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Numerical Model

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ARC7 LNG-carrier Manoeuvring

Numerical Model

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D/2019/3241/215

This publication should be cited as follows:

Villagómez, J.; Verwilligen, J.; Mostaert, F. (2019). ARC7 LNG-carrier Manoeuvring: Numerical Model. Version 2.0. FHR Reports, 17_093_1. Flanders Hydraulics Research: Antwerp.

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Document identification

Customer:	Flanders Hydraulics Research	Ref.:	WL2019R17_093_1
Keywords (3-5):	Manoeuvring model, LNG-carrier, ARC7		
Text (p.):	27	Appendices (p.):	/
Confidentiality:	☒ Yes	Released as from:	04/09/2025

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Head of Division:	Mostaert, F.	Getekend door: Frank Mostaert (Signature) Getekend op: 2020-03-03 16:52:38 +01:00 Reden: Ik keur dit document goed <i>Frank Mostaert</i>
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Abstract

The following report describes the implementation of the manoeuvring model of the ARC7 LNG-carrier. The tuning process was performed based on experimental manoeuvring tests and full scale trials. These were compared with fast simulations results. Main adaptations involved the inertial characteristics, propeller diameter and thrust, wind coefficients and the model tuning coefficients.

Manoeuvrergedrag > Open water > Simulaties

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1 General

In order to develop mathematical manoeuvring model for the ARC7, the results of previous adaptation were used. The only pod-driven scale model tested in the towing tank of FHR, concerns an estuary vessel equipped with two Z-drives (Delefortrie *et al.*, 2017), (Vos *et al.*, 2015). These pods, only allow the application of positive rpm's. An initial adaptation to the dimension of the ARC7 was performed and reported in (Vos, et al., 2018). This model was used as a training vessel for the coastal pilots of DABL.

The manoeuvring model of the estuary vessel was altered to the specifications of the ARC7-Pods and a simplified thruster model was applied in order to simulate the central pod. With this approach the operational range of the pods in the simulation model are limited to the below mentioned conditions:

- For the three pods the propeller rate is limited to positive rpm's
- For the central pod, the simplified model is only validated for longitudinal application (steering angle 0° or 180°), so no steering can be performed with the central pod.

This adaptation was taken as the base to tune the numerical results with the experimental data and full scale trials in this report.

The adaptations performed in the model are described in detail in this report. These are the following:

- The inertial characteristics of the vessel were updated.
- Modification of propeller diameter and force of the thruster.
- Tuning by comparison in experimental test.
- Tuning by comparison in full scale trials.
- Correction of wind coefficients.
- The hull coefficients were transformed to symmetrical.
- Creation of UKC conditions for the ballast loading.

2 Load Files Adaptation

Some values of inertial characteristics were modified to correspond with the available ship data. (See Table 1 and 2). The values that are not mentioned in the table remain the same. The sbw files were updated with the same corresponding values.

2.1 Load Files

Table 1 – Modifications in Load File T=9.9m (load_LNG_YAMAL_ARC7_299_500_99)

Parameter	Previous value	New value	Source
RM	103983750	104513700	2418DA101Z035-rev0-ballast_and_laden.pdf
XG	2.74	2.06	2418DA101Z035-rev0-ballast_and_laden.pdf
Frontal area wind	1837	1837	H2418_Wind Load Coefficients_to Owner.pdf
Lateral area wind	8207	8207	H2418_Wind Load Coefficients_to Owner.pdf
Wind Coefficients	See File	See File	H2418_Wind Load Coefficients_to Owner.pdf windCoeff.xls

Table 2 – Modifications in Load File – T=11.8m (load_LNG_YAMAL_ARC7_299_500_118)

Parameter	Previous value	New value	Source
RM	103983750	127269000	2418DA101Z035-rev0-ballast_and_laden.pdf
XG	2.74	-0.02	2418DA101Z035-rev0-ballast_and_laden.pdf
Frontal area wind	1837	1751	H2418_Wind Load Coefficients_to Owner.pdf
Lateral area wind	8207	7714	H2418_Wind Load Coefficients_to Owner.pdf
Wind Coefficients	See File	See File	H2418_Wind Load Coefficients_to Owner.pdf windCoeff.xls

3.1 Manoeuvring speeds for loading design condition (T=11.8m)

Table 3 – Manoeuvring speeds with 3 pods – T=11.8m

Manoeuvring speeds (3 pods)				
	RPM	UKC=150%	UKC=20%	UKC=10%
	[-]	[kn]	[kn]	[kn]
Manoeuvring Full Ahead	94	14.5	13.8	10.7
Half Ahead	73	11.3	10.8	8.3
Slow Ahead	51	7.9	7.5	5.8
Dead Slow Ahead	30	4.6	4.3	3.4

Table 4 – Manoeuvring speeds with 2 pods – T=11.8m

Manoeuvring speeds (2 pods)				
	RPM	UKC=150%	UKC=20%	UKC=10%
	[-]	[kn]	[kn]	[kn]
Manoeuvring Full Ahead	94	11.4	10.9	8.4
Half Ahead	73	8.8	8.5	6.5
Slow Ahead	51	6.2	6.0	4.6
Dead Slow Ahead	30	3.6	3.3	2.7

3.2 Manoeuvring speeds for ballasted condition (T=9.9m)

Table 5 – Manoeuvring speeds with 3 pods – T=9.9m

Manoeuvring speeds (3 pods)				
	RPM	UKC=150%	UKC=20%	UKC=10%
	[-]	[kn]	[kn]	[kn]
Manoeuvring Full Ahead	94	14.5	13.8	10.7
Half Ahead	73	11.3	10.8	8.3
Slow Ahead	51	7.9	7.5	5.8
Dead Slow Ahead	30	4.6	4.3	3.4

Table 6 – Manoeuvring speeds with 2 pods – T=9.9m

Manoeuvring speeds (2pods)				
	RPM	UKC=200%		
	[-]	[kn]		
Manoeuvring Full Ahead	94	11.8		
Half Ahead	73	9.2		
Slow Ahead	51	6.5		
Dead Slow Ahead	30	3.8		

4 Comparison with LNG carrier (ILAWA Ship Handling and Training centre)

Experimental data with a twin azipod LNG-carrier from ILAWA was partially available. Although the tests were performed in deep water and the lack of more details about the test, the results were useful to perform a general comparison with the results of the mathematical model under some tested manoeuvres. In order to assess the behavior of the model, some manoeuvres were selected to be performed by using only the two outer azipods.

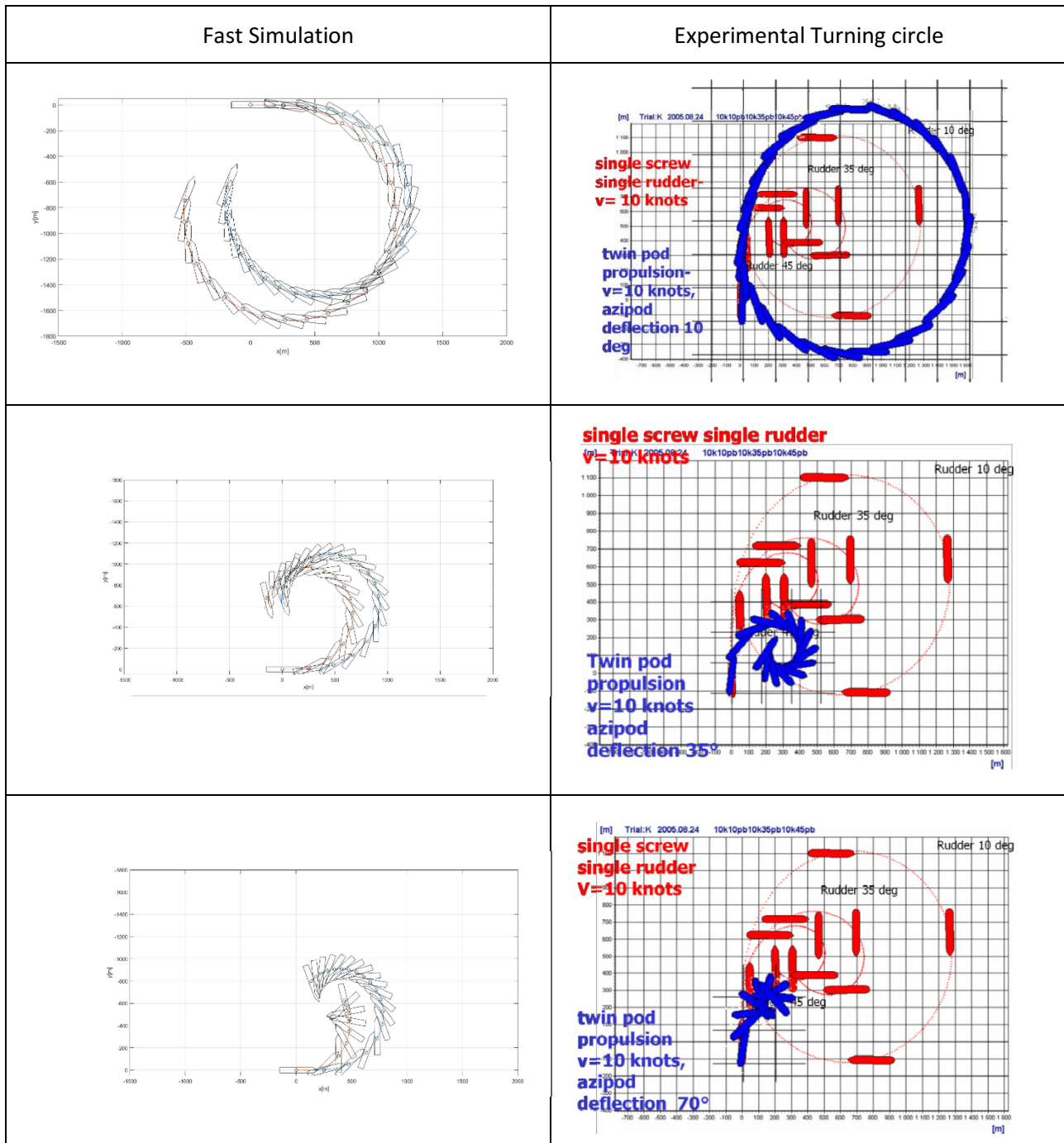
Figure 3 – Ilawa training model of a large LNG carrier equipped with two azipods



4.1 Turning circles by using 2 azipods

The experimental turning circles (right column) were performed with twin pod propulsion (blue) and with single screw (red), as showed in Figure 4. In order to compare, fast simulations of turning circle with the same deflection angles (10, 35 and 70 deg) were performed (left column). In all the cases, fast simulation were ran in the most depth available condition, 150 UKC in this case. Fast simulations show the results of both original (non-tuned) model and the tuned model.

Figure 4 – Comparison with ILAWA experimental test (right) and fast simulations (left: no-tuned (blue) and tuned (red) model)



From the Figure 4, a qualitative comparison can be done. The trajectory of simulations of the tuned model still have greater tactical diameters and advance than the experimental ones, except in the turning circle with azipod deflection of 10 degrees, in which the results are quite similar (around 1600m). Also, it can be verified that the tuning effect is to increase the turning capability of the vessel in relation to the untuned model. In order to do not modify too much the coefficients obtained from the experimental test, the variation of the tuning factors were limited. It was considered of greater importance to try to get close to the full scale trials, especially in the the zig-zag manoeuvre (See Section 1.4.3). The turning circle manoeuvre with azipods at high direction angles produces a rotation with tactical diameters less than one length of the vessel. It has been few studied, further investigation is needed in order to understand the dynamics in this situations and the capabilities of a tabular model to simulate it realistically.

4.2 Crash stop tests

Experimental results of crash stop tests were available with a two azipods model (Table 7). In general, according to opinion of Masters, the crash stop distance can be 50% of the same stopping distance compared to conventional propeller (Ship Handling Centre Ilawa). By using azipods, pilots have a choice between different modes of stopping manoeuvre:

- Stopping by changing the direction of propeller rotation.
- Stopping by turning the padded propulsor around 180deg.
- Stopping by indirect manoeuvre.

In order to evaluate the response of the mathematical model, fast simulations were performed to compare the test indicated in red (Table 7).

Table 7 – Experimental Crash Stop Tests

No	Description of stopping manoeuvre	Remarks	Stopping distance (in L)	Thrust direction when stopping
1	Stopping by changing the direction of propeller revolution	Ahead 80 rev/min Astern 100 rev/min Vo=12.5 kn Tr=60 s	2.9	
2	Stopping by turning the podded propulsors by 90o	Ahead 80 rev/min Vo=12.7 kn Pod slew velocity 7.5 deg/s	4.0	
3	Stopping by turning the podded propulsors by 90o	Ahead 80 rev/min Vo=12.7 kn Pod slew velocity 7.5 deg/s	6.4	
4	Stopping by turning the podded propulsor around (180°).	Ahead 80 rev/min Vo=12.5 kn Pod slew velocity 7.5 deg/s	3.1	

Table 8 – Crash Stop Test – Fast Simulation Results

	Maneuver	Time [s]	Distance [m]	x-Distance [m]	Stopping x-distance [m]
Tuned model		999.00	2296.21	1671.60	5.6
		1511.00	2437.15	1250.00	4.2
		156.00	676.95	674.60	2.3
Untuned model		1057.00	2476.44	1311.80	4.4
		1658.00	2923.26	809.00	2.7
		309.00	1066.61	1051.70	3.5

From the Table 8 is possible to verify that the effect of the tuning increases the stopping distance on indirect manoeuvres. However, in the stopping manoeuvre in which the vessel turns the propeller 180 deg the distance is reduced. The results of simulation are of the same order in comparison with the experimental test and they were considered realistic.

The trajectories of the crash stop test for the three maneuvers are showed in Figure 5, Figure 6 and Figure 7.

Figure 5 – Crash stop test – Stop turning the propulsor angle +90deg. Untuned (blue) and tuned (red) model

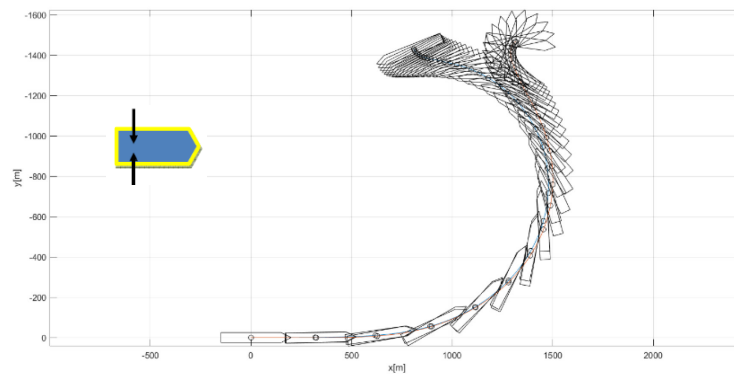


Figure 6 – Crash stop test – Stop turning the propulsor around 180deg. Untuned (blue) and tuned (red) model

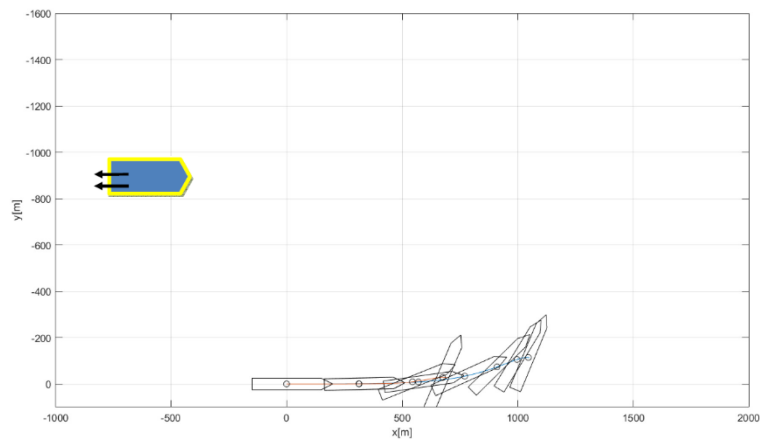
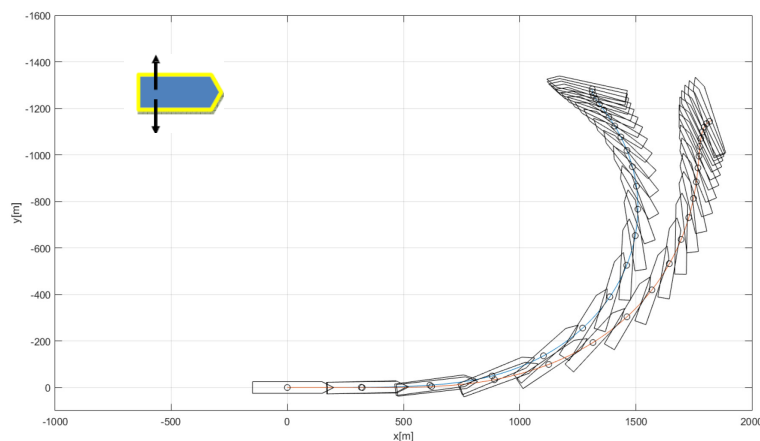


Figure 7 – Stop turning the propulsor angle -90deg. Untuned (blue) and tuned (red) model



5 Full scale trial tests

A set of full scale trial was available to compare the results of the maneuvering model. There were only used the tests with positive rpm, in order to match with the model capabilities. In this section the term “propellers” will be used to refer to the three azipods. In some tables, the central azipod is denominated as “thruster”.

5.1 Crash stop – Changing the propellers direction from 0 to 180deg

The crash stop test in full scale was available for comparison. Time series of yaw angle, travel distance, ship speed and rpm are showed in Figure 8. As the propeller angles were not provided, it was considered that the manoeuvre begins at $t=36s$ after a reduction of rpm from 137 to 85 in the three azipods. The steering rate was 2.5deg/s . For fast simulation this variation was introduced by using the AUTOPIL file. Table 9 shows the variable definition used in the file. Results are presented in Table 10.

Figure 8 – Crash stop test - Full scale Trails

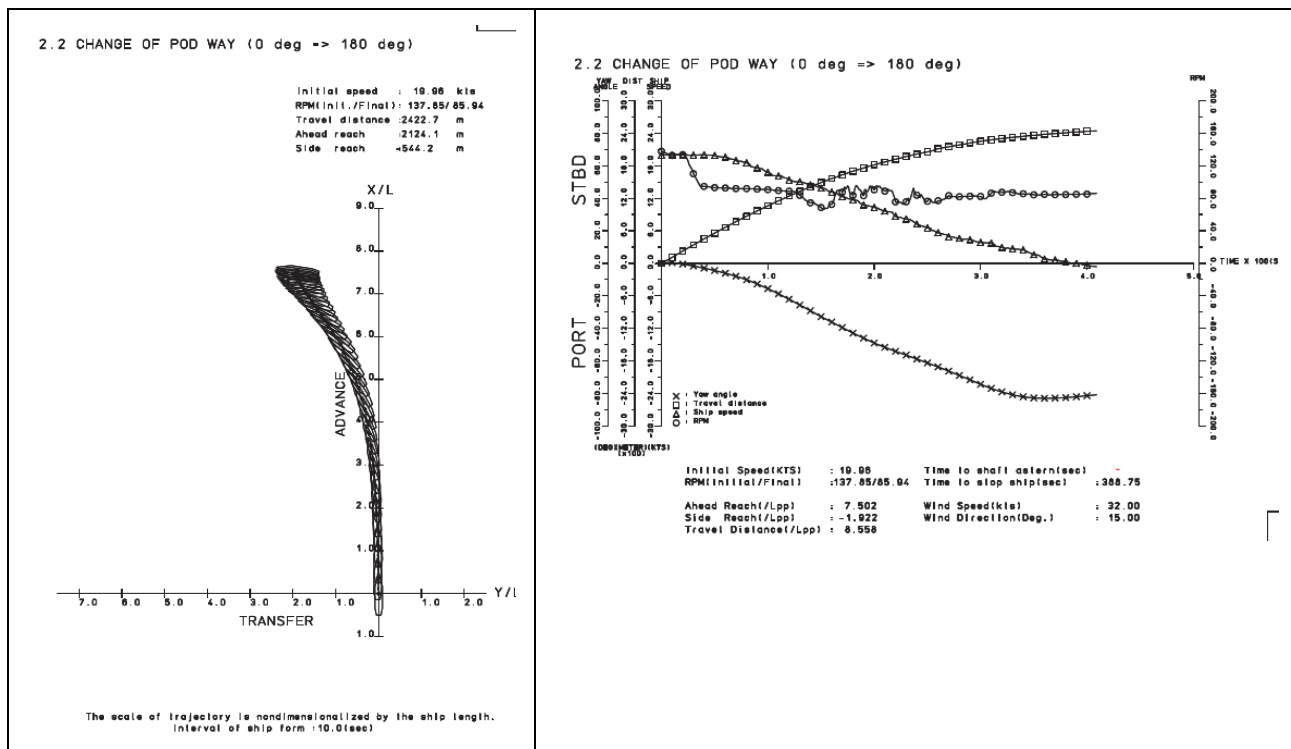


Table 9 – Crash stop – Propeller rates and direction angles

t	Propeller Rate (2POD/Thruster)		Pod/Thruster angle					
	rpm	rps	POD PS	POD SB	THRUSTER	POD PS	POD SB	THRUSTER
[s]			[deg]	[deg]	[deg]	[rad]	[rad]	[rad]
0.00	137.85	2.30	0.00	0.00	0.00	0.00	0.00	0.00
20.00	137.85	2.30	0.00	0.00	0.00	0.00	0.00	0.00
36.00	85.94	1.43	0.00	0.00	0.00	0.00	0.00	0.00
108.00	85.94	1.43	180.00	-180.00	180.00	3.14	-3.14	3.14
3600.00	85.94	1.43	180.00	-180.00	180.00	3.14	-3.14	3.14

Figure 9 – Trajectory for the crash stop from fast simulations.

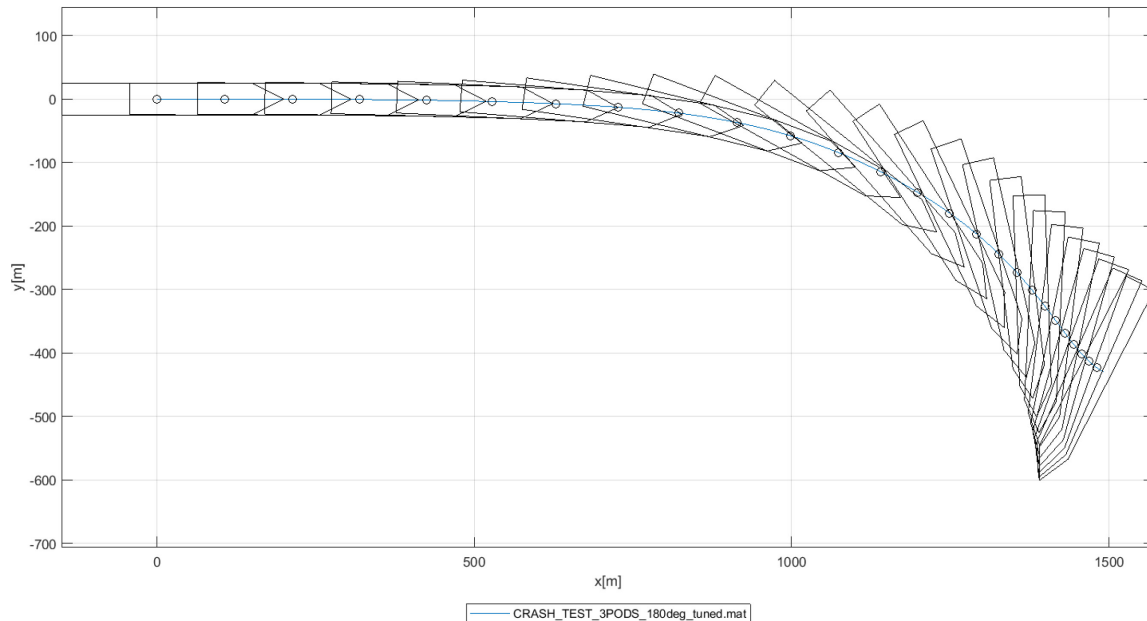


Table 10 – Crash stop - Comparison between Full scale and Fast Simulations

	Full scale test	Simulation	Units
Initial speed	19.95	21.15	knots
RPM - Initial	137.85	137.85	rpm
RPM - Final	85.94	85.94	rpm
Time to stop the ship	388.75	257.00	s
Ahead Reach/Lpp	7.50	5.23	-
Side Reach/Lpp	-1.92	-1.49	-

From the results it is possible to state that the numerical model can stop faster (around 4 min against 6 min) and has a minor ahead reach that the full scale test (around two Lpp less). The side reach is quite similar (Between 1 and two Lpp).

5.2 Turning circle 35deg (by using 3 azipods)

The full scale test presents quite interesting characteristics and some aspects that shows big differences with a conventional propulsion vessel. In the full scale trials provided (Figure 10), a great drift angle is observed, around 60 degrees. Besides, from the graphic is possible to estimate a yaw ratio approximately near to 1 deg/s. Another aspect is the fast speed drop from 18knots to 2knots. Another interesting characteristic is the high transference in the beginning of the turning circle (around 10% of the length). This combined characteristics were found very hard to reproduce in the numerical model without make big changes in the original coefficients. The results of the turning circle by using fast simulation are presented in Table 12.

Figure 10 – Full scale trials – Turning circle 35 deg.

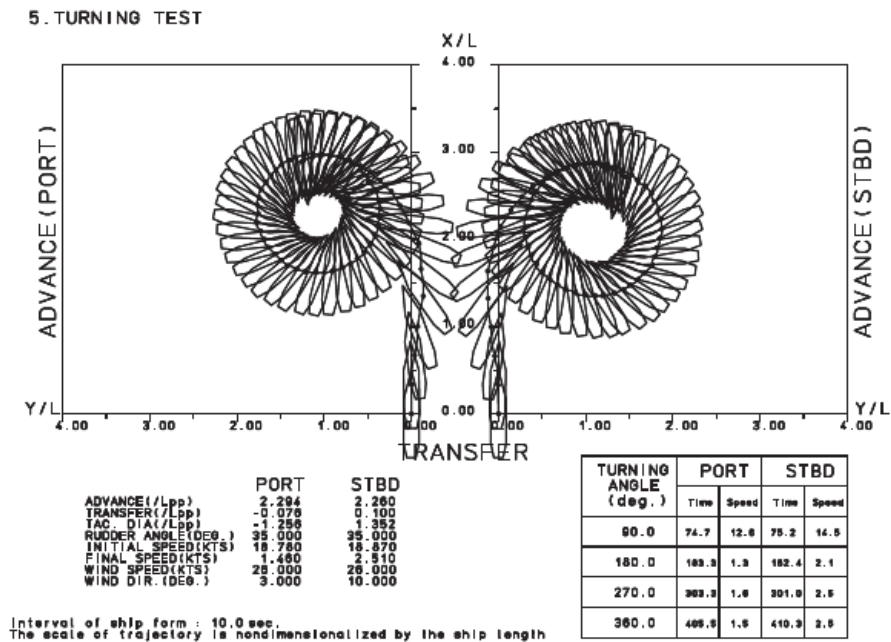


Table 11 – Turning circle – Propulsion rates and direction angles for fast simulation

t	Propulsion rates		Propulsion angle					
	rpm	rps	POD PS	POD SB	POD Central	POD PS	POD SB	POD Central
[s]			[deg]	[deg]	[deg]	[rad]	[rad]	[rad]
0.00	122.21	2.04	0.00	0.00	0.00	0.00	0.00	0.00
14.00	122.21	2.04	35.00	35.00	35.00	0.61	0.61	0.61
500.00	122.21	2.04	35.00	35.00	35.00	0.61	0.61	0.61

Table 12 – Turning circle – Full scale vs fast simulations results

	Portside		Starboard		Unit
	Full Scale Test	Numerical Model	Full Scale Test	Numerical Model	
Initial Speed	18.76	18.86	18.87	18.86	knot
Final Speed	1.48	7.08	1.352	8.60	knot
Rudder Angle	35	35	35	35	deg
Tactical Diam/Lpp	1.256	3.40	1.352	3.90	-
Advance/Lpp	2.294	2.50	2.26	2.73	-
Transfer/Lpp	0.076		0.1		-
Time 90deg	74.7	101	75.2	107	s
Time 180deg	183.3	246	182.4	253	s
Time 270deg	303.3	405	301.0	411	s
Time 360deg	405.5	566	410.3	570	s
Speed 90deg	12.6	10.8	14.5	11.28	knot
Speed 180deg	1.3	7.7	2.1	9.14	knot
Speed 270deg	1.6	7.16	2.5	8.69	knot
Speed 360deg	1.5	7.08	2.5	8.69	knot
Final Drift Angle	60(*)	29.22	60(*)	33.45	deg

Figure 11 – Trajectory of Port side turning circle – Fast simulation

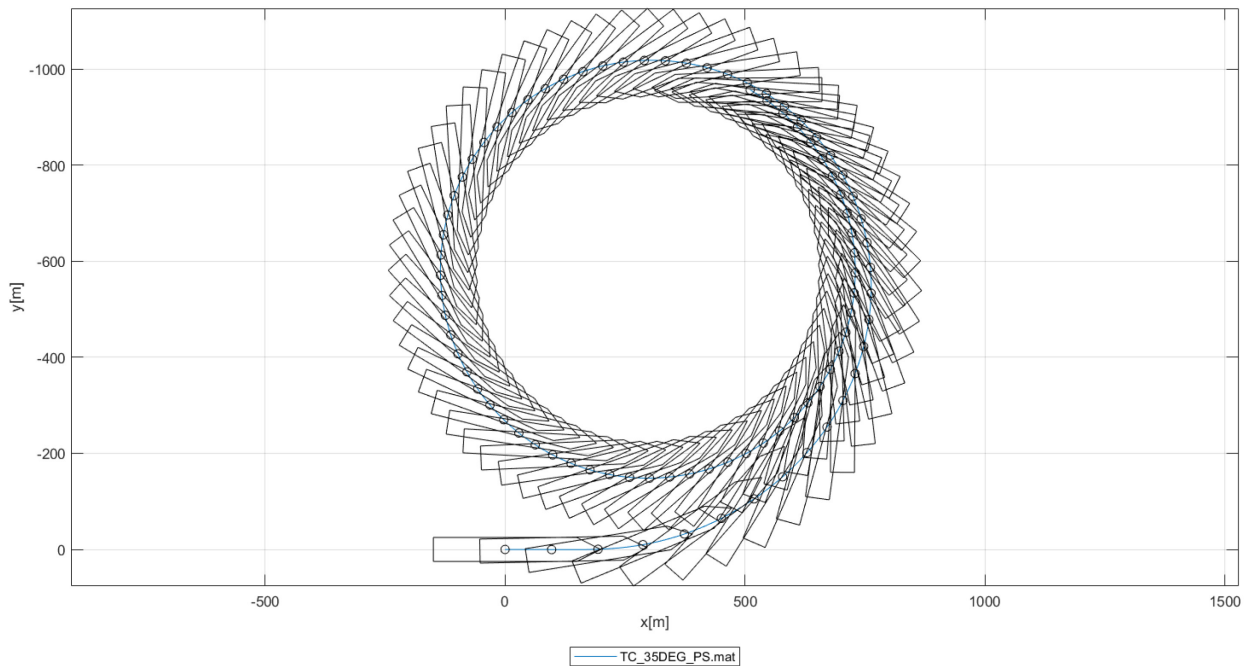
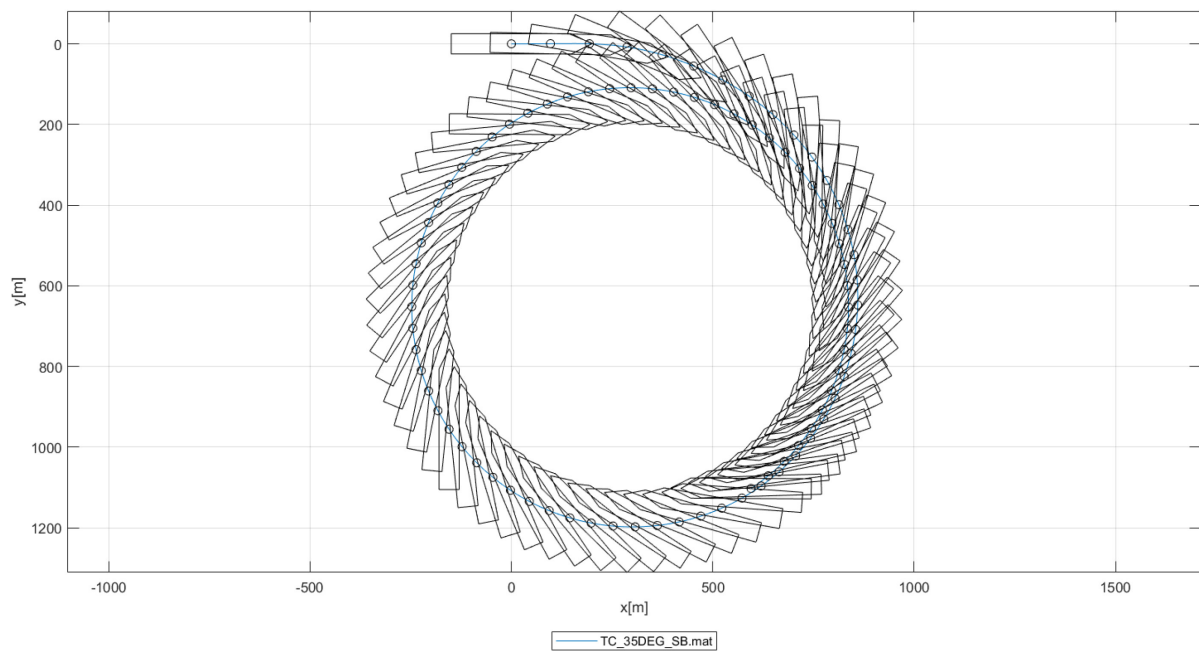


Figure 12 – Trajectory of Starboard turning circle – Fast simulation



It is clear that the turning capability of the full scale turning circle is higher than the tuned model. In the simulations, the tactical diameter is around 2 times greater than the results of the full scale trials. In another hand, the advance is quite similar. The steady drift angle in simulation is around 30deg and in the full scale is around 60deg. This impacts in the final steady speed: 2 knots from full scale trials and around 8 knots in simulations. After many attempts to improve these characteristics, it was considered to focus in the zig-zag manoeuvre in order to avoid modifying the tuning factors too much.

5.3 ZIG ZAG Maneuver 20/20 (by using 3 propellers)

Figure 13 and Figure 14 show the evolution of the full scale trials of the zigzag 10/10 and 20/20 manoeuvres, respectively. The AUTOPIL file was used to reproduce both the initial speed (18.66kn) and the propulsion direction in the time. The 20/20 zigzag manoeuvre was selected to make a comparison with fast simulations. The manoeuvre was simulated in the most deeper condition available(150UKC) by using only two outers azipods and three azipods. The initial speed for all simulations is the same, note that rpm's in the case with two azipods is greater than the maximum rpm of the pods (135 rpm). This was necessary in order to reproduce the same initial conditions of the full scale trials. The load design draft and the ballasted draft were simulated, however the tuning was done trying to match the load design condition. The results of simulation are showed in Figure 15 and Figure 17.

Figure 13 – Full scale trials -ZigZag manoeuvre 10/10

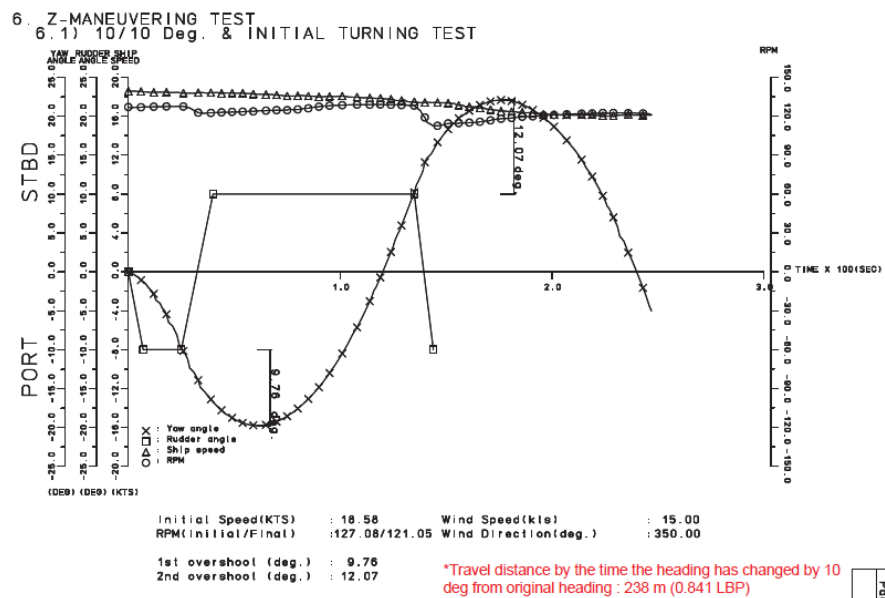
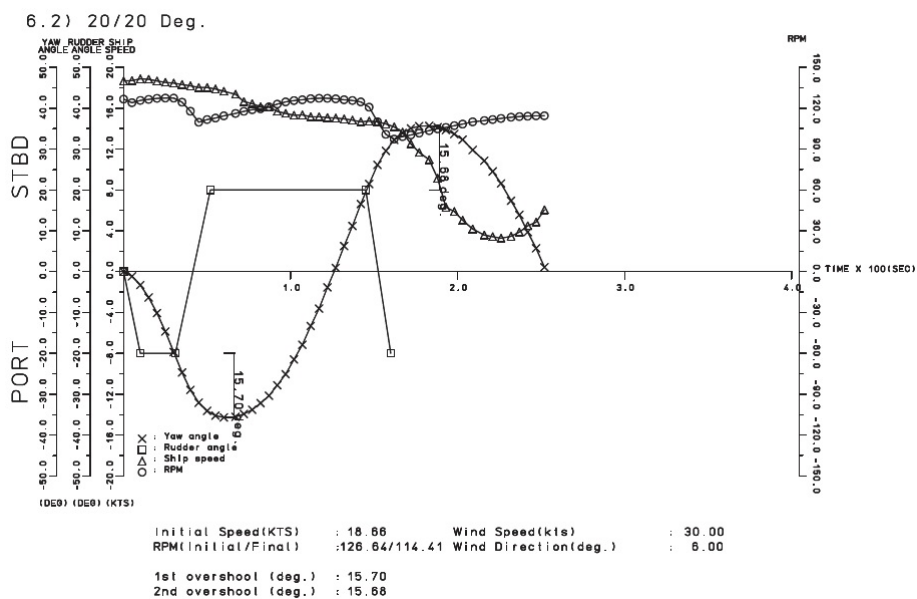


Figure 14 – Full scale trials -ZigZag manoeuvre 20/20



The result of zig-zag simulation for the load design draft shows that response by using two or three azipods is quite similar because the final thrust is the same due the same initial self-propulsion speed. The results shows a quite similar first overshoot angle (33deg vs 35deg) between. The reach time are 116 s and 127 s for simulation and full scale trial, respectively (Figure 15). Although the turning rates are still smaller in the simulation, the general behavior presents a good agreement in the first stage of the manoeuvre. The yaw rate evolution turn during the simulation is presented in Figure 16.

Figure 15 – Simulation Zig zag test vs Full scale – Load design condition – Test with 2 and 3 azipods

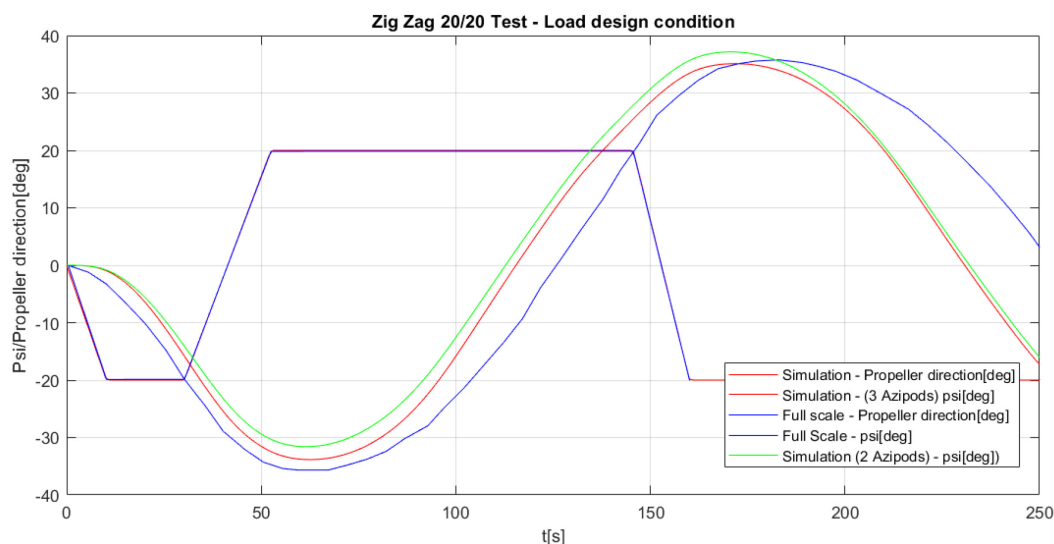


Figure 16 – Simulation ZigZag - Yaw rate evolution – Load design condition

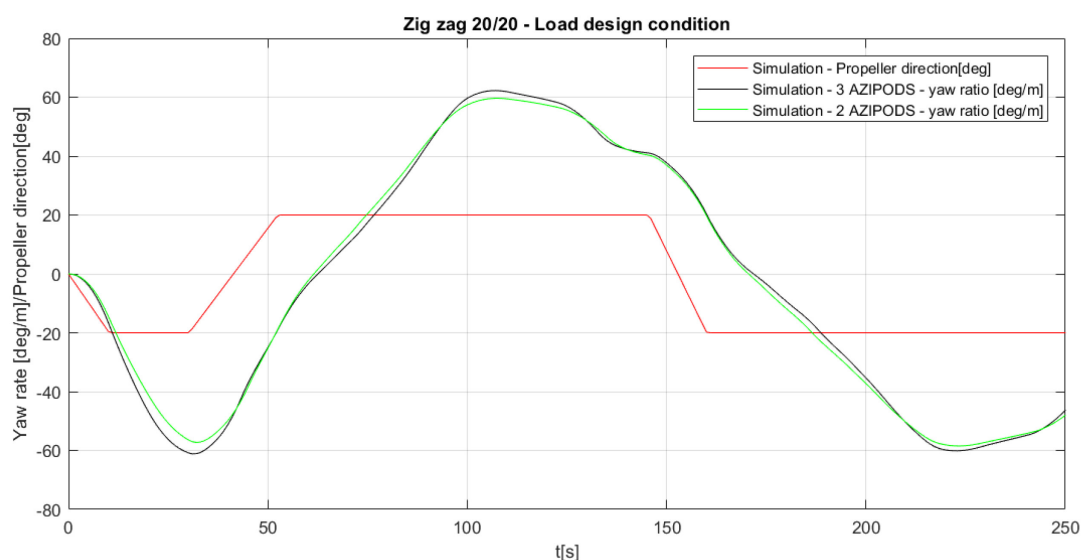


Figure 17 – Simulation Zig zag test vs Full scale - Ballast condition – Test with 2 and 3 azipods

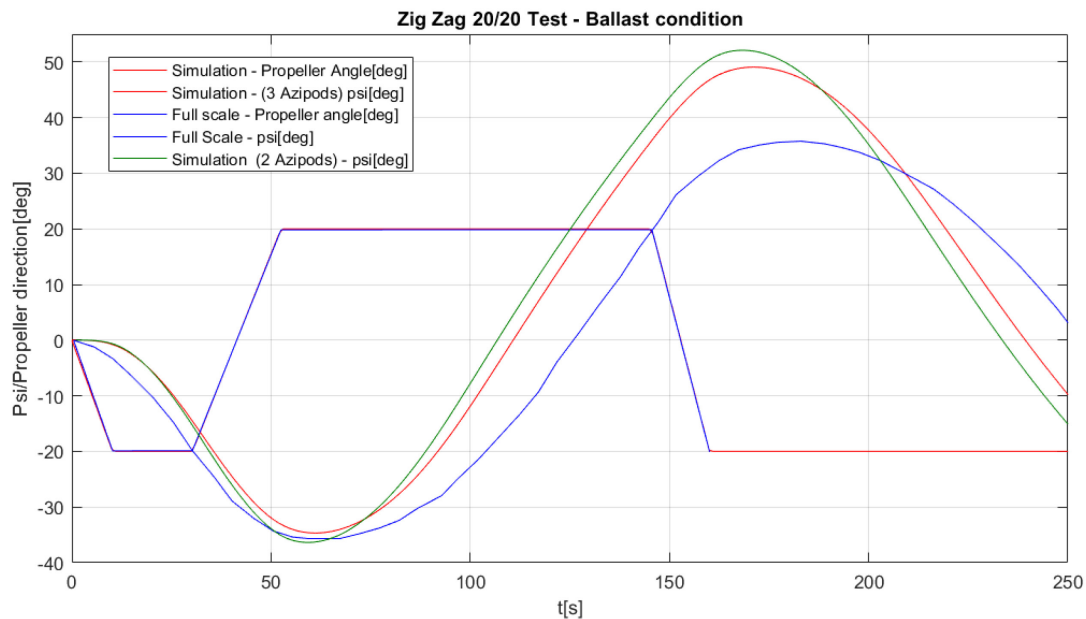
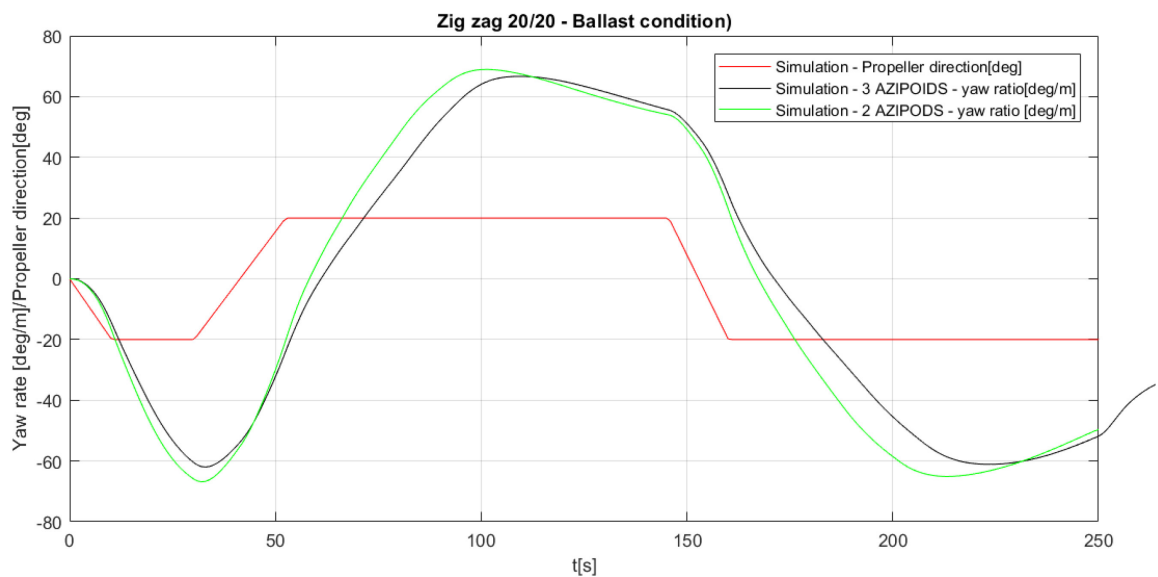


Figure 18 – Simulation ZigZag - Yaw rate evolution - Ballast condition



In order to try a better match in the first stage of the zig-zag manoeuvre and do not increase more the rudder/propeller tuning factors, it was explored the possibility to modify the yaw inertial term. It is known that both presence and configuration of skegs can affect significantly the turning capacity specially by using azipods (Ship Handling Centre Ilawa). In Figure 19, some experimental tests with different skeg configuration are showed and their impact in both tactical diameter and advance. We can assume that the submersed geometry can modify terms related with the turning moment, as N_{γ} and $N_{\dot{\gamma}}$. In this case, a reduction of the 50 percent in the added inertia was tested (Figure 20). After the validation campaign with pilots (Verwilligen, et al., 2019), it was decided to not modify the values of $N_{\dot{\gamma}}$ and keep them in their original values.

Figure 19 – Comparison of Tactical Diameter and Advance with different skog configurations (Ilawa)

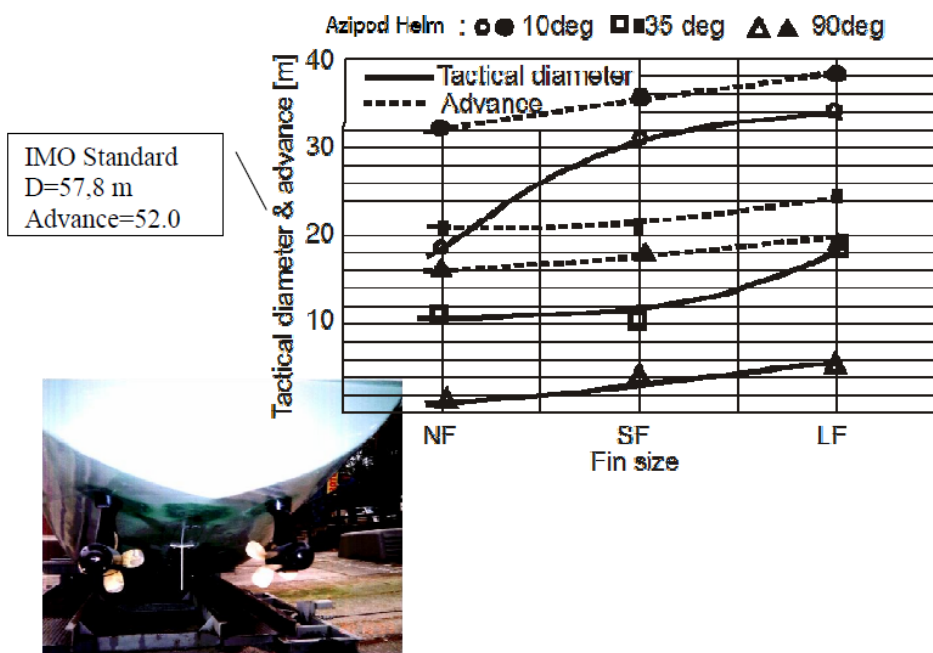
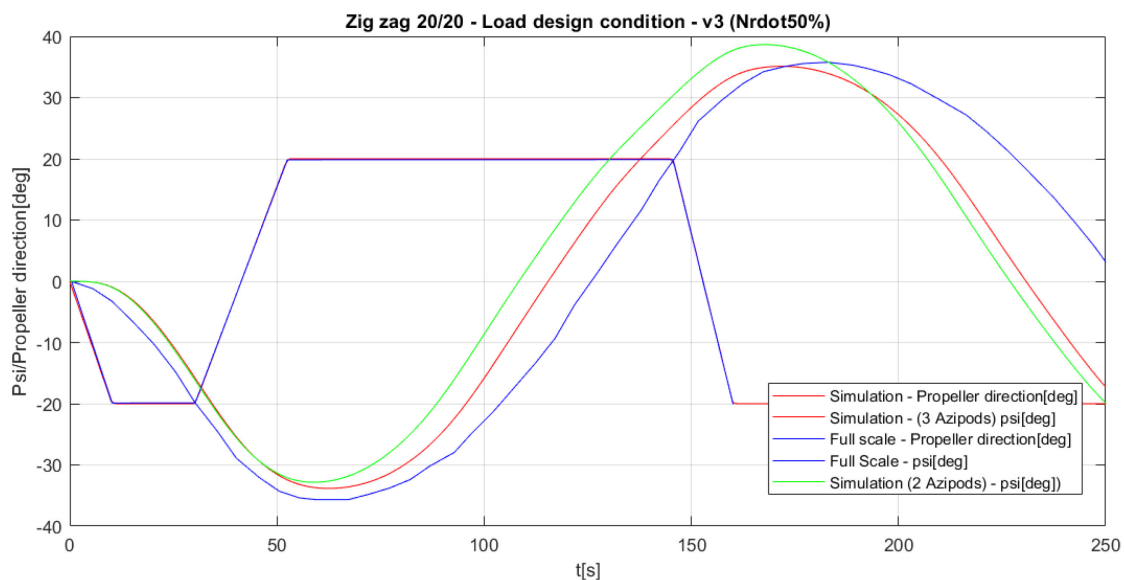


Fig. 6.12 Model of a large LNG carrier equipped with twin pods: turning circle from 6 knots. NF – no skog; SF- small central skog (fin) located in the axe of ship symmetry; LF- large central skog (fin) [4]. Length of the model about 11m

Figure 20 – Zigzag manoeuvre with a reduction of 50% in the Nrdot term.



6 Fast simulation by using tugs instead of propulsion

A verification of the general behavior of the vessel was performed by using the two azipods (PS and SB) with two different initial speeds (+2knots and -2knots) and low propeller rates (-0.5 rps and +0.5rps). The tug force was taken from the equivalent pullout force of a unique azipod acting in the same direction.

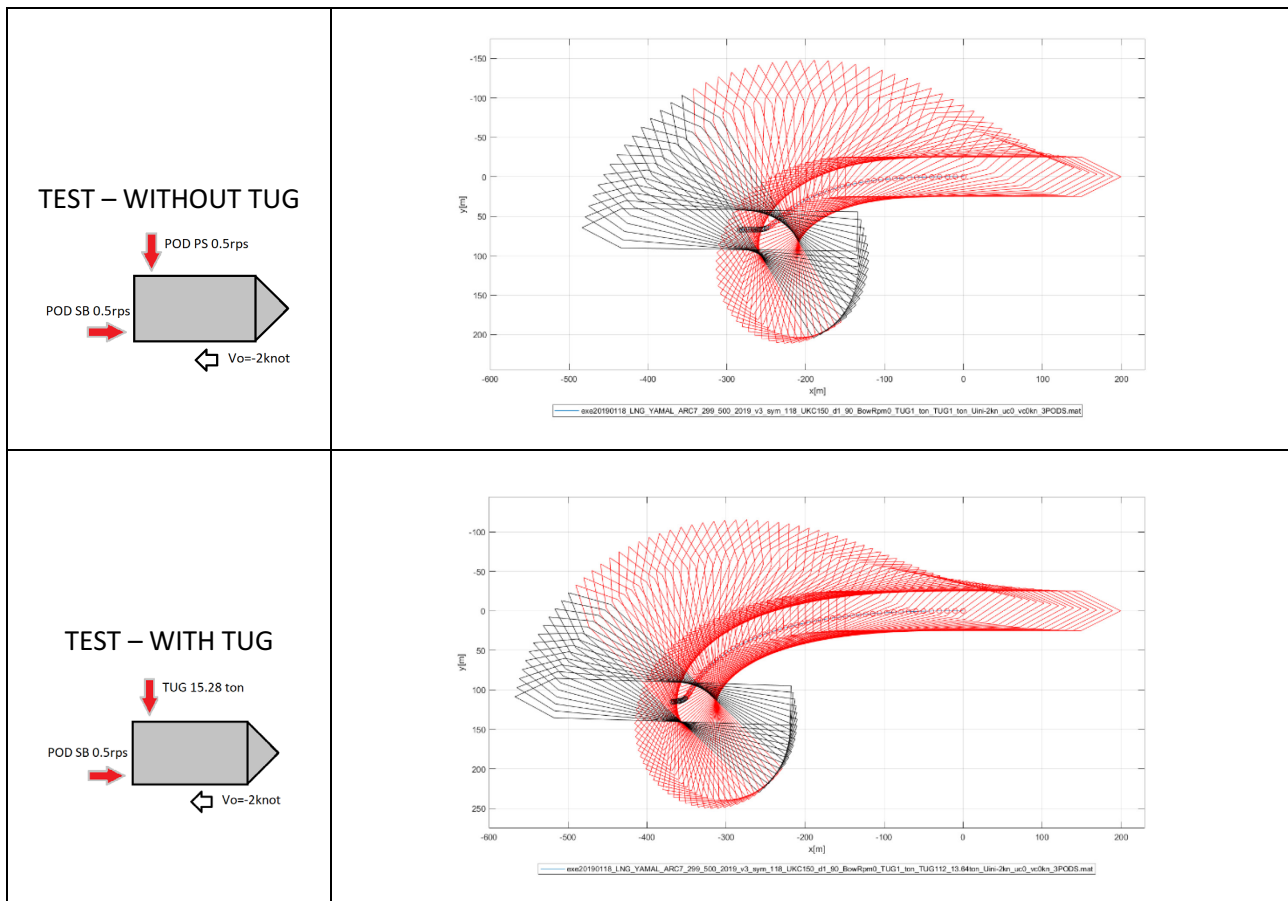
The test were performed comparing the two following configurations.

1. The first configuration is with the starboard azipod at zero degrees and the port side azipod at 90 degrees.
2. The second configuration replaces the port azipod by a tug pushing with an equivalent force.

6.1 TURNING 180deg – Initial speed -2knots

The simulation begins with an initial speed of -2 knots (astern) and it stops when the yaw angle reaches 180deg, as showed in Figure 21. The vessel motion plotted with red color means negative longitudinal speed and black color positive speed.

Figure 21 – Manoeuvre with tug – Negative Initial speed: - 2 knots.

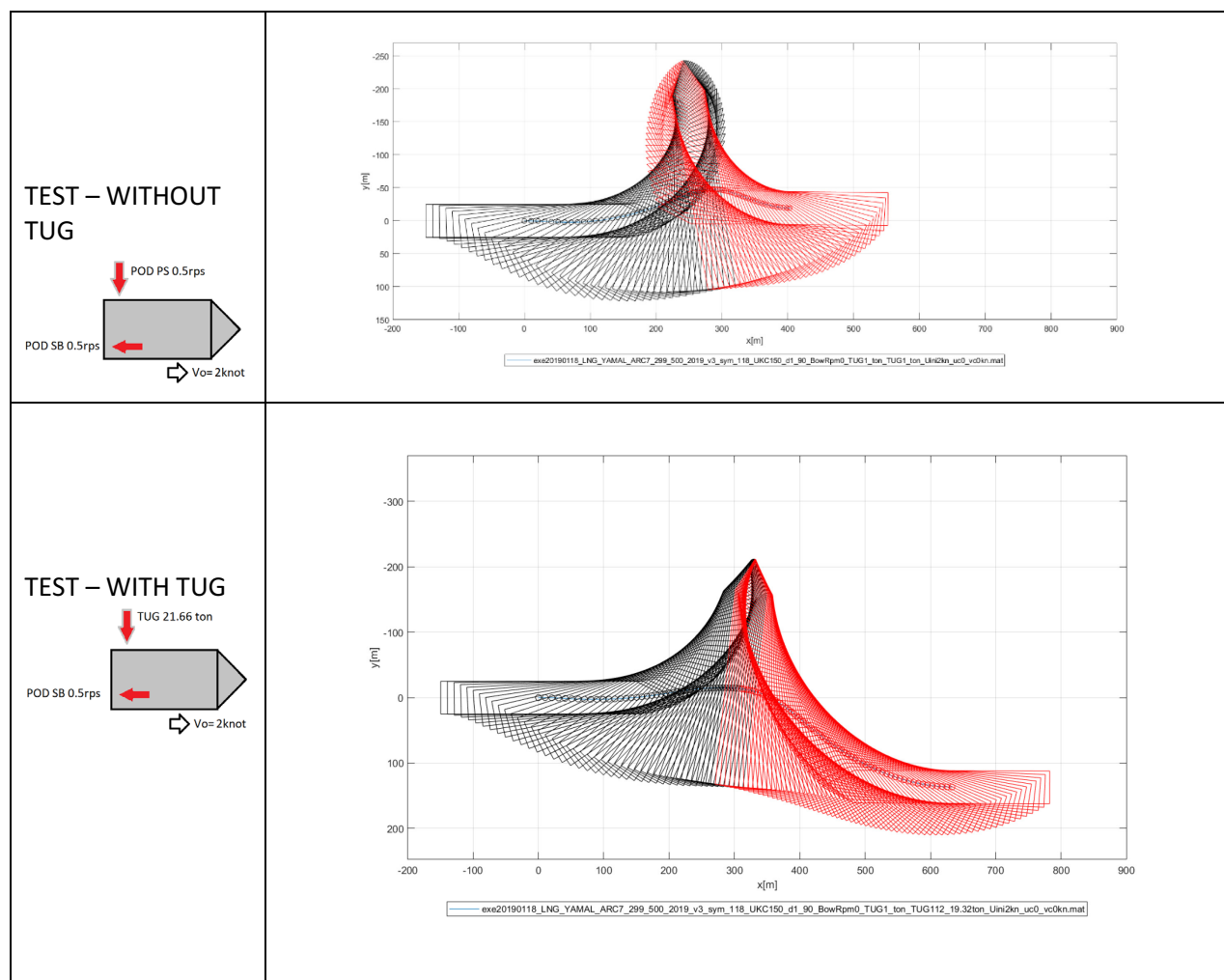


It seems coherent that the turning using a tug take more longitudinal distance to reach 180 deg because at the beginning of the manoeuvre with two pods, both of them works with a positive thrust along the x-axis. In this case, the port side azipod take some seconds to reach its final position at 90 deg. In this time the longitudinal component slows down the vessel more than when two azipods are used. This does not occurs when only a tug is used, in consequence, the turning has a greater longitudinal displacement.

6.2 TURNING 180deg – Initial speed +2knots

The same procedure is performed by using a positive initial speed (2knots) and negative propeller rate (-0.5rps). Results are showed in Figure 22.

Figure 22 – Manoeuvre with tug – Positive Initial speed: 2 knots.



In the same way that the previous case, it is possible to say that the longitudinal component of the portside azipod at the beginning of the simulation slows down faster the vessel than when only the tug is used.

7 Tuning factors

It was implemented a set of new UKC's for the ballast draft. Only one depth water condition for the ballast condition was available from experiments. The coefficients of the experiment with the loading design draft were used to set the corresponding UKC's for the ballast draft. Table 13 presents the complete list of available conditions, including the new ballast implemented files (blue).

Table 13 – Design and ballast files – Coefficients and dcoef files.

	sbw file	T	h	UKC	coeff file	dcoeff file
DESIGN	sbw_E0101A01	11.78	29.45	150%	E0101A01	dcoeff_E0101A01
	sbw_E0101A02	11.78	15.9	35%	E0101A02	dcoeff_E0101A02
	sbw_E0101A03	11.78	14.14	20%	E0101A03	dcoeff_E0101A03
	sbw_E0101A04	11.78	12.98	10%	E0101A04	dcoeff_E0101A04
BALLAST	sbw_E0102A01 (*Deleted)	9.9	29.5	198%	E0102A01	dcoeff_E0102A01
	sbw_E0101A01_ballast	9.9	24.75	150%	E0101A01	dcoeff_E0101A01
	sbw_E0101A02_ballast	9.9	13.365	35%	E0101A02	dcoeff_E0101A02
	sbw_E0101A03_ballast	9.9	11.88	20%	E0101A03	dcoeff_E0101A03
	sbw_E0101A04_ballast	9.9	10.89	10%	E0101A04	dcoeff_E0101A04

In the case of 198UKC for the ballast condition was detected very high values of both time and angle of the first overshoot for zig zag maneuvers 20/20 in relation with the design condition. As the drafts are very similar it was not expected too much difference. It was decided to assume the coefficients of the depth water condition used in the design condition to replace the coefficient of the ballast condition.

Table 14 – Tuning factors of dcoef files

	Ybeta	Nbeta	Ngamma	Fy	NR
dcoeff_E0101A01	0.50	0.70	0.50	2.00	2.00
dcoeff_E0101A02	1.00	0.70	1.00	1.30	1.30
dcoeff_E0101A03	1.00	0.70	1.00	1.00	1.00
dcoeff_E0101A04	1.30	0.70	1.30	1.00	1.00
dcoeff_E0102A01	1.00	1.00	1.00	1.00	1.00

Table 14. Tuning factors of dcoef files Table 14 presents the final dcoef files used in the model. Modification in parameters were done for different reasons:

- Fy and NR were increased to reach higher turning yaw rate.
- Ybeta was decreased to increase the drift angle and Nbeta decreased to keep the directional stability.

The variation of tuning coefficients were performed trying to preserve low values and a certain continuity with the different UKC.

8 Wind coefficients

The wind coefficients were taken from the document: “H2418_Wind Load Coefficients_to Owner.pdf”. An adaptation of the incidence angles were performed due the angle definition in this document. The average of the symmetrical angles was calculated and shown in the following tables.

8.1 Load Design Condition

Table 15 – Wind coefficients - Load condition

Angle sim	Cx	Cy	Ck	Cn
[deg]	[-]	[-]	[-]	[-]
0	0.735	0	0	0
10	0.759	0.113	0.1445	-0.039
20	0.825	0.2635	0.3225	-0.0775
30	0.774	0.42	0.5015	-0.1095
40	0.6825	0.5905	0.7085	-0.1345
50	0.5095	0.695	0.834	-0.1345
60	0.3275	0.8095	0.9605	-0.1235
70	0.1465	0.8755	1.016	-0.108
80	-0.013	0.8865	1.0115	-0.0795
90	-0.0875	0.9275	1.046	-0.0515
100	-0.0985	0.981	1.105	-0.0325
110	-0.1465	0.9275	1.0545	-0.0135
120	-0.2285	0.8385	0.964	0.0025
130	-0.3415	0.765	0.8825	0.011
140	-0.4845	0.6525	0.755	0.011
150	-0.6405	0.501	0.5745	0.005
160	-0.726	0.3125	0.354	0.004
170	-0.756	0.148	0.1665	0.002
180	-0.769	0	0	0

8.2 Ballast Condition

Table 16 – Wind coefficients – Ballast condition

Angle	Cx	Cy	Ck	Cn
[deg]	[-]	[-]	[-]	[-]
0	0.738	0	0	0
10	0.781	0.12	0.1635	-0.0415
20	0.8055	0.265	0.3375	-0.0795
30	0.774	0.4395	0.5535	-0.115
40	0.644	0.605	0.7555	-0.1385
50	0.484	0.7355	0.914	-0.1415
60	0.3135	0.812	0.996	-0.1255
70	0.1355	0.9215	1.1025	-0.113
80	-0.021	0.947	1.1095	-0.082
90	-0.101	0.9635	1.1115	-0.052
100	-0.09	0.954	1.0905	-0.025
110	-0.1365	0.977	1.1285	-0.0085
120	-0.2185	0.877	1.0225	0.0115
130	-0.332	0.82	0.9565	0.023
140	-0.479	0.69	0.8075	0.0185
150	-0.63	0.5205	0.605	0.0115
160	-0.721	0.328	0.377	0.008
170	-0.747	0.1555	0.177	0.0035
180	-0.784	0	0	0

Figure 23 – Cx Wind coefficient – Ballast and design condition.

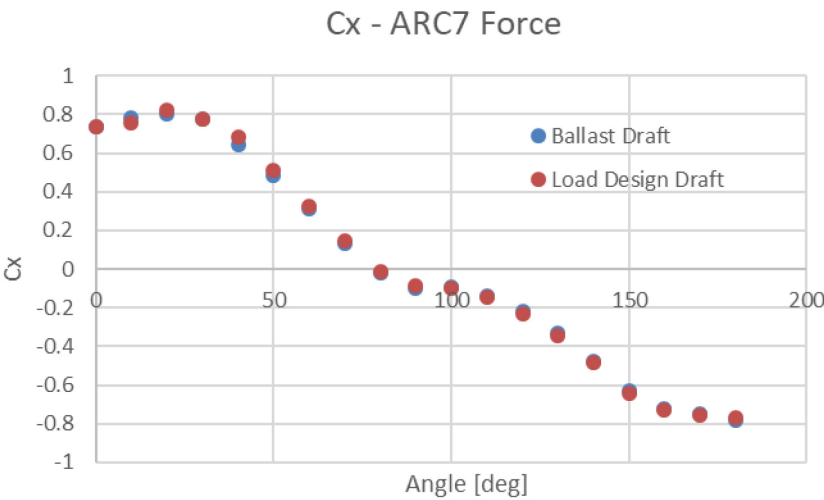


Figure 24 – Cy Wind coefficient – Ballast and design condition.

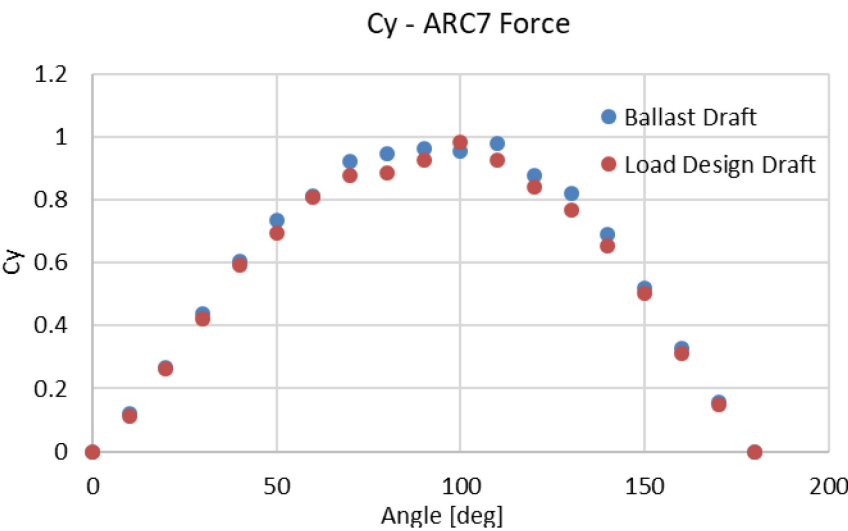
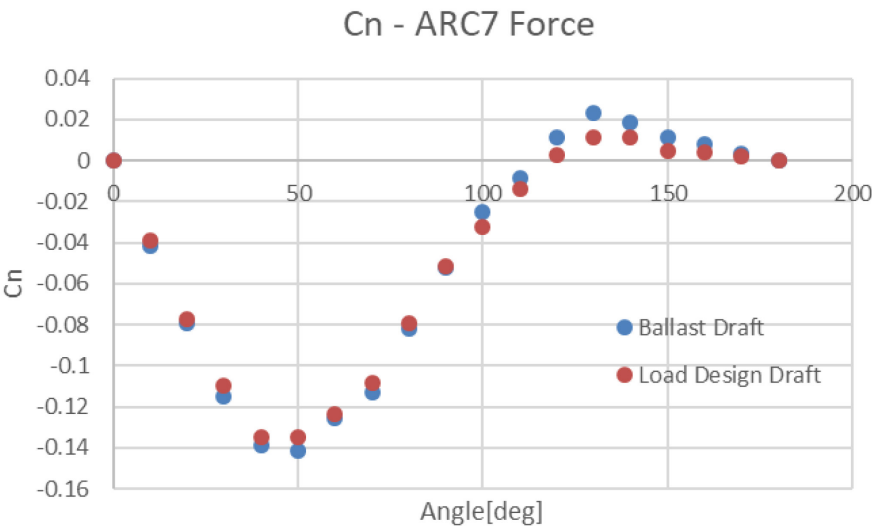


Figure 25 – Cn Wind coefficient – Ballast and design condition.

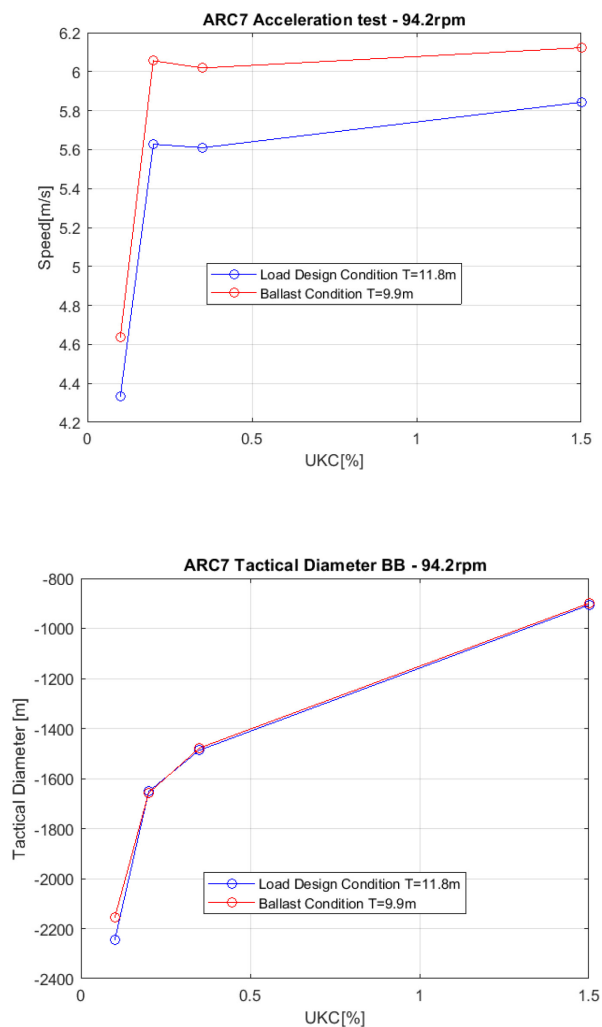


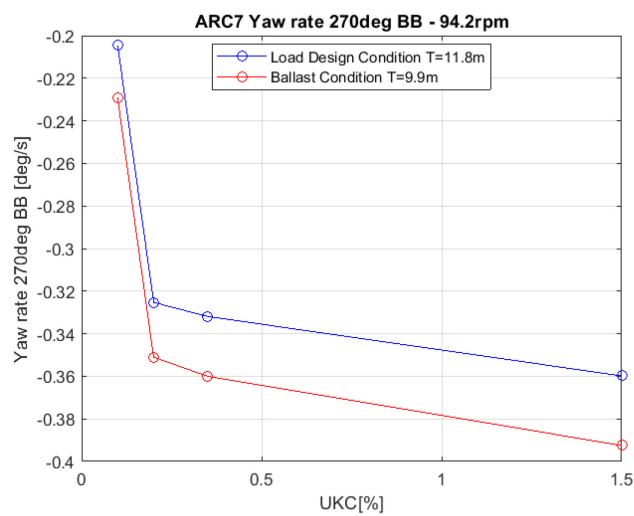
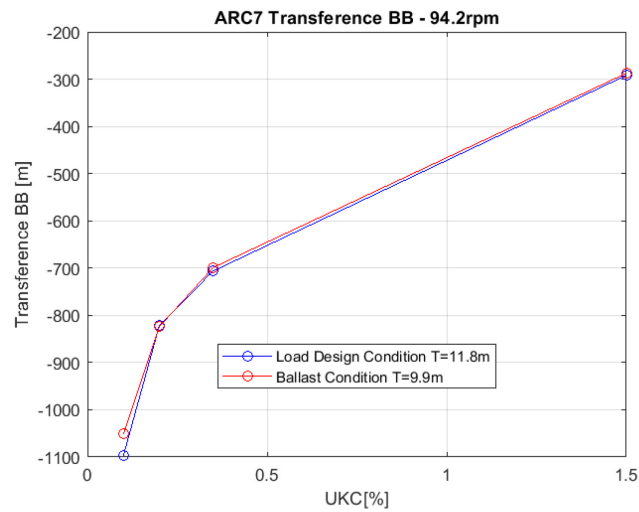
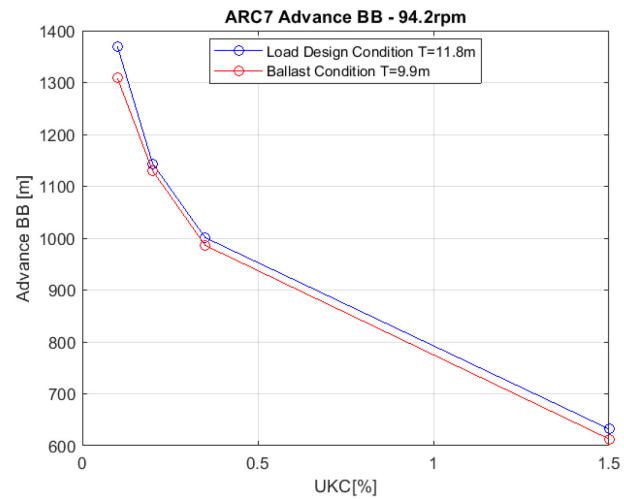
9 Summary of fast simulations

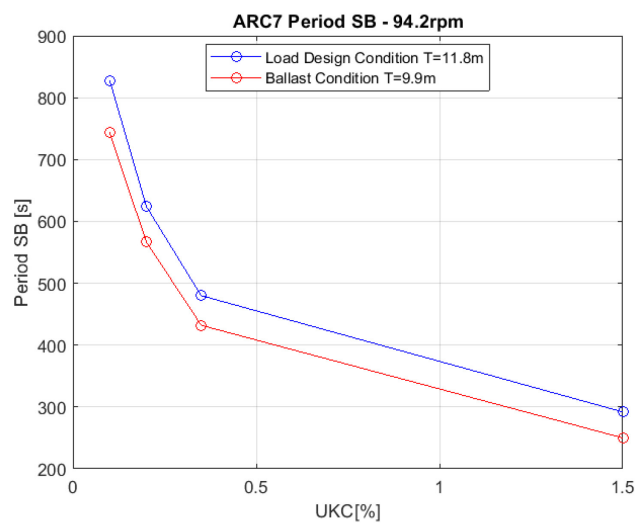
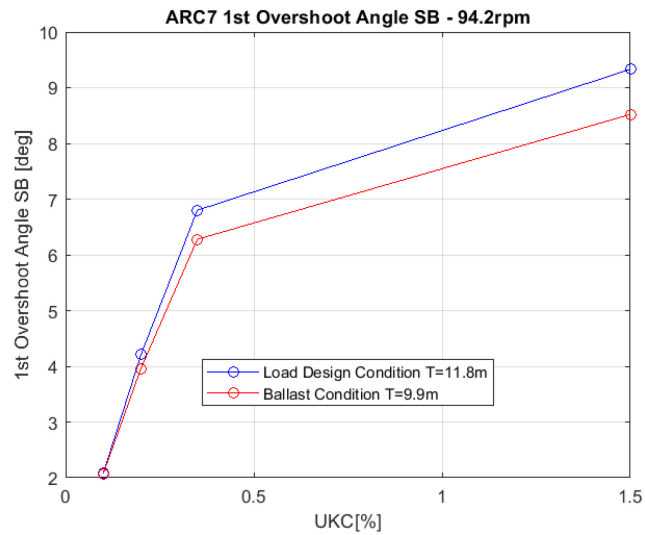
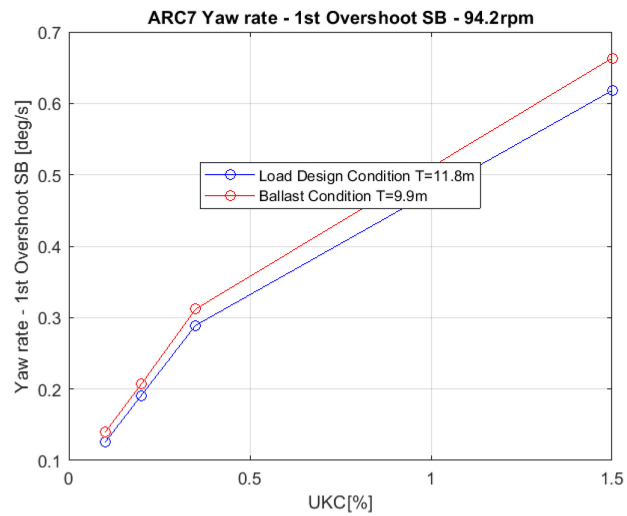
The following fast simulations results for all the UKC and the two load conditions at full ahead (94.2rpm) are presented:

- Initial Speed from acceleration tests
- Turning circle: Advance, Turning circle, yaw rate at 270deg.
- Zig zag: First overshoot angle and period

Figure 26 – Fast simulations results (Acceleration, turning circle and zigzag tests)







10 Conclusions

The modifications performed in the propeller diameter and the thrust allow the model reproduce well the self-propulsion speeds and rpm's according to the cart of the pilot.

Some differences are found trying to reproduce the turning circles manoeuvres: shorter drift angles and higher tactical diameters in relation with full scale trials need further investigation to be more accurately modeled. After many attempts to improve these characteristics, it was considered to focus in the zig-zag maneuver in order to avoid modifying the tuning factors too much. In another hand, the zig zag full scale trial was well reproduced by the model with the tuning coefficients modifications.

In the process of construction of the model some discontinuities in the hull forces were found. To solve this issue the hull coefficients were transformed in symmetrical, in exception of $ChiPNT_{table}$ and $ChiPT_{table}$. This Improved the overall performance in symmetrical maneuvers (i.e. turning circle for both port side and starboard).

11 References

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