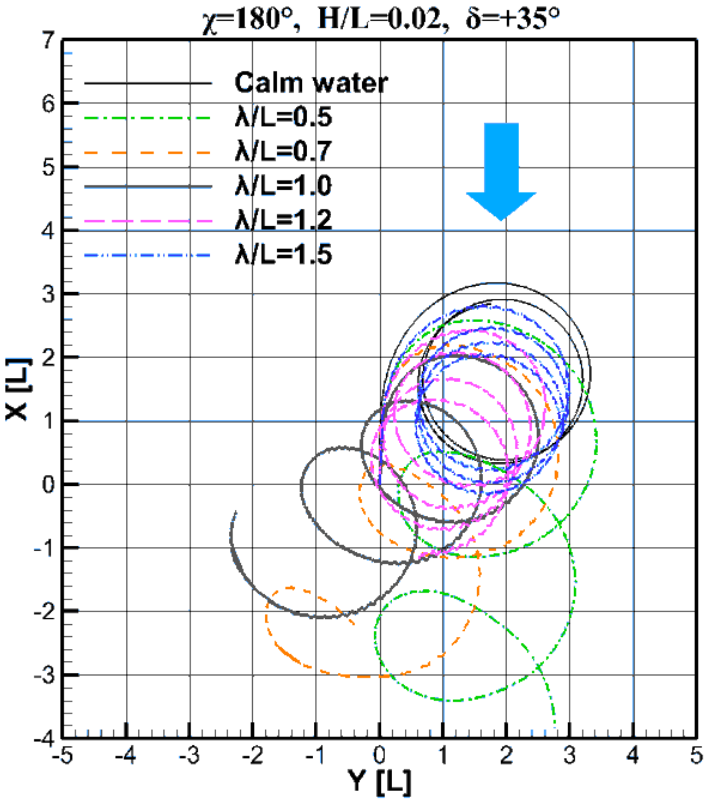
- Free running test results in regular waves
  - Ro-Ro(Hirano 1980), VLCC(Ueno 2003, Lee 2009), S-175(Yasukawa 2006, 2008, 2009), ONR-T(Sanada 2018), DTC(Sprenger 2017), KVLCC2(Sprenger 2017, Kim 2019)
- Free running test results in irregular waves
  - KVLCC2(Yasukawa 2015), KVLCC2 in slow speed(Kim 2019), KVLCC2 & KCS(Hasnan 2020)
- Free running test results in wind and waves
  - Large container ship in heavy wind and regular waves(Fujiwara 2008)

3.1.1 Free running tests in waves (3)

Generally, the ship drifts in a direction different from the wave direction during turning.

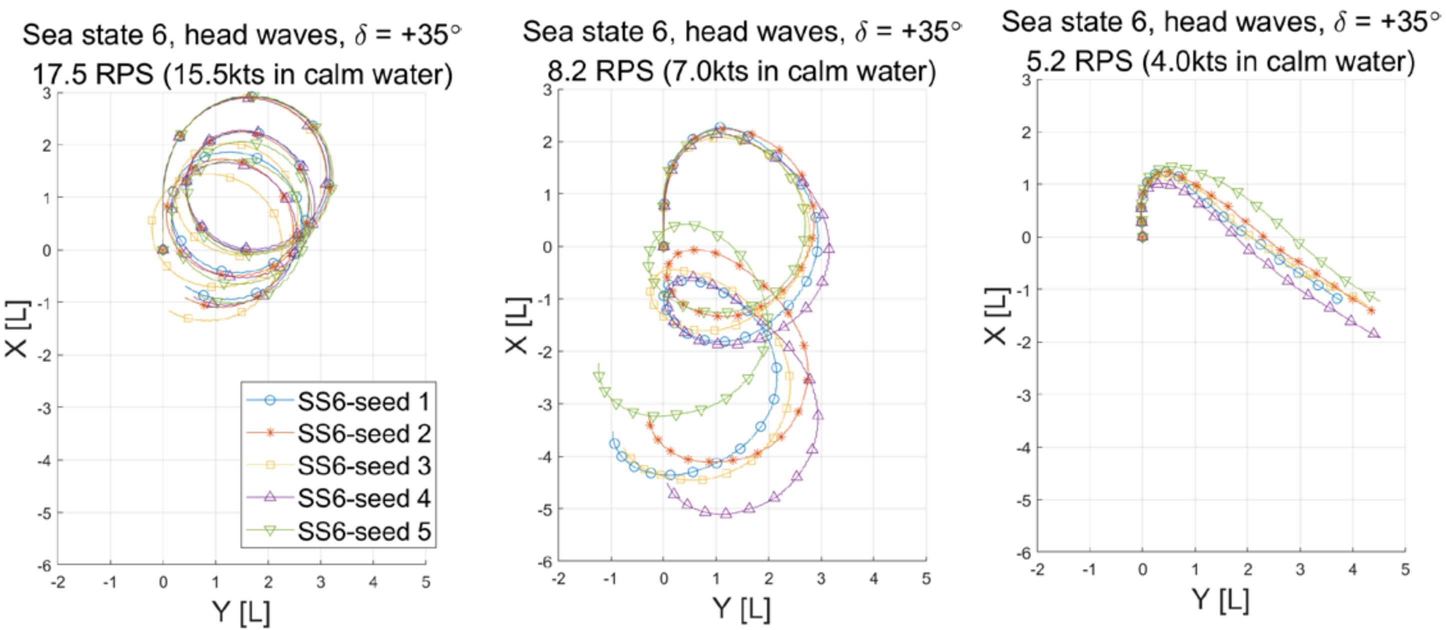
The direction of the drift differs depending on the wavelength-ship length ratio (λ/L).

The ship significantly drifts in shorter wavelengths.



Turning trajectories for KVLCC2 in regular waves (Kim 2019)

3.1.1 Free running tests in waves (4)

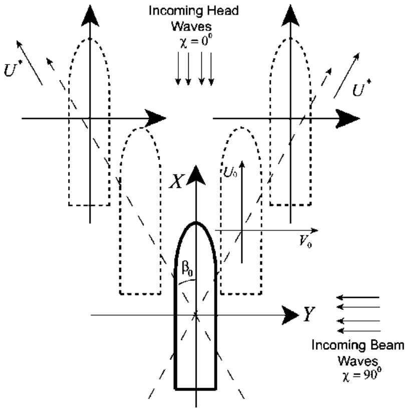


Effect of approach speed on turning trajectories for KVLCC2 in irregular waves (Kim 2019)

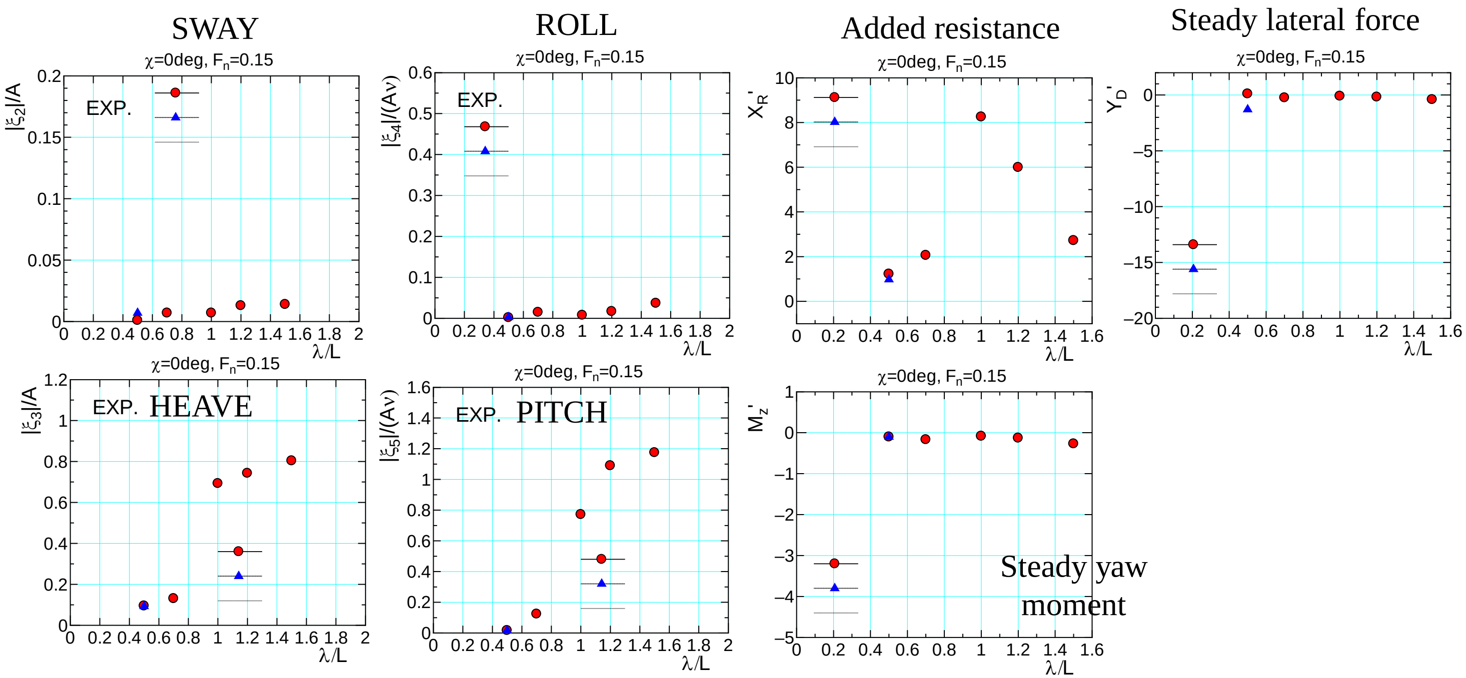
3.1.2 Captive model tests in waves (1) summary

- Captive tests are related with mathematical model and numerical methods
  - Two-time scale method, Unified method, CFD based method etc.
- Incident wave direction variation
  - Fixed(Straight or Oblique tests), Changed(Dynamic or Circular motion tests)
- Research results
  - Oblique test : S-175(Yasukawa 2006), KCS(Choi 2020)
  - Circular motion test : VLCC(Ueno 2001)
  - Waves in shallow water : ULCS(Tello Ruiz 2019)

3.1.2 Captive model tests in waves (2)



Oblique towing test in regular waves
(Yasukawa and Adnun, 2006)



Effect of drift angle on wave-induced motions and wave mean drift forces
for S-175 in regular head waves (Fn=0.15)

3.2.2 Mean wave force methods

- No changes to calm water manoeuvring models.
- Only mean 2nd order wave forces are added.
- The mean 2nd order wave forces calculated previously for all heading, frequencies, speeds and stored as multidimensional tables.

Modular approach

$$\boldsymbol{F} = \boldsymbol{F_M} + \boldsymbol{F_W}$$

Forces modelled as calm water manoeuvring

Mean second order forces table

$$F_{2ndi} = \sum_{n=1}^{N} f_{2ndi_n}(\omega_{0_n}, \mu_n, V)$$

3.2.3 Two-time scale methods

Manoeuvring

- ✓ Low frequency
- ✓ solve at Δt_M

$\Delta t_M = n \, \Delta t_S$

Seakeeping

- ✓ High frequency
- ✓ solve at Δt_S

- No changes to seakeeping and calm water manoeuvring models.
- Wave exciting forces included as external forces (sum al all sinusoidal components, 1st and 2nd order)

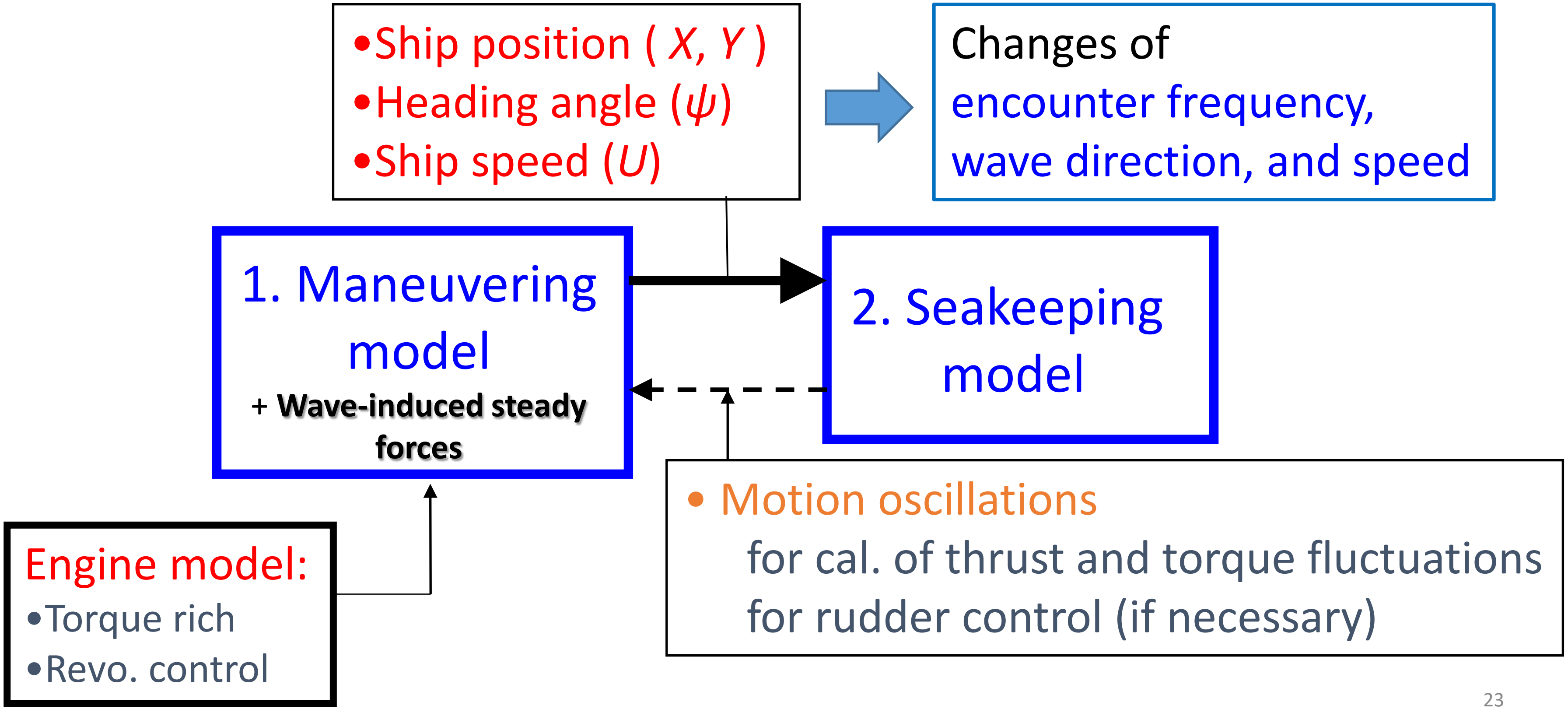
Ship position
Ship orientation
Ship speed V

Information Exchange

Wave mean drift forces and moments

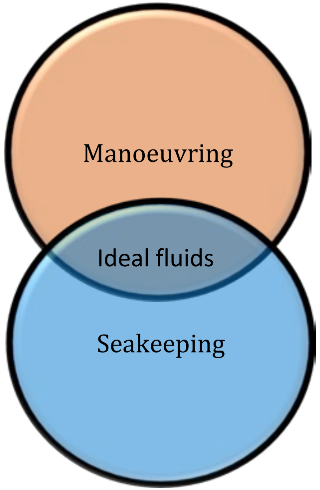
Total ship motion =
Maneuvering + Wave-induced motions

Calculation flow in two-time scale method



3.2.4 Unified method

- One of direct simulation methods
- Changes on the main ideal fluids components of the hull forces.
- Wave exciting forces included as external forces (sum al all sinusoidal components, 1st and 2nd order)



Modular approach

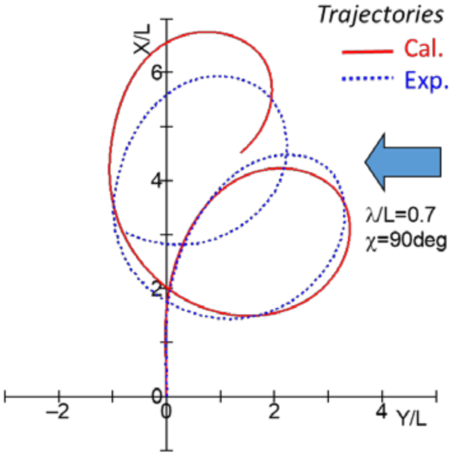
$$\boldsymbol{F_M = F_H + F_R + F_W}$$

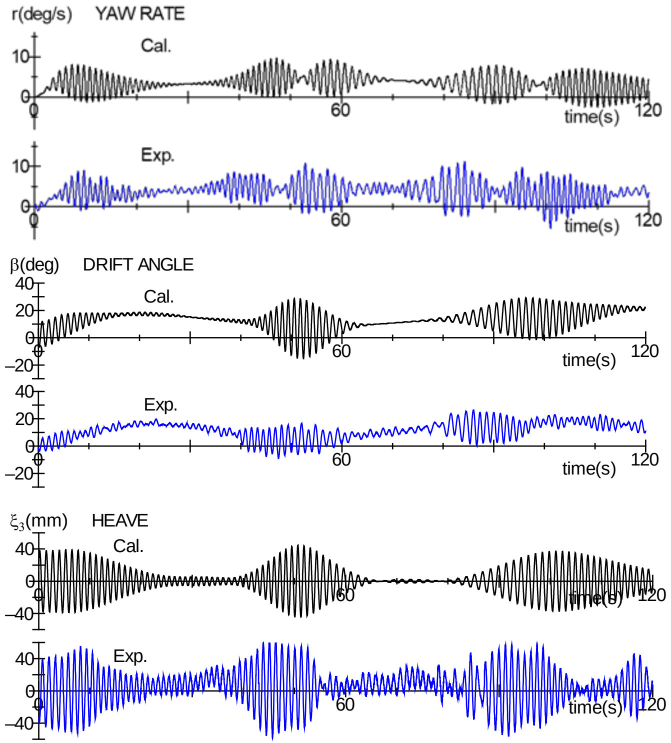
$$\boldsymbol{F_H = F_S + F_{id}}$$

Memory function

$$\boldsymbol{F_{id} = A\ddot{X} + B\dot{X} + \int_{-\infty}^{+\infty} H^V(t-\tau)\,\dot{X}(\tau)d\tau}$$

Calculation example by two-time scale methods





Turning simulation for S-175 in regular beam waves

(Fn=0.15) (Yasukawa and Nakayama, 2009)

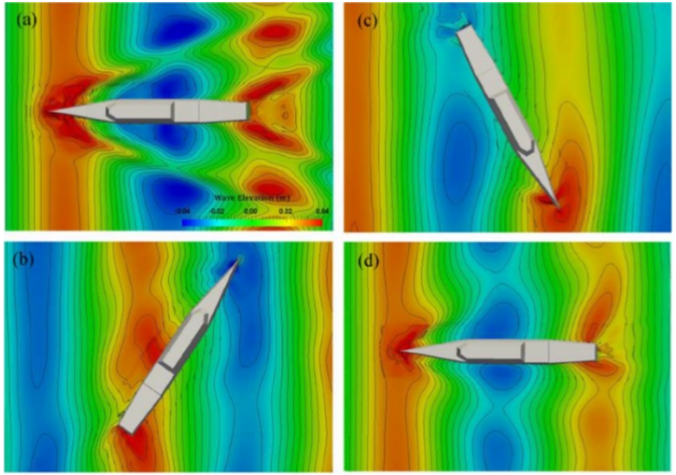
3.2.5 CFD based direct simulation methods (1)

- Direct simulation using computational fluid dynamics (CFD) provide a better understanding of the hydrodynamic problem of ship manoeuvring. It can solve specific local flow details around the hull and its appendages .

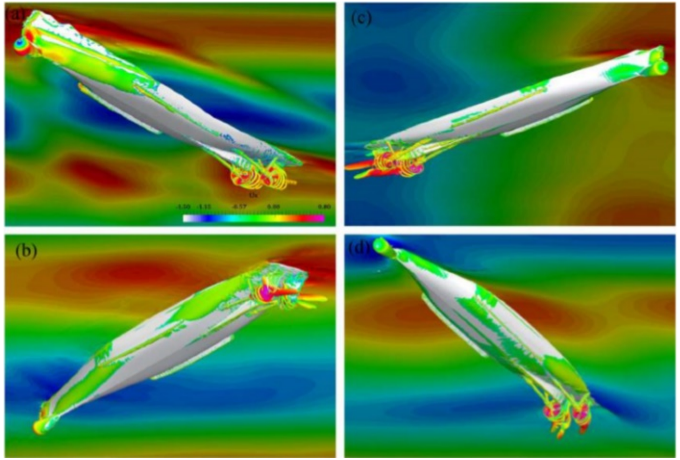
- CFD studies on ship manoeuvre solves the Reynolds-Averaged-Navier-Stokes (RANS) equations for unsteady turbulent flows around free running ship model in regular waves.

- Ship manoeuvring in waves by using a body force propeller model （Carrica et al.， 2012),
- Course keeping control in head and quartering waves ,（Shen and Korpus， 2015),
- Turning circle and zigzag manoeuvre, （Wang et al.， 2016, 2018a, 2018b)

3.2.5 CFD based direct simulation methods (2)



Free-surface elevation during turning in waves (a–d correspond to heading change of 0º, 120º, 240º and 360º, respectively) (Wang et al. 2018b)



Vorticial structures around ship hull during turning in waves (a–d correspond to heading of 0º, 120º, 240º and 360º, respectively) (Wang et al. 2018b)

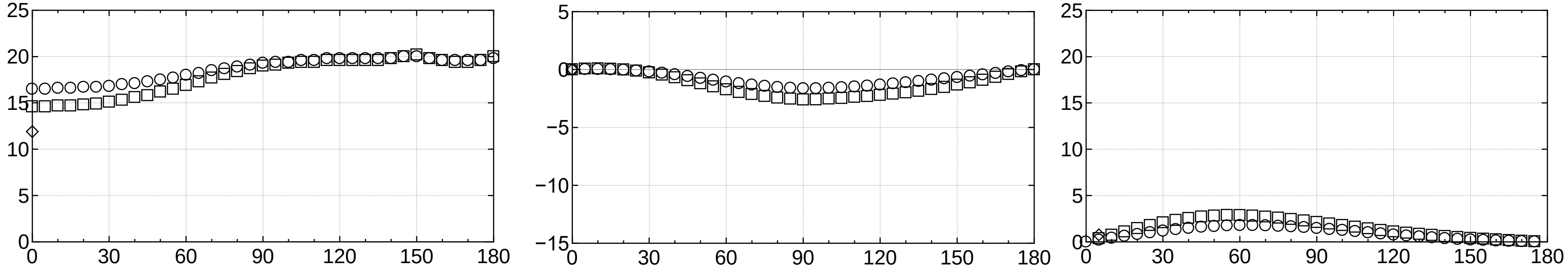
3.3 Steady Sailing Performance and Manoeuvring Limit in Wind and Waves (1)

For discussing the manoeuvring limit in adverse weather conditions, it is useful to evaluate the average steady sailing conditions (SSC), such as check helm, speed drop, hull drift angle, etc., of a ship moving straight in steady wind and waves. In addition, the dynamic stability, or course stability (CS), of the ship should be checked at the SSC. Both the SSC and the CS of ships under external disturbances are called the steady-sailing performance (SSP). For this analysis, the mean wave force methods are normally used.

The basic principle to conveniently obtain the SSP of the ships in steady wind and waves has already been presented by Eda (1968) and Ogawa (1969) as follows:

1. By setting acceleration, angular acceleration, and angular velocity to zero in the motion equations, the equilibria equations, that is, the balance with respect to forces and moments acting on the ship can be obtained. The check helm, speed drop, hull drift angle, and so on are obtained by solving the equilibria equations after setting the environmental condition.
2. The course stability of the ship under adverse conditions is adjudged by evaluating the eigenvalues of the linearized motion equations.

3.3 Steady Sailing Performance and Manoeuvring Limit in Wind and Waves (2)



Results of the SSCs, including the longitudinal ship velocity component u_0, the check helm δ_0 and the hull drift angle β_0 at the average wave period T_P=10s for a pure car carrier (PCC) (Yasukawa et al., 2019)

3.5 Additional Aspect of Manoeuvring Simulation in Waves

3.5.1 Effects of waves and motions on propeller performance

3.5.2 Effect of ventilation in propeller performance

3.5.3 Engine dynamics for simulation

- Wave-propeller interaction
- Wave-engine interaction

Skip the details

4. MINIMUM ENGINE POWER REQUIREMENT (1)

- **Revisions on 2013 Interim Guidelines for Determining Minimum Propulsion Power**

Resolution MEPC.232(65) **2013. Mar.**	• ***Adopts*** the 2013 Interim Guidelines for determining minimum propulsion power … • … applied … during ***Phase 0 (~2014)***.
Resolution MEPC.255(67) **2014. Oct.**	• … applied … during Phase 0 and ***Phase 1 (2015~2019)***.
Resolution MEPC.262(68) **2015. May.**	• ***Amendments to level 1 assessment***: • Parameters a and b for determination of the minimum power line values were changed.
MEPC.1/Circ.850/Rev.2 **2017. July**	• … extend the validity of the 2013 Interim Guidelines to EEDI ***phase 2 (2020~2024)***….

MEPC 76
2021. June

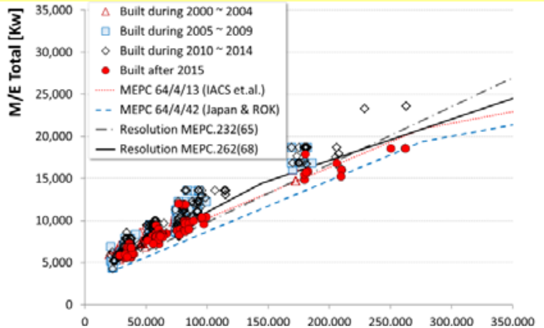
- ***Finalizing*** the revision of the Interim minimum power guidelines
- Definition of "***Adverse conditions***"
- Assessment procedure
  : ***Deletion/Retention*** of Appendix 2 (***Assessment Level 2***)
  - ***Ship speed***
  - Thrust deduction ***t*** & wave fraction ***w***

4. MINIMUM ENGINE POWER REQUIREMENT (2)

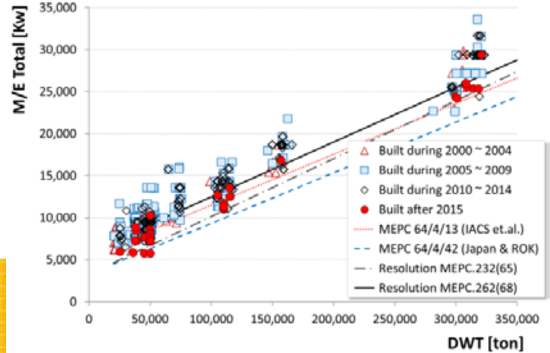
- **Two Assessment Levels**

✓ Level 1, Minimum power lines

Minimum Power Line Value [MCR, kW] = a x (DWT [tons]) + b



Bulk carriers



Tankers

✓ Level 2, Simplified Assessment

Define conditions

- Adverse condition
- +
- Advance speed

Calculate resistance

- Calm water resistance (R_{cw})
- +
- Aerodynamic resistance (R_{air})
- +
- Added resist. in waves (R_{aw})
- +
- Appendage resistance (R_{app})

Calculate req. power

- Required advance coeff. (J)
- Required RPS (n)
- Required delivered power (P_D)

Available power $Q \leq Q_{max}$ (n)

4. MINIMUM ENGINE POWER REQUIREMENT (3)

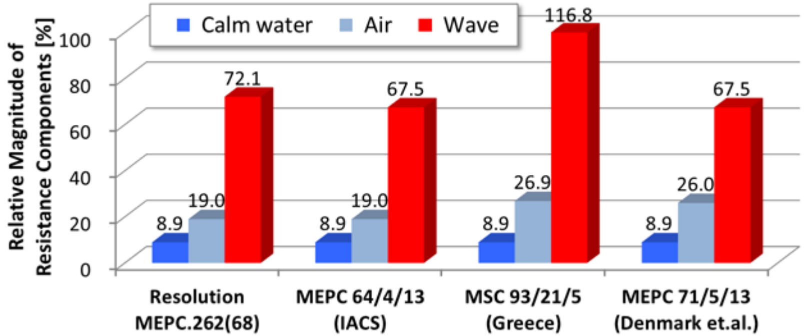
- **Adverse Weather Condition**
  - ✓ Discussions on the adverse weather condition

IACS, EE-WG 1/4, 2010	IACS et.al., MEPC 62/5/19, 2011	MEPC 64, 2012 MSC 93/21/5, 2014
•Manoeuvrability at ***one engine failure*** •***7 knots*** at ***BF5*** (BV, GL) •***6 knots*** at ***BF8*** (DNV)	•***Interview*** w/ operators •SS 7 or 8 (***BF 9 or 10***) : possibility 2 or 0.5% •***2(~4) knots***	• ***Jap. / Kor. : BF 7*** (***H_S: 4m, V_W: 15.5 m/s***) • ***IACS : BF 8*** (***H_S: 6m, V_W: 19 m/s***) • ***Greece : at least BF 9*** (***H_S: 7m, V_W: 23 m/s***)

Res. MEPC 232(65), 2013	Denmark & Japan, MEPC 68/3/7, 2015	Denmark et.al., MEPC 71/5/13, 2017
•***BF 8*** •***H_S: 5.5m, V_W: 19 m/s*** •Consistency w/ Lev. 2 assessment	•***BF 9 is too severe*** : Impractical to satisfy. ⇐ 1.5~5 times larger main engine	•***BF 9*** •***H_S: 6m, V_W: 22.6 m/s*** •Conservative viewpoints

- ✓ Application of the adverse weather conditions on KVLCC2

References	$H_{1/3}$ [m]	T_P [s]	V_W [m/s]
Resolution MEPC.262(68), 2015	5.5	7.0~15.0	19.0
MEPC 64/4/13 (IACS), 2012	6.0	8.0~15.0	19.0
MSC 93/21/5 (Greece), 2014	7.0	-	23.0
MEPC 71/5/13 (Denmark et.al.), 2017	6.0	8.8~12.2	22.6



Relative magnitude of resistance components under different adverse weather conditions (100% means the total resistance by the Resolution MEPC.262(68))

4. MINIMUM ENGINE POWER REQUIREMENT (4)

- **Discussions on Added Resistance in waves, Wake Fraction, *w* and Thrust Deduction Factor, *t***

IACS (MEPC 62/INF.21, EE-WG 2/2/8), 2011

R_{aw}: Model test / ***Potential / Viscous*** / Empirical

t & *w* : Model test / ***empirical*** (MEPC 64/4/13, 2012)

SHOPERA (MEPC 70/INF.33), 2016

R_{aw}: ***Empirical method***

China (MEPC 71/5/8), 2017

R_{aw}: ***A proposal*** for numerical method

t & *w* : ***t = 0.1***, *w* from model test / empirical

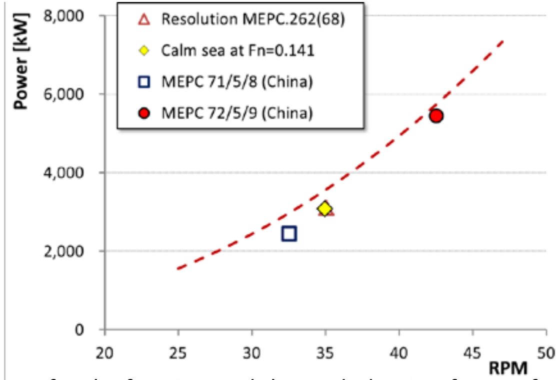
China (MEPC 72/5/9, MEPC 72/INF.16), 2018

R_{aw}: A proposal for numerical method

t & *w* : ***t = 0.1***, ***w = 0.15***

✓ Application of the self propulsion factors on KVLCC2

References	Wake fraction	Thrust deduction
Resolution MEPC.262(68)	0.350	0.245
Calm sea at Fn=0.141	0.347	0.233
MEPC 71/5/8 (China)	0.350	0.100
MEPC 72/5/9 (China)	0.150	0.100



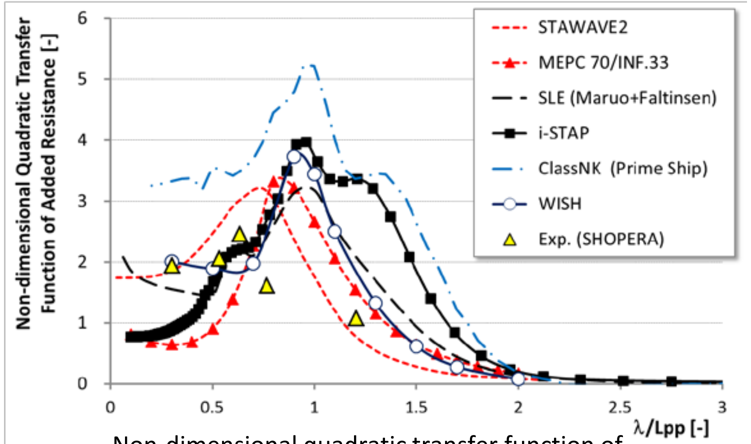
Effects of wake fraction and thrust deduction factors for KVLCC2
(Dashed line is a power limit curve under the assumed MCR condition)

4. MINIMUM ENGINE POWER REQUIREMENT (5)

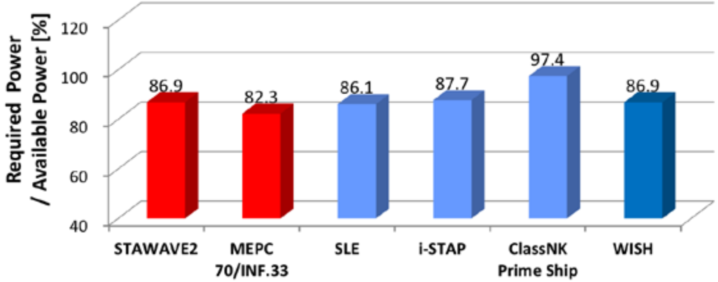
- **Added Resistance in waves**

✓ Considerable estimation methods of wave added resistance

-	Type	Motion induced	Reflection correction
STAWAVE2 (MARIN)	Empirical	Jinkine's method	Experimental data
MEPC 70/INF.33 (SHOPERA)			
S.L.E (HHI)	2D Strip	Maruo method	Faltisen asymptotic
i-STAP (KRISO)			NMRI empirical
Class NK PrimeShip			
WISH (SNU MHL)	3D Panel	Pressure integration	



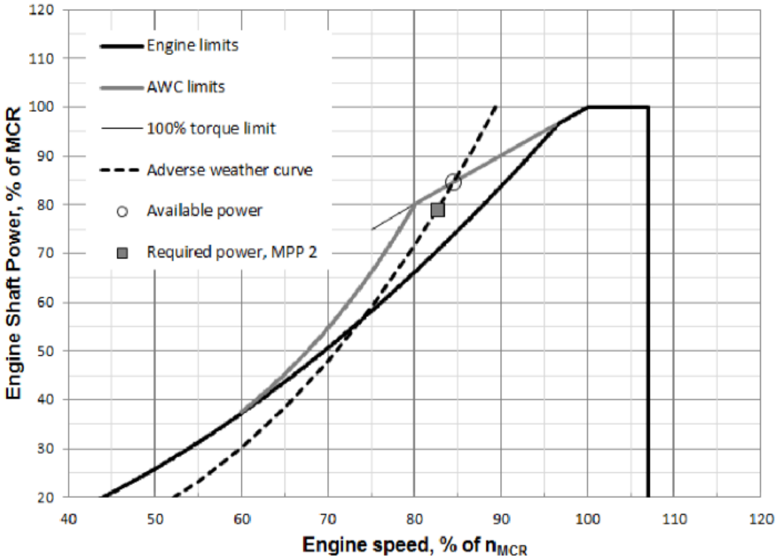
Non-dimensional quadratic transfer function of wave added resistance for KVLCC2 at Fn = 0.055



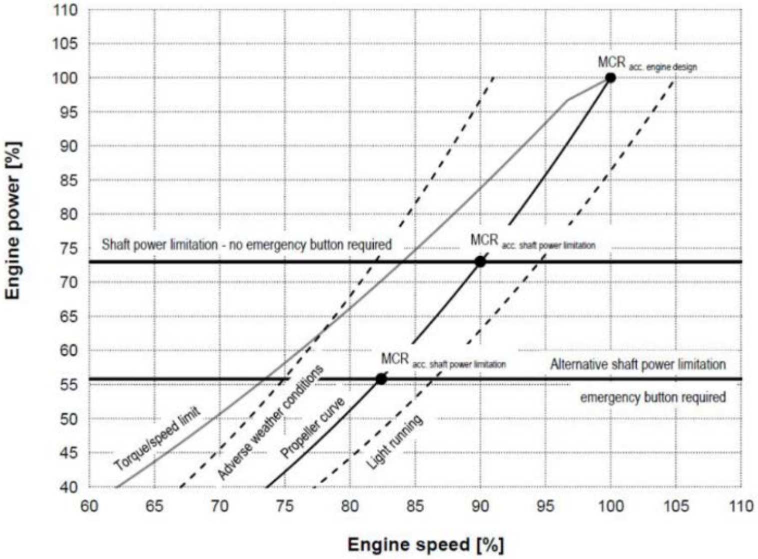
Ratios of the required power over the available power by the wave added resistance estimates on KVLCC2

4. MINIMUM ENGINE POWER REQUIREMENT (6)

- **Discussion on Engine Load Control & Shaft Power Limitation**
  - ✓ Increase of engine torque at low engine loads
  - ✓ Shaft/Engine Power Limitation



Extension of engine load limit
by "Adverse Weather Condition" functionality
(Denmark, MEPC 74/5/17, 2019)



Concept of Shaft/Engine Power Limitation
(France et al., MEPC 74/5/5, 2019)

5. CONCLUSIONS (1)

5.1 Prediction Methods of Ship Manoeuvring in Waves

- A large number of works on manoeuvring in waves methods have been published during in this period. Experimental research remains valuable and is being used complementary to numerical research. Due to technological developments in progress, tests in irregular waves with large wave height are becoming more feasible.
- Direct CFD simulations of ship maneuvering in waves were presented by several authors. Using CFD simulations of self-propulsion and turning motions as well as zig-zag maneuvers of a free running ship model in regular waves can be conducted. However, due to the high computational cost and even longer time simulation requirement, direct CFD maneuvering simulations in irregular waves are still a changeling problems.
- Until now, the problem of manoeuvring in deep water waves has been mainly treated, but the problem has been extended to shallow water area.
- As an application example of the calculation of manoeuvring in waves, there are many studies on the manoeuvring limit of ships by analysing the steady sailing performance.

5. CONCLUSIONS (2)

5.2 Benchmark data

The SIMMAN research project has facilitated new data for the KCS and the ONRT in regular waves. These data is quite valuable to support the validation and certification of numerical simulation method.

5. CONCLUSIONS (3)

5.3 Minimum Engine Power Requirement

The issues brought about from IMO-MEPC71 and following meetings were addressed concerning the minimum power requirements. The accurate estimations of the wave added resistance and the self-propulsion factors in higher propeller load condition are a decisive factor for the simplified assessment.

6. RECOMMENDATIOS (1)

Update the following guidelines:

- Free Running Model Tests in Waves
- Captive Model Tests for Measuring Forces in Waves

6. RECOMMENDATIOS (2)

To improve the numerical method for manoeuvring in waves, the following actions are needed:

- Validate the numerical methods for mean wave drift forces, especially steady lateral force and steady yaw moment acting on an advancing ship in cooperation with the seakeeping committee.
- Provide the captive test data on the hydrodynamic forces acting on the ship in waves, such as
  - ✓ Oblique towing test data in waves
  - ✓ Circular motion test data in waves
  - ✓ PMM test data in waves
  - ✓ Rudder force data in waves when ship is straight moving.

  for validation of CFD in cooperation with the manoeuvring committee.
- Investigate the effect of wave height on the propeller performance and the coupling with the main engine in cooperation with the propulsion committee.

6. RECOMMENDATIOS (3)

Validate the Level 2 – Simplified Assessment Method of the 2013 Interim Guidelines (MEPC 232(65)) by enhanced and comprehensive methods.

Investigate the concept of “Shaft Power Limitation” (ShaPoLi) introduced for the first time at MEPC 73 (MEPC 73/5/1) and deliberated at following sessions (MEPC 74/5/5, MEPC 75/6/6), as a measure to overcome intrinsic conflict between safety and environmental regulatory requirements.