Proceedings, 5th International Conference on Ship Manoeuvring in Shallow and Confined Water (MASHCON 2019), Ostend, Belgium, 19-23 May 2019.

BENCHMARKING OF DIFFRAC, FATIMA, HYDROSTAR, MOSES, NEMOH, OCTOPUS, PDSTRIP, RAPID, SEAWAY, SLENDERFLOW AND WAMIT AGAINST MEASURED VERTICAL MOTIONS OF THE DUISBURG TEST CASE CONTAINER SHIP IN SHALLOW WATER

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SUMMARY

In this paper, we present a comparison of calculated and measured vertical motions of the Duisburg Test Case (DTC) container ship, in calm water or head waves, at rest or with forward speed.

At forward speed in calm water, running sinkage and trim (squat) have been compared with the potential-flow methods implemented in SlenderFlow and RAPID software. In head seas, bow and stern vertical motions have been compared with strip theory (OCTOPUS, PDStrip, SEAWAY) and panel method wave-induced motion codes (DIFFRAC, FATIMA, HydroSTAR, MOSES, NEMOH, WAMIT).

The results in this paper are intended to form a useful set of benchmarking data for assessing the suitability of each code in different conditions, for container ships in shallow water.

NOMENCLATURE

CoG	Ship centre of gravity
DTC	Duisburg Test Case container ship
RAO	Response Amplitude Operator
WG4	‘Wave Gauge 4’ mounted on model test carriage, 4.03 m forward of midships
s_a	Mean sinkage at aft perpendicular (m)
s_f	Mean sinkage at forward perpendicular (m)
x	Distance forward of aft perpendicular (m)
z_a	Heave amplitude at aft perpendicular (m), defined as half of peak-to-peak heave
z_f	Heave amplitude at forward perpendicular (m), defined as half of peak-to-peak heave
ε_a	Heave phase at aft perpendicular (deg), ahead of wave elevation at CoG
ε_f	Heave phase at forward perpendicular (deg), ahead of wave elevation at CoG
ζ	Wave amplitude (m), defined as half of wave height

1 INTRODUCTION

Model tests of the Duisburg Test Case (DTC) were undertaken at Flanders Hydraulics Research as part of the EU-funded SHOPERA project, and have been made available as a set of benchmarking data for the MASHCON 2019 conference (Van Zwijnsvoorde et al., 2019).

In this paper, we shall use the cases from Van Zwijnsvoorde et al. (2019) shown in Table 1.

Table 1. Test cases used for comparison

Test number	Static UKC (% draft)	Speed (full-scale)	Wave height (full-scale)	Wave period (full-scale)
C1	100%	6 knots	0.00 m	-
C2	100%	16 knots	0.00 m	-
C3	20%	6 knots	0.00 m	-
CW1	100%	0 knots	4.86 m	13.0 s
CW2	100%	6 knots	5.55 m	13.0 s
CW3	100%	16 knots	5.56 m	13.0 s
CW4	20%	0 knots	1.98 m	15.7 s
CW5	20%	6 knots	1.90 m	15.7 s

The used scale factor is 89.11. The test cases CW2 and CW5 are semi-blind, i.e. only wave data were provided.

2 MODEL TEST DATA ANALYSIS

Post-processing of the model test data described in Van Zwijnsvoorde et al. (2019) has been undertaken by Ghent University and Flanders Hydraulics Research to compare the test data with numerical predictions.

For calm water tests, the mean values are computed based on 30% to 95% of the steady state interval.

For tests in waves, a sample of the time records was selected using the time and periods recommended in Appendix 1 of Van Zwijnsvoorde et al. (2019). Then, a Fourier analysis has been performed by fitting the data to Eq. (1) using a least square method with eight unknown parameters $(a_0, a_1, b_1, a_2, b_2, a_3, b_3, \omega_1)$.

$$f = a_0 + \sum_{j=1}^{3} a_j \cos(j\omega_1 t) + b_j \sin(j\omega_1 t) \qquad (1)$$

The computed phase angles have been corrected to correspond to a case where the incident wave has a zero phase at the CoG. For this purpose the spatial phase difference $(kx_{WG4} - kx_{CoG})$ between the position of WG4 and the CoG has been used. This correction was needed to allow further comparison between experiments and numerical results. Bear in mind that only the first harmonic components for the wave and ship motions are used in this case and they are presented dimensionless. The latter has been obtained by dividing the respective magnitudes $(\sqrt{a_1^2 + b_1^2})$ by half of the wave heights reported in Table 6 in Van Zwijnsvoorde et al. (2019).

3 HULL MODELLING

The hull sections used for OCTOPUS, PDStrip, SEAWAY and SlenderFlow were developed at Perth Hydro, by reading the DTC IGES file into DELFTship and calculating offsets at 21 evenly-spaced waterlines from the keel to the design waterline. One station was placed at the aft extremity of the waterline (*x* = -0.7), followed by 26 evenly-spaced stations from the aft extremity of the stern bulb (*x* = 8.4) to the forward extremity of the bow bulb (*x* = 366.1).

The 4680-panel hull surface mesh used for WAMIT was developed at Perth Hydro, using the OCTOPUS 3D Mesher and the publicly-available DTC IGES file. This same mesh was converted at Ghent University to HydroSTAR format using the HydroSTAR *convert* tool, and to NEMOH format using a modified version of the open-source *meshmagick* tool. For MOSES, the mesh was refined at Bentley Systems, so that it consisted of triangles only.

The 6514-panel mesh used for DIFFRAC and FATIMA was developed at Marin from the DTC IGES file.

The section offsets and surface meshes are shown in Figure 1.

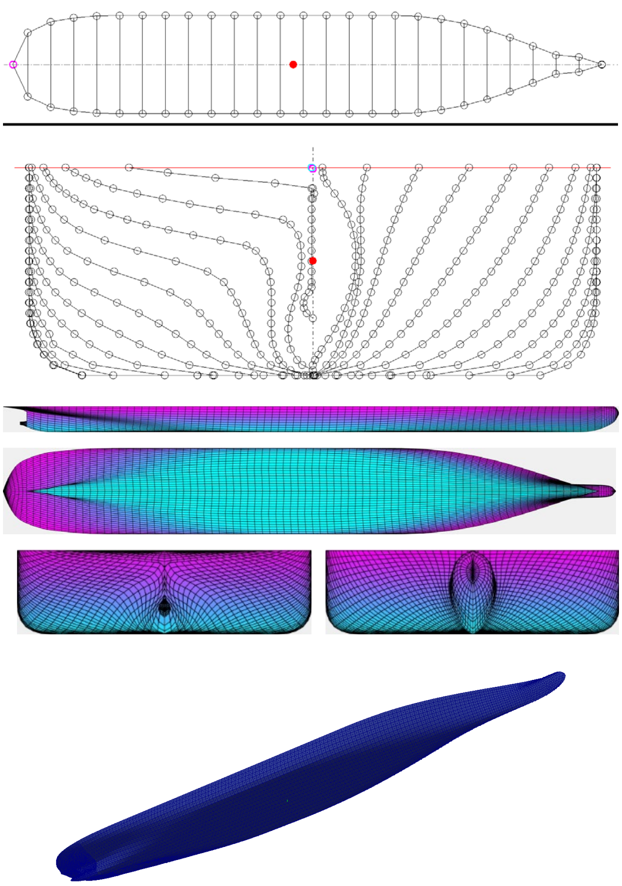

Figure 1: (top) hull sections; (middle) 4680-panel surface mesh; (bottom) 6514-panel surface mesh

4 SHIP MOTION CODES

Ship motion codes used are shown in Table 2.

Table 2. Software used for benchmarking study

Program, version	Type	Forward speed	Developer	Reference	Calculations done by
DIFFRAC	Linear 3D radiation/diffraction panel code	No	Marin	Buchner et al. (2001)	Marin
FATIMA	Linear 3D radiation/diffraction panel code using Rankine sources	Yes, using nonlinear potential flow solution (RAPID)	T.J.M. Bunnik	Bunnik (1999)	Marin
HydroSTAR v8.00	Linear 3D radiation/diffraction panel code	Yes, using encounter frequency correction	Bureau Veritas	Bureau Veritas (2011)	Ghent University
MOSES v11.0	Linear 3D radiation/diffraction panel code	Not used here	Bentley Systems	Ultramarine (2012)	Bentley Systems
NEMOH v2.03	Linear 3D radiation/diffraction panel code	No	École Centrale Nantes	Babarit and Delhommeau (2015)	Ghent University
OCTOPUS v6.4.14	Strip theory code	Yes	ABB	Amarcon (2009)	Ghent University
PDStrip v27	Rankine-source strip theory code	Yes	H. Söding	Söding (2006)	Perth Hydro
RAPID	Nonlinear Rankine-source potential flow method	Yes	H.C. Raven	Raven (1996)	Marin
SEAWAY v2017	Strip theory code	Yes	J.M.J. Journée	Journée (2001)	Ghent University
SlenderFlow	Steady slender-body shallow-water code	Yes	T.P. Gourlay	Ha and Gourlay (2018)	Perth Hydro
WAMIT v7.2	Linear 3D radiation/diffraction panel code	No	WAMIT Inc.	WAMIT (2016)	Perth Hydro

5 ADDITIONAL SOLVER SETTINGS

In NEMOH, CoG RAOs and vertical motions at specific points were calculated externally based on the wave loads and hydrodynamic coefficients returned by NEMOH.

In OCTOPUS, shallow-water hydrodynamic coefficients were calculated using the method of Keil (1974). Modified strip theory was used for all calculations. Classical wave loads were used at 100% UKC, and diffraction wave loads at 20% UKC.

In PDStrip, no flow separation was specified along the hull, with zero wave steepness (linear motions). The transom was set up as wet at zero forward speed and dry at non-zero forward speeds.

In RAPID, the open-water method was used (the effect of channel walls was neglected).

In SEAWAY, calculations were done using classical or diffraction wave loads, and ordinary or modified strip theory.

In SlenderFlow, the linear rectangular-canal method was used, based on the towing tank width.

In WAMIT, the direct solver was used, with the source method.

6 RESULTS: MEAN SINKAGE

Results for mean sinkage are shown in Table 3 and Figure 2.

Table 3. Mean sinkage results

	Sinkage at aft perpendicular s_a		
	Model test	SlenderFlow	RAPID
C1	0.049	0.050	0.029
C2	0.438	0.418	0.274
C3	0.110	0.085	0.069
CW2	blind	0.050	-
CW3	0.522	0.418	-
CW5	blind	0.085	-
	Sinkage at forward perpendicular s_f		
	Model test	SlenderFlow	RAPID
C1	0.081	0.085	0.091
C2	0.737	0.699	0.646
C3	0.132	0.144	0.131
CW2	blind	0.085	-
CW3	0.735	0.699	-
CW5	blind	0.144	-

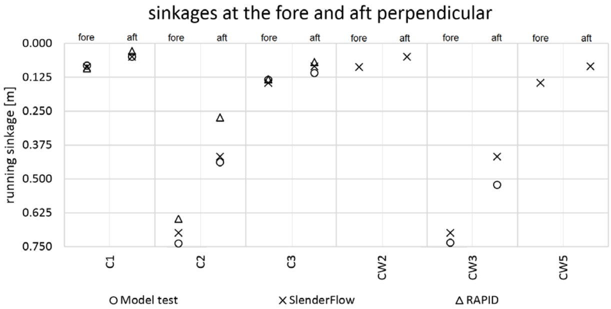

Figure 2 Sinkage results

7 RESULTS: MOTION AMPLITUDES

Motion amplitude results are shown in Table 4 to Table 8 and Figure 3 to Figure 7, for test cases CW1 to CW5.

Table 4. Results for test CW1, 100% UKC, 0 knots

	z_a/ζ	ε_a	z_f/ζ	ε_f
Model tests	0.330	52	0.502	191
DIFFRAC open water	0.262	52	0.553	176
DIFFRAC channel	0.280	25	0.615	172
HYDROSTAR	0.257	58	0.520	177
MOSES	0.272	67	0.532	178
NEMOH	0.267	57	0.526	178
OCTOPUS	0.621	105	0.188	272
PDSTRIP	0.494	90	0.419	200
SEAWAY Class. Ord.	0.674	105	0.255	256
SEAWAY Diff. Ord.	0.353	89	0.445	197
SEAWAY Class. Mod.	0.674	105	0.255	256
SEAWAY Diff. Mod.	0.353	89	0.445	197
WAMIT	0.245	59	0.513	176

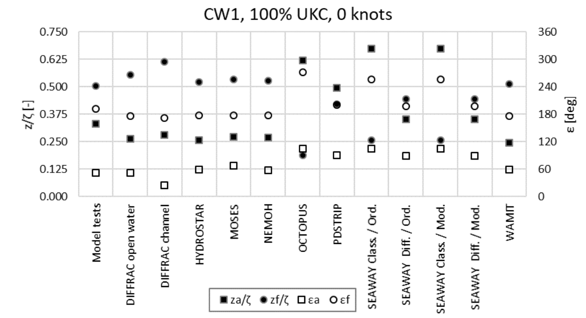

Figure 3 Results for test CW1, 100% UKC, 0 knots

Table 5. Results for test CW2, 100% UKC, 6 knots

	z_a/ζ	ε_a	z_f/ζ	ε_f
Model tests			Blind	
FATIMA	0.280	50	0.534	148
HYDROSTAR	0.420	53	0.536	161
OCTOPUS	0.635	82	0.288	237
PDSTRIP	0.585	74	0.444	179
SEAWAY Class. Ord.	0.722	86	0.394	240
SEAWAY Diff. Ord.	0.407	70	0.476	173
SEAWAY Class. Mod.	0.661	85	0.352	229
SEAWAY Diff. Mod.	0.417	68	0.498	174

Table 6. Results for test CW3, 100% UKC, 16 knots

	z_a/ζ	ε_a	z_f/ζ	ε_f
Model tests	0.282	22	0.342	133
FATIMA	0.277	355	0.427	111
HYDROSTAR	0.522	0	0.483	130
OCTOPUS	0.511	32	0.359	166
PDSTRIP	0.536	34	0.363	146
SEAWAY Class. Ord.	0.612	44	0.418	186
SEAWAY Diff. Ord.	0.432	25	0.384	142
SEAWAY Class. Mod.	0.491	39	0.342	166
SEAWAY Diff. Mod.	0.427	21	0.420	136

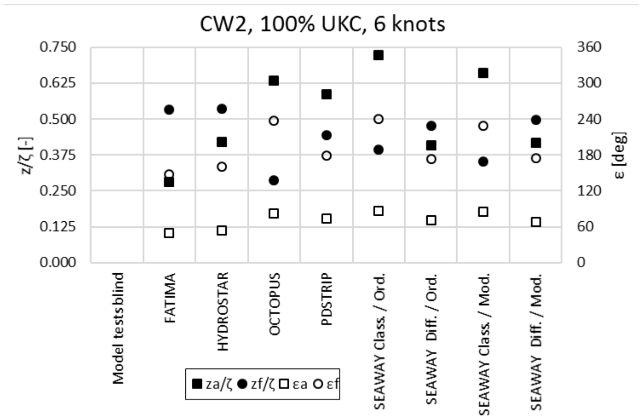

Figure 4 Results for test CW2, 100% UKC, 6 knots

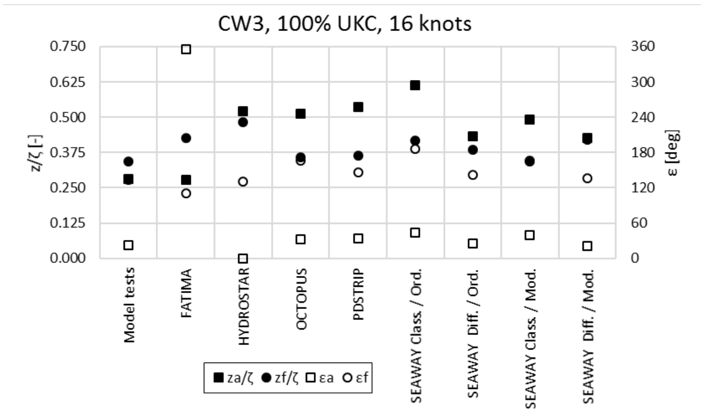

Figure 5 Results for test CW3, 100% UKC, 16 knots

Table 7. Results for test CW4, 20% UKC, 0 knots

	z_a/ζ	ε_a	z_f/ζ	ε_f
Model tests	0.275	36	0.392	180
DIFFRAC open water	0.358	57	0.465	158
DIFFRAC channel	0.353	39	0.411	176
HYDROSTAR	0.358	59	0.445	159
MOSES	0.380	64	0.452	156
NEMOH	0.368	58	0.455	161
OCTOPUS	0.538	71	0.051	273
PDSTRIP	0.563	83	0.222	187
SEAWAY Class. Ord.	0.579	59	0.175	194
SEAWAY Diff. Ord.	0.441	77	0.397	174
SEAWAY Class. Mod.	0.579	59	0.175	194
SEAWAY Diff. Mod.	0.441	77	0.397	174
WAMIT	0.349	59	0.439	158

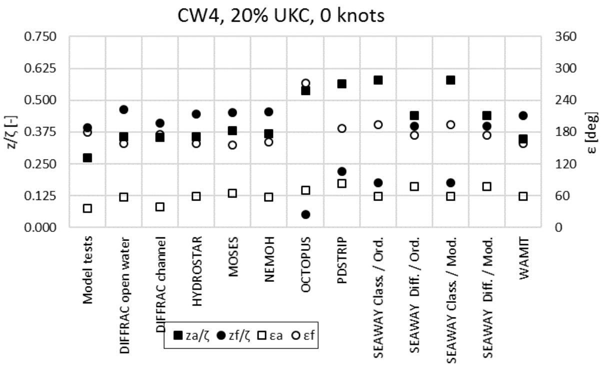

Figure 6 Results for test CW4, 20% UKC, 0 knots

Table 8. Results for test CW5, 20% UKC, 6 knots

	z_a/ζ	ε_a	z_f/ζ	ε_f
Model tests	Blind			
FATIMA	0.352	37	0.293	135
HYDROSTAR	0.474	35	0.359	154
OCTOPUS	0.501	80	0.210	258
PDSTRIP	0.586	61	0.234	204
SEAWAY Class. Ord.	0.587	49	0.247	227
SEAWAY Diff. Ord.	0.471	49	0.321	161
SEAWAY Class. Mod.	0.496	55	0.153	232
SEAWAY Diff. Mod.	0.479	47	0.352	159

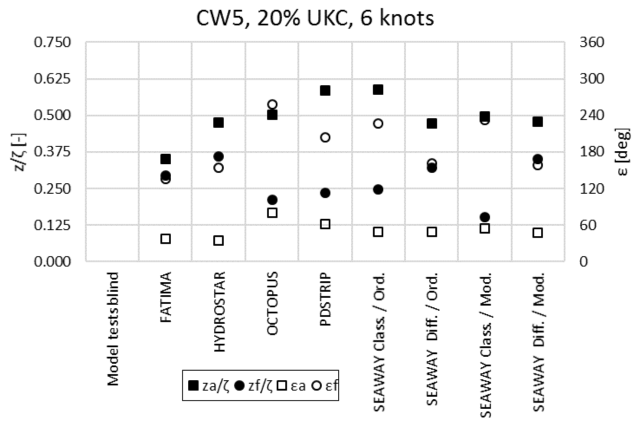

Figure 7 Results for test CW5, 20% UKC, 6 knots

8 EFFECT OF TOWING TANK WIDTH

Calculations have been done using DIFFRAC on the effect of towing tank width on wave-induced vertical motions. Results are shown in Figure 8 for 100% UKC.

We see that at certain frequencies, strong heave amplification is predicted to occur as a result of the wall effect. Strong heave amplification in towing tank model tests at particular frequencies was described in a previous benchmarking study (Gourlay et al. 2015, Figure 11).

For 20% UKC, the effect of towing tank width, as calculated using DIFFRAC, is shown in Figure 9. At the model test frequency, heave motions are predicted to be smaller in the towing tank than in open water.

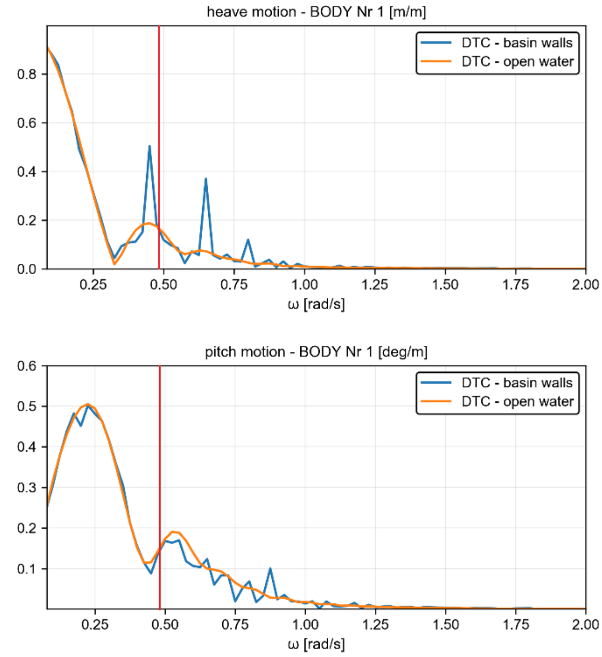

Figure 8: Heave (top) and pitch (bottom) for DTC hull at zero speed in FHR towing tank or in open water, as calculated using DIFFRAC for 100% UKC. Red line shows model test wave frequency.

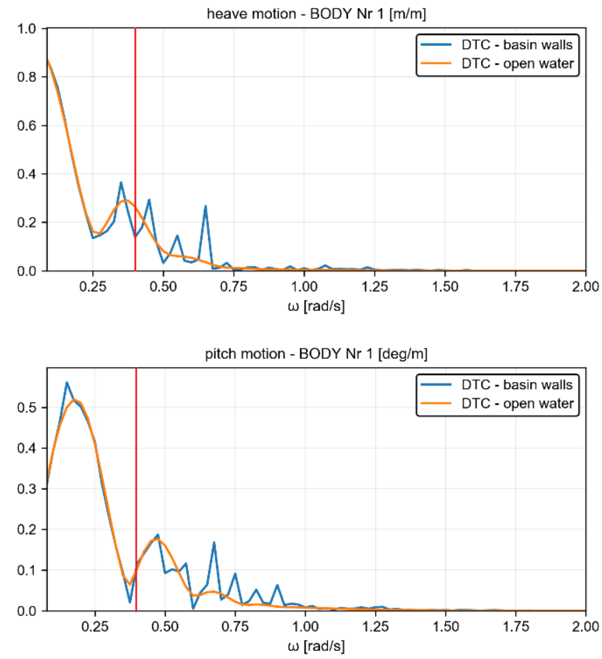

Figure 9: Heave (top) and pitch (bottom) for DTC hull at zero speed in FHR towing tank or in open water, as calculated using DIFFRAC for 20% UKC. Red line shows model test wave frequency.

9 CONCLUSIONS

Detailed conclusions on the applicability of each code may be made once the blind model test data is released. At this stage, the following preliminary conclusions may be made:

- All of the zero-speed radiation/diffraction panel codes (DIFFRAC, HydroSTAR, MOSES, NEMOH, WAMIT) give comparable results, that are much closer to the zero-speed model test results than the strip theory codes (OCTOPUS, PDStrip, SEAWAY).
- The diffraction wave load method in SEAWAY gives better results than the classical wave load method in SEAWAY, for all cases so far.
- The towing tank walls are predicted to have an important effect on vertical motions at particular frequencies.

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11 AUTHORS BIOGRAPHY

Tim Gourlay, PhD, is principal consultant at Perth Hydro. He undertakes ship hydrodynamics modelling and measurements for industry and government in Western Australia. His previous experience includes participating in a 2015 benchmarking study on model-scale ship motions in waves, as well as full-scale measurements on over 70 ships.

Evert Lataire Prof., naval architect, is currently head of the Maritime Technology Division at Ghent University. He has written a PhD on the topic of bank effects mainly based upon model tests carried out in the shallow water towing tank of FHR. His fifteen year experience includes research on ship manoeuvring in shallow and confined water such as ship-ship interaction, ship-bottom interaction and ship-bank interaction.

Guillaume Delefortrie, PhD, naval architect, is expert nautical researcher at Flanders Hydraulics Research and visiting professor at Ghent University. He is in charge of the research in the Towing Tank for Manoeuvres in Confined Water and the development of mathematical models based on model tests. He has been secretary of the 27th and 28th ITTC Manoeuvring Committee and is chairman of the 29th ITTC Manoeuvring Committee.

Luca Donatini, naval architect, is a PhD student at Ghent University. He is currently working on a project aimed at improving the modelling of hydro/meteo effects in the ship manoeuvring simulator of Flanders Hydraulic Research. His previous experiences encompass seakeeping studies to allow inland vessels on a Belgian sea trajectory and the inclusion of hydro/meteo effects in an open source mooring dynamics code. He also has an extensive experience in atmospheric and spectral wave modelling from global to regional scales.

Manasés Tello Ruiz PhD, Naval Architect and Marine Engineer, is a Research Staff at Ghent University. He has been involved in several (inter-)national projects with main focus on manoeuvring, seakeeping, and wave energy converters. Currently, he is working on ship air pollution and machine learning techniques applied to ship hydrodynamics. At present he is also a member of the ITTC Specialist Committee of Manoeuvring in Waves, at which he has been appointed as secretary.

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