On the development of a ship simulation model for maneuvering tasks in waves

Maria ACANFORA*, Marco ALTOSOLE, Ernesto FASANO, and Davide LAURIA

*maria.acanfora@unina.it

Industrial Engineering Department, Università degli studi di Napoli "Federico II", Naples, Italy

Layout of the presentation

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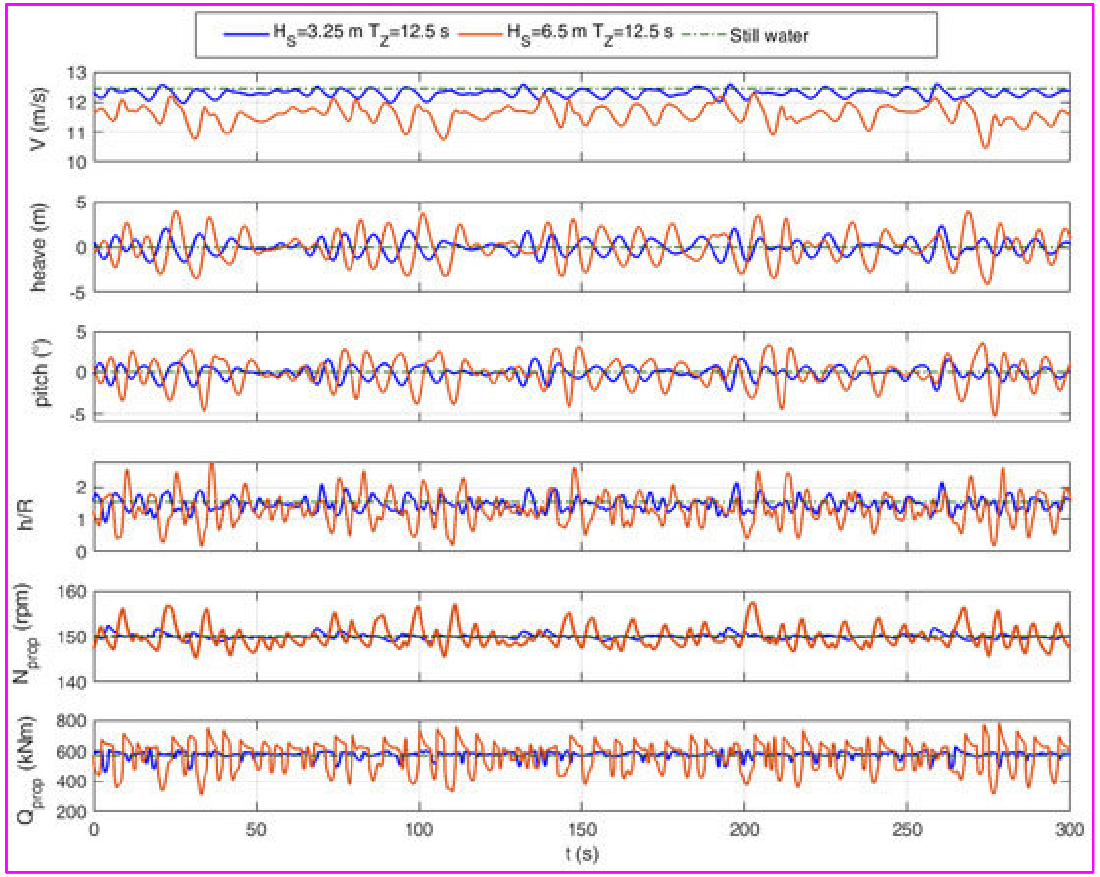
I. Introduction

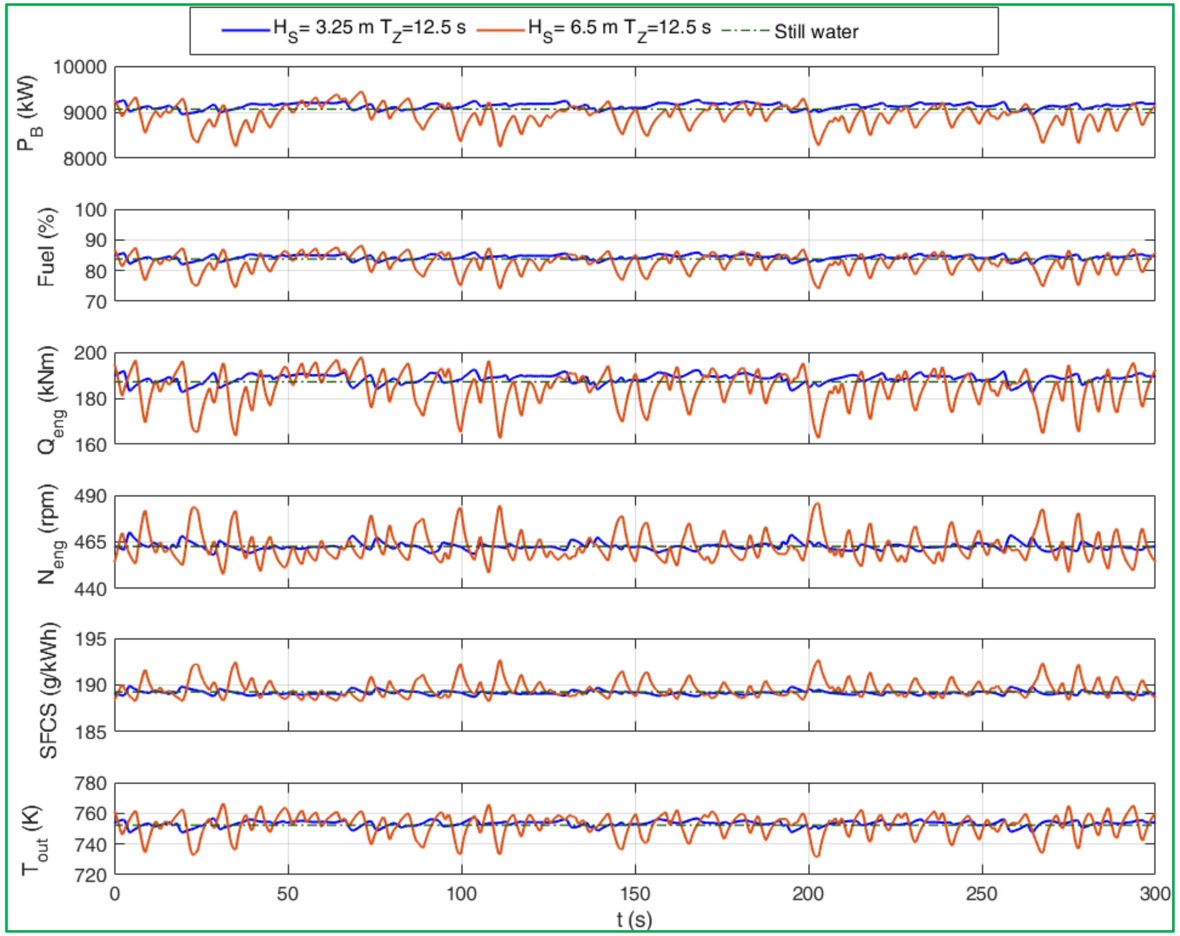
Motivation

- Interest of the Maritime Industry in greener propulsion systems on-board
- Novel hybrid propulsion systems to be designed and adopted
- Needs of dynamic simulation for characterizing beforehand the behaviour of such systems in the marine environment (wind, wave, currents, etc…)
- A good simulator for ship manoeuvring in waves, with the possibility of including propeller and engine models is expected

I. Introduction

- A previous research regarded the coupling between the dynamics of a ro-pax in irregular waves (straight runs) and a marine diesel engine behaviour. M. Acanfora, M. Altosole, F. Balsamo, L. Micoli, and U. Campora, "**Simulation Modeling of a Ship Propulsion System in Waves for Control Purposes**," JMSE 2022.

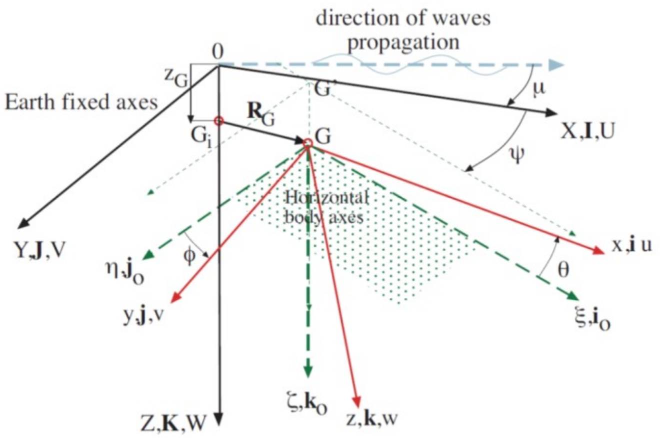




- The current research aims at implementing manoeuvring models in waves, on a VLCC (data available for comparisons)

II. Numerical model for the hull dynamics in waves

$$
\begin{cases}
(m+a_{11})\dot{u} + m(qw - rv) + a_{15}\dot{q} = -mgsin\theta + X_{wave} + X_{man} - k_{11} - k_{15} + X_{prop} + X_{res} + X_{rud} \\
(m+a_{22})\dot{v} + m(ru - pw) + a_{24}\dot{p} + a_{26}\dot{r} = mgcos\theta sin\phi + Y_{wave} + Y_{man} - k_{22} - k_{24} - k_{26} + Y_{rud} \\
(m+a_{33})\dot{w} + m(pv - qu) + a_{35}\dot{q} = mgcos\theta cos\phi + Z_{wave} - k_{33} - k_{35} \\
(I_x + a_{44})\dot{p} + (I_z - I_y)qr + a_{42}\dot{v} + a_{46}\dot{r} = K_{wave} + K_{man} - k_{44} - k_{42} - k_{46} + K_{rud} \\
(I_y + a_{55})\dot{q} + (I_x - I_z)rp + a_{15}\dot{u} + a_{53}\dot{w} = M_{wave} - k_{55} - k_{53} - k_{31} \\
(I_z + a_{66})\dot{r} + (I_y - I_x)pq + a_{62}\dot{v} + a_{64}\dot{p} = N_{wave} + N_{man} - k_{66} - k_{62} - k_{64} + N_{rud}
\end{cases}
$$



- Numerical model in time domain, 6DoF
- So-called blended (or hybrid) numerical model for ship dynamics in wave:
  - ➢ The inertia, Froude-Krylov and restoring forces and moments are evaluated accounting for all the relevant non-linearities
  - ➢ Convolution integral approach for added mass and damping effects
  - ➢ Linear diffraction and radiation forces and moments
- Numerical modelling of propeller actions and ship resistance
- Numerical modelling of ship rudder and manoeuvring actions

Input

- ➢ Environmental action:
  - Wave
  - ~~Wind~~
  - ~~Current~~
- ➢ Propeller action → $T_{prop} = \rho K_T N_{prop}^2 D_{prop}^4$, $Q_{prop} = \rho K_Q N_{prop}^2 D_{prop}^5$
- ➢ Rudder action
- ➢ Ship resistance → $X_{res} = \frac{1}{2}\rho V_S^2 S\, C_T$

SHIP DYNAMICS

II. Numerical model for the hull dynamics in waves

Numerical modelling of rudder and maneuvering actions

MMG model for the steering actions

$$\begin{cases} X_{RUD} = -(1-t_r)F_N \sin\delta \\ Y_{RUD} = (1+a_h)F_N \cos\delta \\ K_{RUD} = -(1+a_h)\, Z_{rud}\, F_N \cos\delta \\ N_{RUD} = (X_{rud} + a_h\, x_h)\, F_N \cos\delta \end{cases}$$

Rudder normal force F_N is expressed as:

$$F_N = \frac{1}{2}\rho A_R U_R^2 f_\alpha \sin\alpha_R$$

$$U_R = \sqrt{u_R^2 + v_R^2}$$

$$\alpha_R = \delta - \tan^{-1}\left(\frac{v_R}{u_R}\right) \simeq \delta - \frac{v_R}{u_R}$$

- The MMG model bases on the knowledge of pertinent experimental coefficients for the estimation of steering actions
- t_r, a_h and x_h are the coefficients representing the hydrodynamic interaction between hull, rudder and propeller

Non-linear model of ship manoeuvring

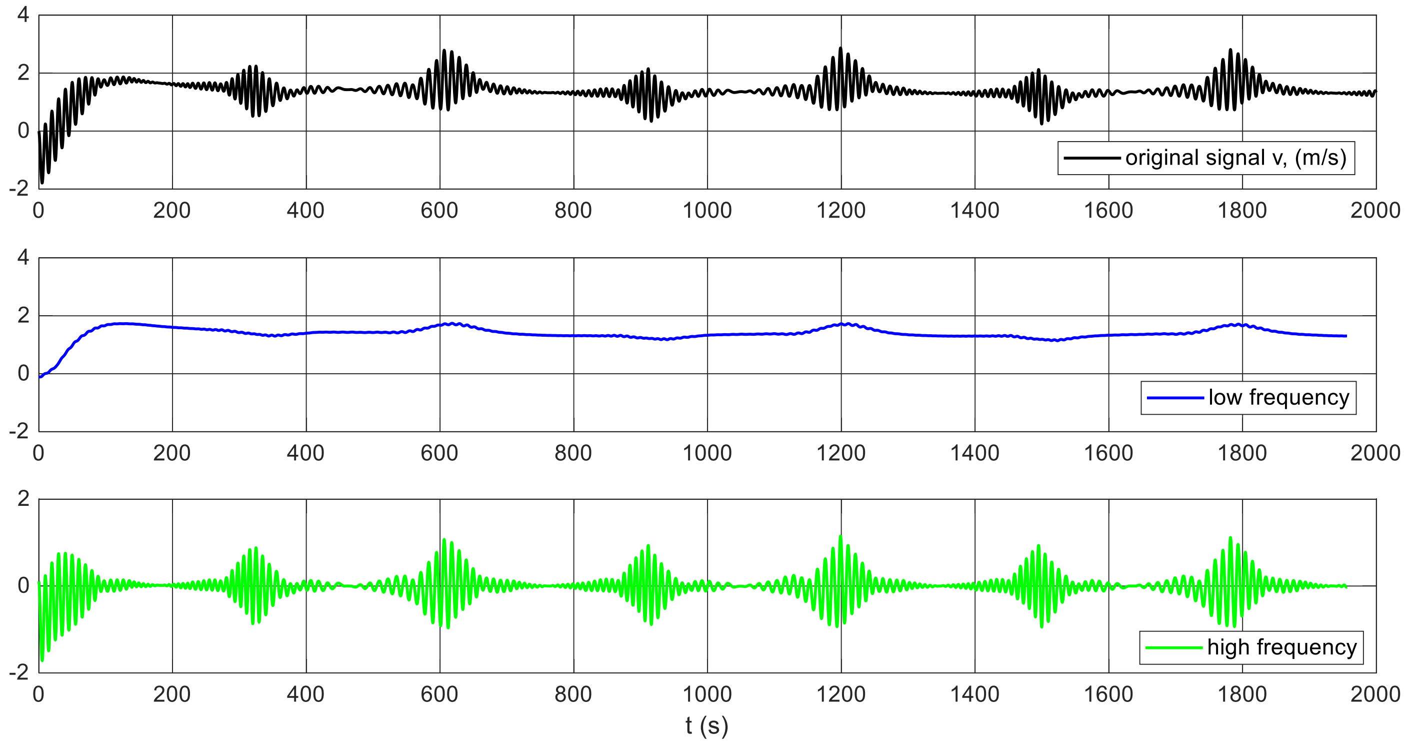
$$\begin{cases} X_{man} = X_{vv}v^2 + X_{rr}r^2 + X_{vr}vr + +X_{vvvv}v^4 \\ Y_{man} = Y_v v + Y_r r + Y_{vvv}v^3 + Y_{rrr}r^3 + Y_{rrv}vr^2 + Y_{vvr}rv^2 \\ N_{man} = N_v v + N_r r + N_{vvv}v^3 + N_{rrr}r^3 + N_{rrv}vr^2 + N_{vvr}rv^2 \\ K_{man} = -Y_{man}(Z_G - T/2) \end{cases}$$

- Only relevant derivatives are kept
- Derivatives refer to yaw and sway speed components
- The manoeuvring in waves is implemented by the so-called direct superposition approach
- The model accounts also for effects on roll due to manoeuvring

II. Numerical model for the hull dynamics in waves

Proposal for a novel modeling of maneuvering actions in waves:

→Zero-delay decomposition of yaw and sway speed components within the time domain simulation (by combining the exponential smoothing approach with a proper transfer function)



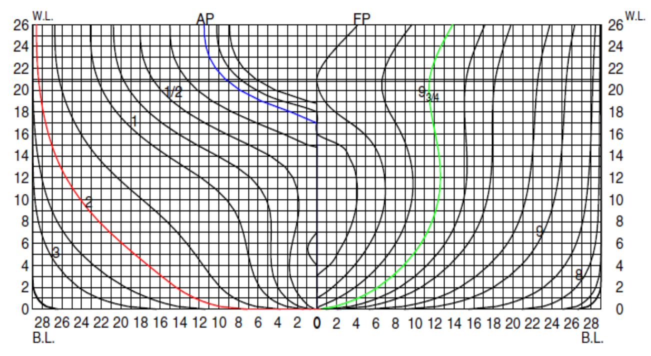
- ❖ Low frequency part is associated to manoeuvring coefficients
- ❖ High frequency part is associated to seakeeping coefficients

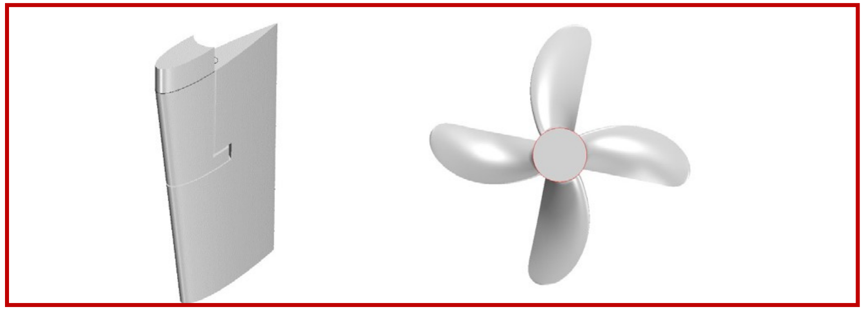
III. Case study

The KVLCC2 is a very large crude carrier developed by the KRISO towing tank for research purposes.

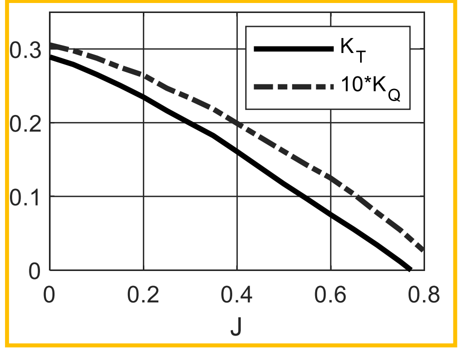
AVAILABLE INPUT DATA:

- Hull lines
- Rudder and propeller geometry
- Propeller coefficient curves in still water
- Maneuvering derivatives in still water
- Steering action coefficients for the MMG model in still water





Characteristic	Value
Length between perpendiculars, L [m]	320
Breadth, B [m]	58
Draft, T [m]	20.8
Displacement [m^3]	312622
Long. center of gravity LCG from aft perp. [m]	171.1
Vertical center of gravity VCG [m]	18.56
Roll radius of gyration [B]	0.4
Yaw radius of gyration [L]	0.25
Rudder lateral area [m^2]	136.7
Turn rate [degree/s]	2.34
Propeller Diameter [m]	9.86

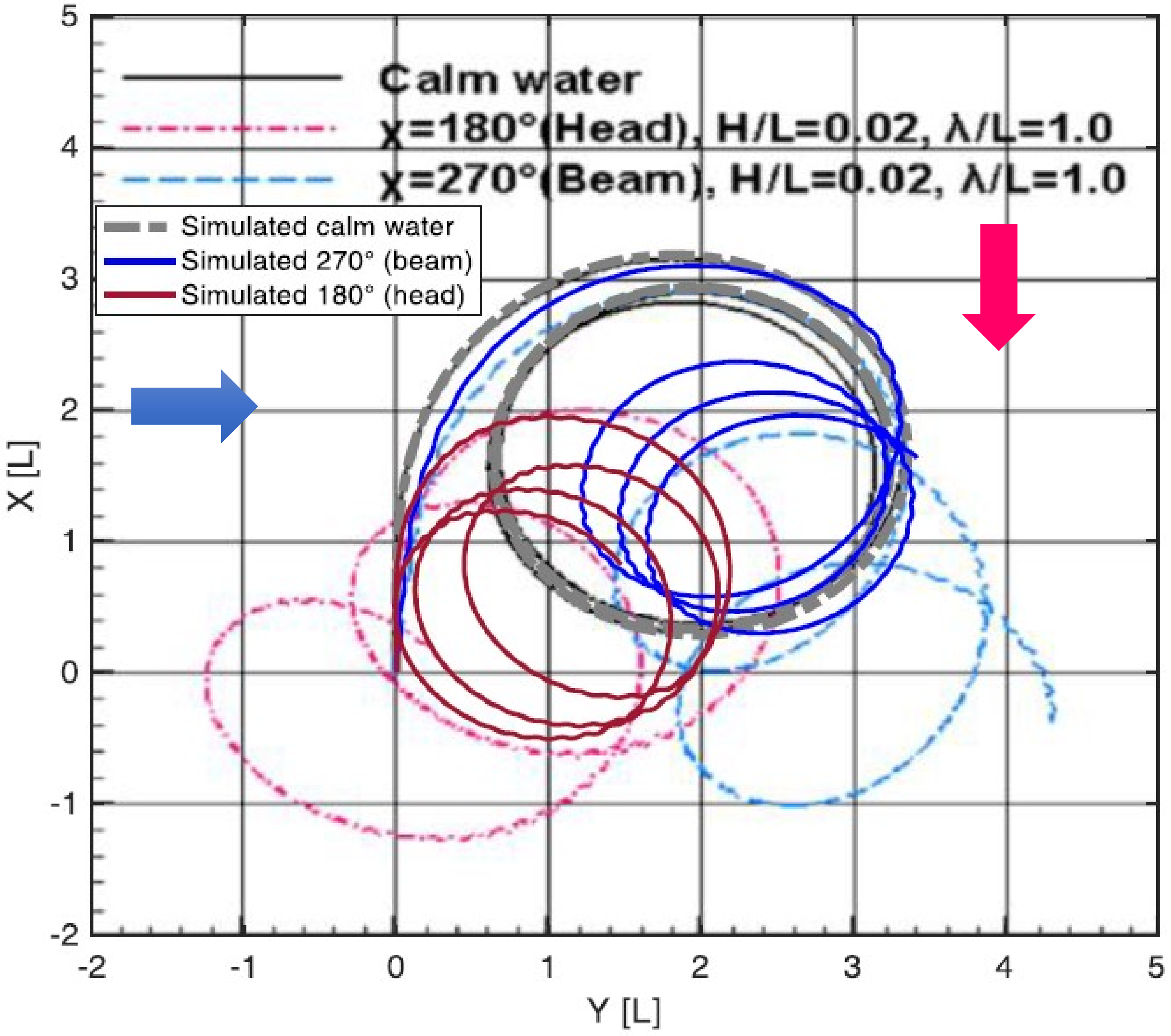


X'_{vv}	−0.040	m'_x	0.022
X'_{vr}	0.002	m'_y	0.223
X'_{rr}	0.011	J'_z	0.011
X'_{vvvv}	0.771	t_P	0.220
Y'_v	−0.315	t_R	0.387
Y'_R	0.083	a_H	0.312
Y'_{vvv}	−1.607	x'_H	−0.464
Y'_{vvr}	0.379	C_1	2.0
Y'_{vrr}	−0.391	C_2 $(\beta_P > 0)$	1.6
Y'_{rrr}	0.008	C_2 $(\beta_P < 0)$	1.1
N'_v	−0.137	γ_R $(\beta_R < 0)$	0.395
N'_R	−0.049	γ_R $(\beta_R > 0)$	0.640
N'_{vvv}	−0.030	ℓ'_R	−0.710
N'_{vvr}	−0.294	ε	1.09
N'_{vrr}	0.055	κ	0.50
N'_{rrr}	−0.013	f_α	2.747

https://www.simman2014.dk

IV. Results

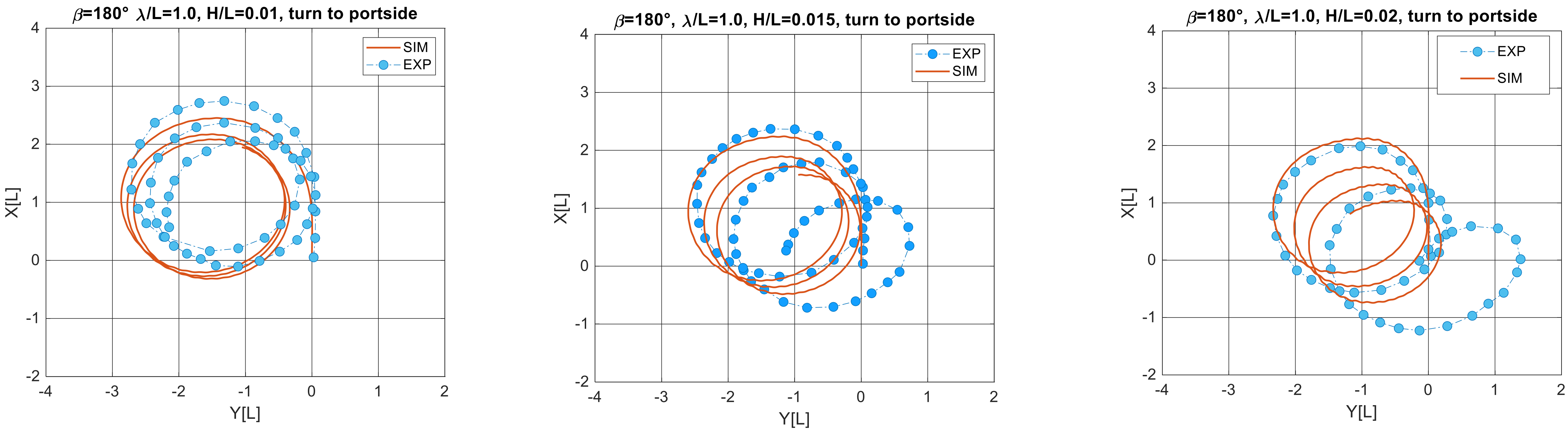
Turning circle in head and beam waves to starboard side, rudder deflection 35°: direct superposition approach



- ✓ Still water simulation finely matches the experimental data
- ✓ **Regular wave simulations** of the turning circle appear sufficiently fine if we consider the following aspects:
  - ❑ Qualitative agreement of the turning radius
  - ❑ Qualitative agreement of the drifting directions, consistent with the wave directions (both in head and in beam waves)
  - ❑ An additional turn is observed compared to the experimental data, given the same simulation time

IV. Results

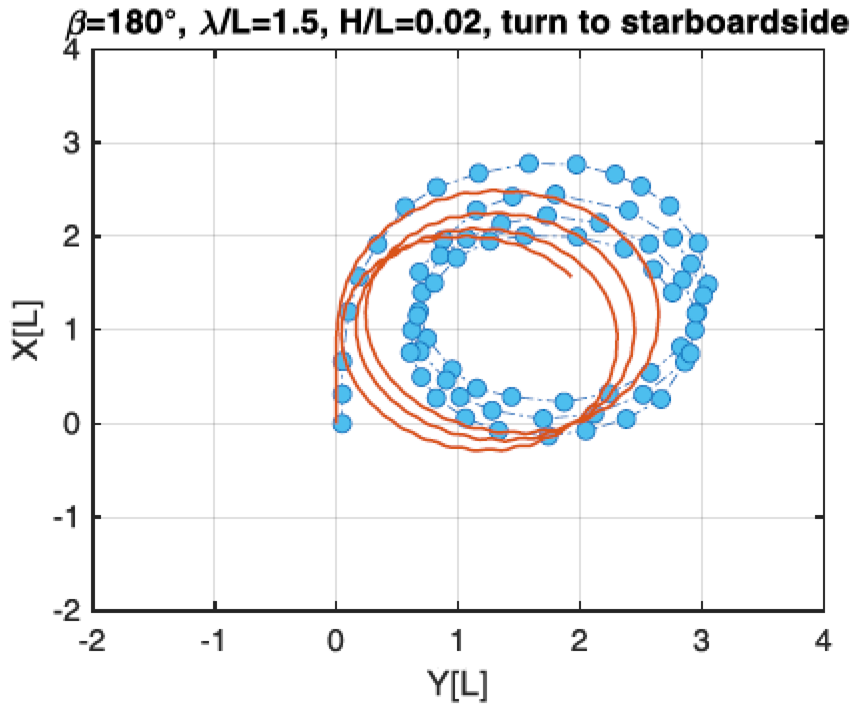
Turning circle in head waves to port side, rudder deflection 35°, direct superposition approach: increasing wave height

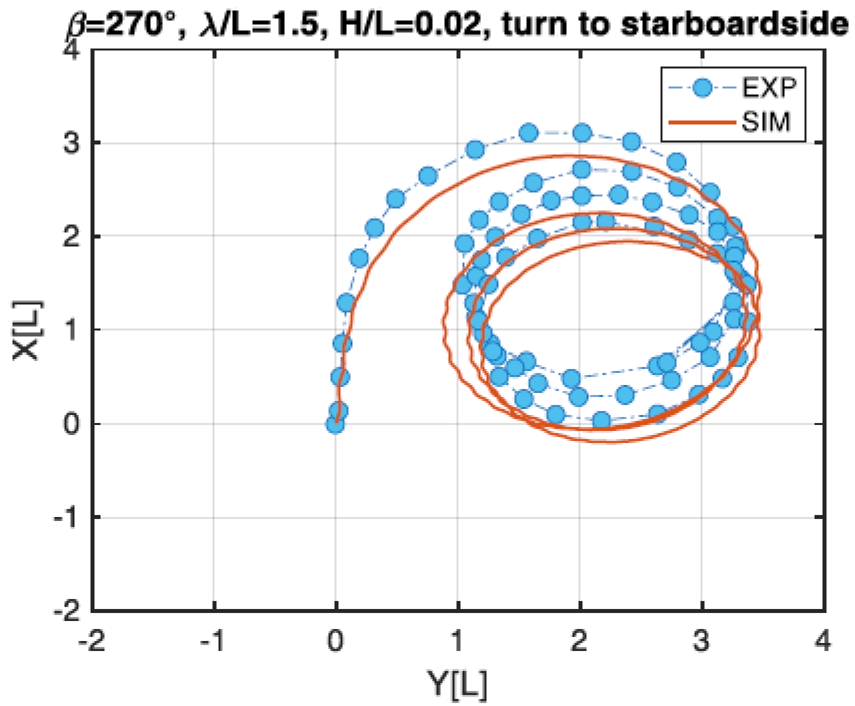


- ❑ In the experimental data the drifting distances increase with increasing wave height
- ❑ Qualitative agreement of the increase in drifting distances with increasing wave height in the numerical simulation
- ❑ Qualitative agreement of turning radius for all cases
- ❑ Fair matching of turning path especially for the smaller wave height case

IV. Results

Turning circle in head waves to starboard side, rudder deflection 35°, direct superposition approach, longer waves

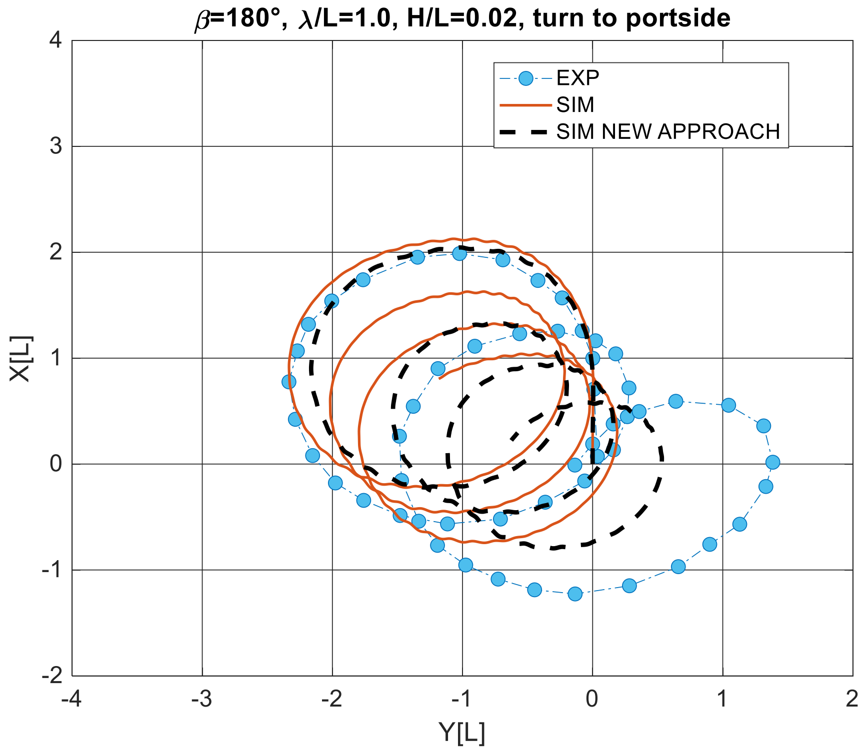




- ❑ In the experimental data the drifting distances reduce with increasing wave length
- ❑ Qualitative agreement in drifting distances with increasing wave height in the numerical simulation
- ❑ Qualitative agreement in the turning radius
- ❑ An overall better agreement is found for the beam sea case

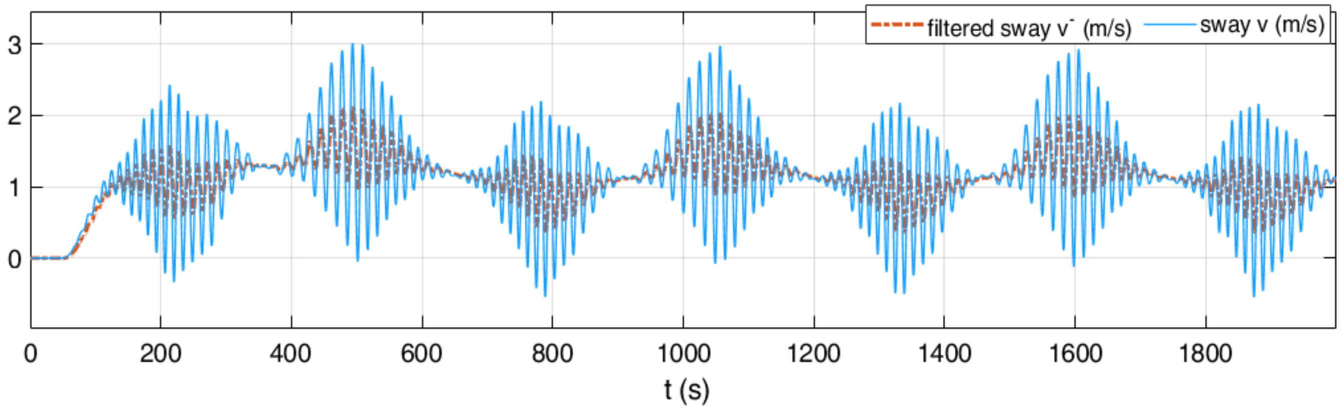
IV. Results

Turning circle in head waves to port side, rudder deflection 35°, comparison between direct superposition vs zero-delay filtering



The new approach based on speed filtering shows:

- a certain improvement in modelling the initial part of the turning circle
- a better agreement in the drifting distances, in spite of somewhat smaller turning diameters

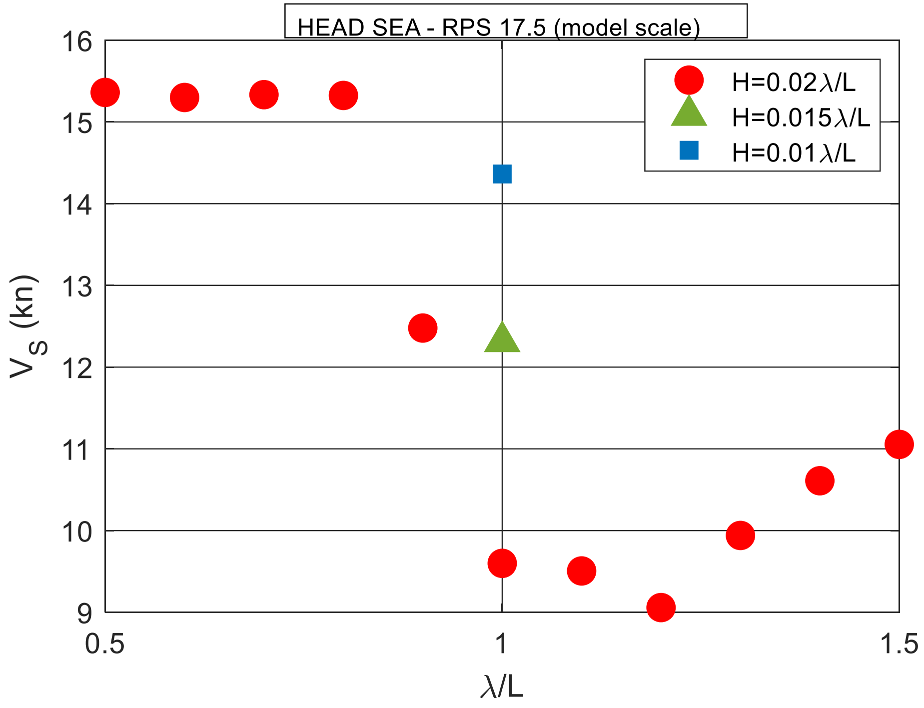


- The implemented filtering technique ensures a zero delay filtered signal, although there are still high frequency components

IV. Results

DISCUSSIONS

- Simulations were carried out for long waves (λ/L=1 and λ/L=1.5): the range of applicability of the numerical model for ship resistance in waves reasonably limits to the sea states characterized by wave length greater than ship length, where radiation and diffraction actions are not predominant.
- Ship speed, for λ/L=1, is overestimated of almost 10% in straight run simulations: this might be responsible for the observed additional turn.
- Ship resistance curve in still water was derived as quadratic extrapolation from a limited amount of points!



λ/L	exp (knots)	sim (knots)	error (knots)	err %
0.5	12.1	15.3	3.2	26%
0.7	10.9	15.1	4.2	39%
1	8.6	9.5	0.9	10%
1.2	10.2	9.2	-1	-10%
1.5	12.6	11.6	-1	-8%

M. Acanfora, M. Altosole, F. Balsamo, L. Micoli, and U. Campora, "*Simulation Modeling of a Ship Propulsion System in Waves for Control Purposes*," JMSE 2022

➢ Conclusions

- A numerical model for ship manoeuvring in waves was applied to a large tanker for the estimation of the turning circle paths.
- The comparison with the experimental data confirmed a fair accuracy of the model for increasing wavelengths.
- A consistent agreement in the drifting directions due to the different wave conditions under investigation was always appreciable.
- The developed approach, based on signal decomposition by means of exponential smoothing, proved to have a certain improvement for the turning circle case where it was applied.
- Although there are several acknowledged limitations in the numerical model, the presented outcomes are in the same range of accuracy of other models dealing with the numerical simulation of turning circle of large vessels in regular waves (see V. Shigunov, O. el Moctar, A. Papanikolaou, R. Potthoff, and S. Liu, "**International benchmark study on numerical simulation methods for prediction of manoeuvrability of ships in waves**," *Ocean Eng.*, vol. 165, pp. 365–385, Oct. 2018; R. Suzuki, M. Ueno, and Y. Tsukada, " ," *Appl. Ocean Res.*, vol. 113, p. 102732, Aug. 2021.)

THANK YOU FOR YOUR ATTENTION

QUESTIONS?