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Accessibility of Car and Truck Carriers of Wallenius-Wilhelmsen to the port of Zeebrugge

Sub report 2
Development and validation of a Car and Truck Carrier

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Accessibility of Car and Truck Carriers of Wallenius-Wilhelmsen to the port of Zeebrugge

Sub report 2 – Development and validation of a Car and Truck Carrier

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Abstract

This report had been written but not finished in 2013 while executing the simulation study in the framework of the accessibility study of car carriers of Wallenius to the port of Zeebrugge. Two simulation models for a 227 m Car Carrier and a 200 m Car and Truck Carrier had been developed but finally only the 227 m Car Carrier was evaluated as being realistic. In this report the available data and the procedure for the scaling of the simulation models is described and the full or partial results are summarised.

If the simulation models for the Fidelio and the MS Tosca will be used for a study or training, the manoeuvring characteristics should be recalculated with the latest executable of the simulation software. The simulation results in this report are probably not identical anymore.

Fields of knowledge: Manoeuvreergedrag – open water – simulaties

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1 Introduction

This report gives a summary of the tasks and results for the modelling of a 227 m and a 200 m car carrier of Wallenius and Wilhelmsen.

A question form with an overview of the requested information for the ship characteristics had been sent to the shipping company. Based on information found on the website of Wallenius it can be recognised that all vessels are Panamax size. One vessel in service with a length over all of 227 m has been selected by the shipping company out of their fleet (199 m, 227 m and 265 m vessels). The 265 m vessels are according to captain Henry Bromeé Mark-V type vessels. The ship mathematical model Odyssea in the simulator database of FHR (used during the visit of captain Bromeé on the 7th of March 2013) is based on information from Mark-V vessels and could be further adjusted to the Wallenius fleet if information is made available. The information can be used for the scaling of existing simulation models to the Wallenius fleet. Nevertheless, based on the visit of the 7th of March and the meeting with Owner Annika Bootsman Kleberg and Capt. Henry Bromeé on the 5th of June, the focus will be on a 227 m vessel and the actual 200 m and 265 m vessels will be available in the simulator database as back-up (if data information is provided for these vessels by the shipping company).

In 2015 the shipping company will have 200 m vessels in operation with a wider beam of 36 m. This vessel type must not be considered.

The report is subdivided in:

- summary of the data for the 227 m car and truck carrier;
- development of the simulation models of the 227 m car and truck carrier;
- summary of the data for the 200 m car and truck carrier;
- development of the simulation models of the 200 m car and truck carrier.

2 Data of the 227 m Car and Truck Carrier

2.1 General information

The ship characteristics are given by the shipping company for the MS Faust and Fedora, LCTC[1] with a length over all of 227.8 m (Table 1). These ships are equipped with a single fixed pitch propeller and a Becker rudder (with flap).

Table 1 – Characteristics of the LCTC Faust

Length over all	[m]	227.8
Length between perpendiculars	[m]	219.3
Beam	[m]	32.26
Depth	[m]	34.7
Draught (fully loaded)	[m]	9.5
Longitudinal position of centre of gravity at fully loaded condition	[m]	105.13 from A.P.
Displacement	[tons]	42,300
Dead Weight tonnage (at maximum draught)	[tons]	30,100
Block coefficient	[-]	0.6116
Engine type	[-]	B&W 8S60ME
Power	[kW]	15,800
Number of revolutions, propeller	[rpm]	105
Service speed	[kn]	20
Number of propellers	[-]	1
Diameter of propeller (D)	[m]	6.6
Number of blades	[-]	5
Pitch ratio of propeller (P/D)	[-]	1.013
Area ratio of propeller (A_E/A_0)	[-]	n/a
Number of rudders	[-]	1
Rudder type	[-]	Becker full spade with flap
Maximum rudder angle	[deg]	64 (normal 35)
Rudder area	[m^2]	36
Bowthruster	[kW]	2000
Sternthruster	[kW]	-
Frontal wind area	[m^2]	1132
Lateral wind area	[m^2]	6885

[1] Long Car and Truck Carrier

2.2 Manoeuvring information from wheelhouse poster and sea trials

Besides the general information in 2.1 for the development of a mathematical manoeuvring model the manoeuvring characteristics from the wheelhouse poster and the sea trials must be examined:

- wheelhouse poster from the Fedora, document 4446DA101Z034-001-B(A)-15-0_Wheelhouse_poster.pdf
- sea trials data from the Fidelio (Figure 1): 4445DA101Z033-001-B(A)-14-0_Sea_trial.pdf

Figure 1 – Fidelio in Zeebrugge (source marinetraffic.com)

2.2.1 Wheelhouse poster

Based on the wheelhouse poster of the Fedora, characteristics of the following trials can be found:

- acceleration test with telegraph – speed table;
- turning circle;
- crash stop and inertia test.

An important remark while considering the data shown on the wheelhouse poster is that the source of the information is not always clear (e.g. the acceleration test) and that for the turning circle results the values at normal full loaded condition are estimated by the shipyard and must consequently be considered with caution.

Acceleration test

The source of the acceleration test and the resultant telegraph – speed table (Table 2) on the wheelhouse poster is not clear. Additionally for dead slow to harbour full ahead the resultant speed is larger at full loaded condition than at ballast condition despite the smaller mass of the vessel at ballast condition. This unnatural difference in speed for loaded and ballast condition is visualized in Figure 2.

At sea full ahead the speed in ballast condition is larger than at loaded condition which is expected and in correspondence with the sea trial data at this telegraph position. For the other telegraph positions estimated values are probably taken which are not corrected based on the sea trial data.

Figure 2 – Speed – propeller rate relationship for loaded and ballast condition of the Fedora

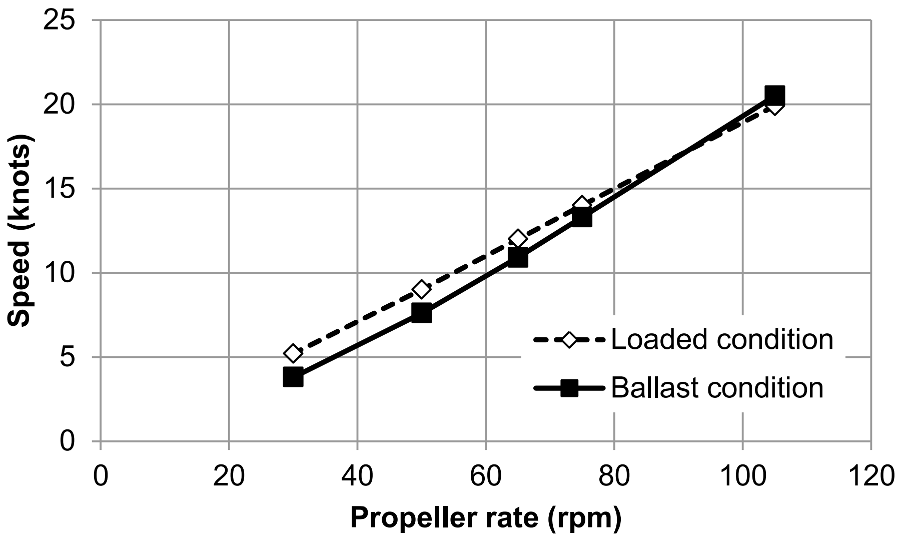

Table 2 – Telegraph – speed table of the Fedora

		Loaded	Ballast
Telegraph	Propeller rate	Speed	Speed
	[rpm]	[knots]	[knots]
SEA FULL AHEAD	105	19.9	20.5
FULL AHEAD	75	14.0	13.3
HALF AHEAD	65	12.0	10.9
SLOW AHEAD	50	9.0	7.6
DEAD SLOW AHEAD	30	5.2	3.8

Turning circle manoeuvre

The turning circle manoeuvres are reported on the wheelhouse poster for a normal ballast condition at sea full ahead (97.5 rpm) and half ahead (65.0 rpm) speed and for a normal full loaded condition in deep and shallow water for full sea and half speed. The maximum rudder angle applied during the turning circles is 35 deg. The results are reported in Table 3 and Table 4. Some doubtful values are highlighted in italic and seen in the sea trial data at ballast condition. The influence of the environmental circumstances during the trials will have been responsible for the varying speed values at the different time steps.

Table 3 – Turning circle at wheelhouse poster: characteristics for full sea speed, rudder angle 35 deg

		Normal ballast (sea trial)		Normal full loaded (estimated)	
		PORT	STARBOARD	PORT	STARBOARD
Advance/Lpp	[-]	1.88	2.38	3.07	3.12
Transfer/Lpp	[-]	1.10	1.41	1.54	1.55
Tact. Diam./Lpp	[-]	2.09	2.41	3.48	3.52
Initial speed	[knots]	20.5	20.5	19.9	19.9
Final speed	[knots]	4.8	*7.8*	6.5	6.7
Time 90 deg	[s]	84	92	106	103
Speed 90 deg	[knots]	9.9	8.5	11.0	11.4
Time 180 deg	[s]	209	184	223	219
Speed 180 deg	[knots]	*3.0*	8.5	7.8	7.9
Time 270 deg	[s]	308	294	354	353
Speed 270 deg	[knots]	5.8	*3.9*	6.8	6.9
Time 360 deg	[s]	412	446	491	492
Speed 360 deg	[knots]	4.8	*7.8*	6.5	6.7

Table 4 – Turning circle at wheelhouse poster: characteristics for half speed, rudder angle 35 deg

		Normal ballast (sea trial)		Normal full loaded (estimated)			
		Deep water		Deep water		Shallow water	
		PORT	STARBOARD	PORT	STARBOARD	PORT	STARBOARD
Advance/Lpp	[-]	1.77	1.96	2.94	2.95	3.24	3.26
Transfer/Lpp	[-]	0.97	0.82	1.51	1.49	2.44	2.43
Tact. Diam./Lpp	[-]	1.69	1.29	3.41	3.42	4.91	4.88
Initial speed	[knots]	10.9	10.9	12.0	12.0	NA[2]	NA
Final speed	[knots]	2.6	*5.9*	4.5	4.6	7.9	7.9
Time 90 deg	[s]	139	151	159	159	185	186
Speed 90 deg	[knots]	8.3	*4.5*	7.1	7.1	9.4	9.4
Time 180 deg	[s]	296	270	333	336	366	366
Speed 180 deg	[knots]	*2.6*	*1.1*	5.2	5.2	8.5	8.4
Time 270 deg	[s]	417	401	526	533	557	559
Speed 270 deg	[knots]	*2.6*	*3.6*	4.6	4.7	8.1	8.1
Time 360 deg	[s]	546	559	725	735	753	756
Speed 360 deg	[knots]	*2.6*	*5.9*	4.5	4.6	7.9	7.9

[2] Not available

Zigzag manoeuvre

There is no information available on the wheelhouse poster for the zigzag manoeuvres.

Crash stop manoeuvre and inertia test

The estimated data from the crash stop and inertia tests taken from the wheelhouse poster are shown in Table 5.

Table 5 – Crash stop and inertia data at wheelhouse poster

		Loaded condition		Ballast condition	
		Time [s]	Distance [m]	Time [s]	Distance [m]
Using engine full astern	Full sea speed	482	2684	471	2455
	Full speed	489	2199	458	1952
	Half speed	478	1918	394	1521
Using engine stop	Full sea speed	1432	5326	1208	4352
	Full speed	1370	4464	1138	3604
	Half speed	1328	4014	1091	3216

2.2.2 Sea trial data

The sea trial report from the Fidelio contains trial results of the IMO standard manoeuvres executed at a ballast draft of 8.018 m, which differs from the design draft of 9.5 m and the usual draft of 9.0 m during operation at the port of Zeebrugge.

These sea trial data will thus have to be translated to the ship behaviour at larger draft as model tests at different drafts executed at Flanders Hydraulics Research with a ship model of a containership have shown that the manoeuvring behaviour of a vessel changes with the actual draft of the vessel ([1] and [2]).

A summary is given of the available information from the full scale trials at ballast draft for:

- an acceleration test;
- a turning circle manoeuvre;
- a zigzag manoeuvre.

Acceleration test

Speed tests are executed at sea full telegraph position. Different runs have been repeated to be able to set up a speed-power-rpm curve. These tests do not give real values at lower telegraph positions.

Turning circle manoeuvre

The turning circle manoeuvres are available for full sea speed at two rudder angles 35 and 65 degrees (Table 6) while at half speed only the 35 deg turning circles have been executed (Table 7). The trial data are influenced by the environmental circumstances, giving speed variations during the turning circles which are rather unnatural.

Table 6 – Turning circle at sea trial (ballast draft): characteristics for full sea speed, rudder angle 35 or 65 deg

		Rudder angle 35 deg		Rudder angle 65 deg	
		PORT	STARBOARD	PORT	STARBOARD
Advance/Lpp	[-]	1.880	2.386	2.622	3.006
Transfer/Lpp	[-]	-1.1	1.416	-1.842	1.582
Tact. Diam./Lpp	[-]	-2.092	2.406	-3.716	2.508
Initial speed	[knots]	19.6	18.7	18.9	20.0
Final speed	[knots]	4.798	7.752	4.508	5.9
Time 90 deg	[s]	84.4	91.5	132.9	135.0
Speed 90 deg	[knots]	9.9	8.5	11.7	6.1
Time 180 deg	[s]	209.0	184.4	337.2	275.0
Speed 180 deg	[knots]	3.0	8.5	4.5	9.6
Time 270 deg	[s]	308.0	294.0	478.3	455.2
Speed 270 deg	[knots]	5.8	3.9	9.1	4.9
Time 360 deg	[s]	411.6	445.6	646.7	617.6
Speed 360 deg	[knots]	4.8	7.8	4.5	5.9

Table 7 – Turning circle at sea trial (ballast draft): characteristics for half speed, rudder angle 35 deg

		PORT	STARBOARD
Advance/Lpp	[-]	1.776	1.956
Transfer/Lpp	[-]	-0.966	0.818
Tact. Diam./Lpp	[-]	-1.694	1.292
Initial speed	[knots]	12.1	12.0
Final speed	[knots]	2.612	5.9
Time 90 deg	[s]	139	151.1
Speed 90 deg	[knots]	8.3	4.5
Time 180 deg	[s]	296.6	269.7
Speed 180 deg	[knots]	2.6	1.1
Time 270 deg	[s]	417.3	401.3
Speed 270 deg	[knots]	0.0	3.6
Time 360 deg	[s]	545.8	558.6
Speed 360 deg	[knots]	2.6	5.9

Zigzag manoeuvre

The zigzag manoeuvres are available for full sea speed at 10/10[3] and 20/20 (Table 8).The first and second overshoot angle differ considerably with first a course change to port followed by a course change to starboard.

Table 8 – Zigzag manoeuvre at sea trial (ballast draft): characteristics of 20/20 and 10/10 tests

		20/20	10/10
Initial speed	[knots]	19.5	19.8
RPM (initial/final)	[rpm]	102.4/98.7	102.5/101.6
First overshoot angle	[deg]	18	11
Second overshoot angle	[deg]	9.4	7.7

[3] rudder angle/course change

2.2.3 Comparison of the data from the sea trial and the wheelhouse poster

The sea trial data and the data on the wheelhouse poster are identical for the reported trial data on the wheelhouse poster which confirms the exact reporting of the trial data without a correction between them for the environmental circumstances such as the wind effect. The full scale trials have been executed at a draft of 8.018 m so that it can be supposed that for the design draft of 9.5 m the characteristics will be different as well. Research at the Towing Tank for Manoeuvres in Shallow Water for (slender) container ships have shown that a ship is becoming more stable with decreasing draft. Supposing that this trend can also be used for the development of the PCTC Fidelio (although the rather small change of the draft between ballast and loaded condition with 1.5 m) the consequence will be that the manoeuvrability of the ship at design draft could be better than what is seen during the full scale trials at ballast draft.

2.3 Becker rudder

The finished plan of the Becker Flap rudder from the Fidelio is made available. This plan contains a general view about the efficiency of the Becker-High-Performance rudder equipped to single screw vessels and its use. *The main advantage of the Becker rudder is that already at smallest rudder angles a high side force is generated*[4]*.*

The maximum side force is reached at approximately 30 to 35 deg, whereas the flap stands at 60 to 70 deg to ship's center line. At rudder angles of 45 deg or bigger (flap over 90 deg) the Becker rudder can be used as stern thruster. At these angles the side force is a little less than the maximum side force, but there is a minimum of residual longitudinal thrust.

When running astern, the helm should not be put to more than 10 deg (flap 20 deg) in order not to destroy too much the water flow to the propeller.

No graph with the variation of the side force or lift coefficient C_L as function of the rudder angle or inflow angle to the rudder is given but the performance description of the Becker rudder system should be used as background for modeling.

[4] Text in italic is taken from document BeckerRudderFaust.pdf

3 Development of the 227 m Car and Truck Carrier

Based on the information made available by the shipping company a mathematical manoeuvring model is developed for a 227 m car and truck carrier in deep and shallow water. The methodology and the manoeuvring characteristics of the developed simulation model of the ship Fidelio are described in this chapter. All results are calculated with an executable of the simulator software available in 2013. If the simulation models will be used in future projects the fast time simulations results should be repeated with the latest available executable.

3.1 Methodology

At Flanders Hydraulics Research mathematical manoeuvring models can be developed in two ways:

- based on scaling of existing mathematical manoeuvring models of simulation ships;
- based on model tests executed in the Towing Tank for Manoeuvres in Shallow Water.

For this simulation study the development of the 227 m car and truck carrier is based on the first method. An existing mathematical manoeuvring model of a 265 m car carrier is scaled to the dimensions of the Fidelio summarized in Table 1. The loading condition and characteristics of the engine, propulsion and rudder (Becker rudder) system are adjusted to the required characteristics of the Fidelio.

3.2 Modelling of the 227 m car carrier

3.2.1 Scaling of the 227 m car carrier

The scaling of the Fidelio is based on the 265 m car carrier Odyssea from the simulator database with characteristics as shown in Table 9. The block coefficient of the Odyssea is only 0.476 and thus very small compared to the block coefficient of the Fidelio (Table 1). This small block coefficient corresponds to the block coefficient of the simulator ship Autobus from which the Odyssea is derived.

Table 9 – Characteristics of the car carrier Odyssea from the simulator database

Parameter	**Unit**	**Value**
Length over all	m	265.00
Length between perpendiculars	m	246.96
Breadth	m	32.19
Draft	m	11.00

Block coefficient (draft 11 m)	-	0.476
Displacement (draft 11 m)	tons	42,659
UKC 1 model	%T	300
UKC 2 model	%T	20

The mathematical manoeuvring model of the Odyssea corresponds to the “De Voorst” type which is a regression model with some parts with a more physical background. Scaling is based on the program SCAMCO (SCAling of Mathematical COefficients) which gives as output new nbw[5] files and thus new mathematical manoeuvring coefficients.

The scaling factors for the length λ, for the beam β, for the draft τ and for the ratio of the speed advance coefficient ν are:

$$\lambda = \frac{requested\ length}{original\ length} = 0.888$$

$$\beta = \frac{1}{\lambda}\frac{requested\ beam}{original\ beam} = 1.129$$

$$\tau = \frac{1}{\lambda}\frac{requested\ draft}{original\ draft} = 0.973$$

The scaling factor for the propeller rate is calculated using the Excel file opschaling_motor.xls and is represented by

$$\upsilon = \frac{(u/n)_{requested}}{(u/n)_{original}} = 1.002$$

The rudder efficiency must also be scaled through the scaling parameter α_1 which gives a ratio of the rudder area of the requested and the original area:

$$\alpha_1 = \frac{1}{\lambda^2}\frac{requested\ rudder\ area}{original\ rudder\ area} = \frac{1}{\lambda^2}\frac{36\ m^2}{62.64\ m^2} = 0.72880$$ [6]

For the scaling according to the draft the power σ for deep (300% UKC) and shallow (20% UKC) water must be determined based on the values in Table 10. For the available water depth to draft ratios the values 1.1 for shallow and 2.0 for deep water have been taken.

Table 10 – Relationship between σ and the water depth to draft ratio h/T

h/T	1.0	1.1	1.2	1.3	1.4	1.5	2.0	2.5	3	>3.5
σ	1.00	1.05	1.10	1.13	1.17	1.20	1.40	1.60	1.80	2.00

[5] The structure of the input files has been changed during the development of this simulation model. The De Voorst and Tabular model type have been merged so that a new xml structure is now used. Nevertheless the scaling program SCAMCO is not yet adapted to this new structure.

[6] The rudder area in the sea trial report is only the movable part. It is not clear if the flap is included in this area.

As the block coefficient of the Odyssea is only 0.476, the same block coefficient is obtained after scaling according to the Froude law. Adjusting the scaled mass and moment of inertia to the block coefficient of the Fidelio, which is 0.6512, the mass of the Fidelio is 4.4860577E+07 kg while the moment of inertia is scaled based on the new mass and the length scale factor λ:

$$I_{zz} = I_{zz,original} \frac{mass_{requested}}{mass_{original}} \lambda^2 = 1.35373 \cdot 10^{11} kgm^2$$

Due to the negligible difference between the manoeuvring characteristics in deep and shallow water of the scaled Fidelio, what is not realistic based on the experience with ship models in the Towing Tank for Manoeuvres in Shallow Water, the hull coefficients for the lateral force and the yawing moment due to sway and yaw have been changed so that a larger course stability is obtained in shallow water. The multiplication factors are summarised in Table 11. These values have been adjusted immediately in the xml files with the coefficients and not by using the files dcoeff_*.xml with the adaptation of force components.

Table 11 – Multiplication factors and values for the hull coefficients at 20% UKC

Coefficient	Factor	Unit	Value
BEWCO%YUV	1.5	[kg/m]	-3.268536E+06
BEWCO%YUR	1.5	[kg]	3.700807E+07
BEWCO%RNUV	0.5	[kg]	-1.326794E+08
BEWCO%RNUR	1.5	[kgm]	-1.291582E+10

3.2.2 Determination of the Becker table

The Becker module recalculates given rudder angles to virtual rudder angles.

- If the rudder angle is lower than the angle D1MaxBecker, the virtual rudder angle is given by the ordered rudder angle multiplied by a ratio factor depending on the force or moment component (Table 12).
- If the rudder angle is equal to or higher than the angle D1MaxBecker, the virtual rudder angle is given by the angle D1MaxBecker multiplied by a ratio factor depending on the force or moment component (Table 12).

As the rudder forces and moment mathematical models for all ships with a Becker rudder in the simulator database depend on the first power of the rudder angle (high order coefficients are zero) this ratio factor can be interpreted as a real ratio of the forces and moment with (ratio factor is higher than 1) and without a Becker rudder (ratio factor is 1).

The Becker table has been set to two different values in the equipment file:

- eqp_fidelio_becker1.xml: Becker table copied from the equipment file of the simulation ship Stolt Kimberley;
- eqp_fidelio_becker2.xml: Becker table taken from eqp_fidelio_becker1 with changed values for Ratio factor Y so that the values for Ratio factor Y and Ratio factor N are identical.

Although based on the large ratio factors for Y and N (values up to 3.14) an increase of the original rudder angle dependent coefficients could be considered, the Becker table give the advantage of adjusting the rudder efficiency in much lower steps of rudder angles as found in the rudder angle column of Table 12. Changing rudder coefficients of the mathematical model gives an identical increase of the rudder efficiency for all rudder angles.

Table 12 – Becker table for two versions of the Fidelio and D1MaxBecker equal to 35 degrees

	eqp_fidelio_becker1			eqp_fidelio_becker2		
Rudder angle [deg]	Ratio factor X	Ratio factor Y	Ratio factor N	Ratio factor X	Ratio factor Y	Ratio factor N
-65.0	1.285	1.00	1.82	1.285	1.82	1.82
-60.0	1.285	1.00	2.2	1.285	2.2	2.2
-50.0	1.285	1.00	2.87	1.285	2.87	2.87
-40.0	1.143	1.00	3.09	1.143	3.09	3.09
-35.0	1	1.00	3.06	1	3.06	3.06
-30.0	1	1.00	3.14	1	3.14	3.14
-20.0	1	1.00	3.14	1	3.14	3.14
-10.0	1	1.00	2.88	1	2.88	2.88
0.0	1	1.00	2.11	1	2.11	2.11
10.0	1	1.00	3.54	1	3.54	3.54
20.0	1	1.00	3.85	1	3.85	3.85
30.0	1	1.00	3.85	1	3.85	3.85
35.0	1	1.00	3.75	1	3.75	3.75
40.0	1.143	1.00	3.79	1.143	3.79	3.79
50.0	1.285	1.00	3.52	1.285	3.52	3.52
60.0	1.285	1.00	2.7	1.285	2.7	2.7
65.0	1.285	1.00	2.23	1.285	2.23	2.23

3.3 Fast time simulation through manoeuvring trials

All results for the fast time simulation are available for the loaded condition with a draft of 9.5 m and based on the 200% UKC value for the deep water case (comparison with the ballast draft trial data) and the 20% UKC value for the shallow water case. For some trials the 300% UKC values will be included as well.

In between the validation day on the 29th of August 2013 and the simulation study end of September and beginning of October, the simulator software has been changed with merged mathematical models. The reported results are the characteristics of the fast time simulation runs with the mathematical model for the validation day and these results should be exactly the same as with the mathematical model used for the simulation study.

3.3.1 Acceleration test

The speed-telegraph table for the simulation ship Fidelio in deep and shallow water is obtained through acceleration tests. The results are presented in Table 13.

Table 13 – Telegraph – speed table of the simulation ship Fidelio at 200% and 20% UKC

Telegraph	Propeller rate	Speed at 300% UKC	Speed at 200% UKC	Speed at 20% UKC
	[rpm]	[knots]	[knots]	[knots]
SEA FULL AHEAD	105	19.3	19.3	19.0
FULL AHEAD	75	13.8	13.8	13.6
HALF AHEAD	65	11.9	11.9	11.7
SLOW AHEAD	50	9.1	9.1	9.0
DEAD SLOW AHEAD	30	5.4	5.4	5.4
DEAD SLOW ASTERN	-30	-4.5	-5.3	-4.6
SLOW ASTERN	-50	-7.5	-8.9	-7.9
HALF ASTERN	-65	-9.9	-11.7	-10.3
FULL ASTERN	-75	-11.4	-13.5	-11.9

Deviating values are found for the 300% UKC compared to the values for the other under keel clearances. The sources of these differences have not been examined and should be found in the coefficients[7]. The variation of the telegraph – speed values is logical for the 200% and 20% UKC values.

3.3.2 Turning circle

A comparison can be made between the characteristics of turning circles from the full scale trials at ballast draft and the simulations at loaded condition. The validation by a captain from Wallenius has not given more insight in the difference in manoeuvring behaviour due to the different drafts as only one draft have been used during the simulations. The mathematical manoeuvring model with the eqp_fidelio_becker1 equipment file has been validated on the 29th of August as closer to reality than the other equipment file. A comparison between full scale trials and simulations are summarised in:

- Table 14 for sea full ahead speed (1.75 rps propeller rate) and 35 deg rudder angle ;
- Table 15 for half ahead speed (1.08 rps propeller rate) and 35 deg rudder angle;
- Table 16 for sea full ahead speed (1.75 rps propeller rate) and 65 deg rudder angle.

[7] This is probably due to turning of vessel during acceleration tests. A speed table based on Compute autopilot (thus at straight course) might be more consistent.

Table 14 – Turning circle at 200% UKC: characteristics for sea full ahead speed (1.75 rps propeller rate), rudder angle 35 deg, comparison of full scale trial (ballast draft) and simulation (loaded draft)

				Eqp_fidelio_becker1		Eqp_fidelio_becker2	
		Full scale trial (ballast draft)		Simulation (loaded draft)		Simulation (loaded draft)	
		PORT	STARBOARD	PORT	STARBOARD	PORT	STARBOARD
Advance/L_{PP}	[-]	1.880	2.386	1.95	2.12	2.15	2.3
Transfer/L_{PP}	[-]	-1.1	1.415	-0.99	1.07	-0.76	0.88
Tact. Diam./L_{PP}	[-]	-2.092	2.406	-2.18	2.4	-1.97	2.21
Initial speed	[knots]	19.6	18.7	19.3	19.3	19.3	19.3
Final speed	[knots]	4.8	7.8	5.5	6.1	3.1	3.9

Table 15 – Turning circle at 200% UKC: characteristics for half ahead speed (1.08 rps propeller rate), rudder angle 35 deg, comparison of full scale trial (ballast draft) and simulation (loaded draft)

				Eqp_fidelio_becker1		Eqp_fidelio_becker2	
		Full scale trial (ballast draft)		Simulation (loaded draft)		Simulation (loaded draft)	
		PORT	STARBOARD	PORT	STARBOARD	PORT	STARBOARD
Advance/L_{PP}	[-]	1.776	1.956	1.85	2.02	1.96	2.10
Transfer/L_{PP}	[-]	-0.966	0.818	-0.94	1.03	-0.73	0.85
Tact. Diam./L_{PP}	[-]	-1.694	1.292	-2.14	2.35	-1.85	2.09
Initial speed	[knots]	12.1	12.0	12.0	12.0	12.0	12.0
Final speed	[knots]	2.6	5.9	6.0	6.5	2.4	2.9

Table 16 – Turning circle at 200% UKC: characteristics for sea full ahead speed (1.75 rps propeller rate), rudder angle 65 deg, comparison of full scale trial (ballast draft) and simulation (loaded draft)

				Eqp_fidelio_becker1		Eqp_fidelio_becker2	
		Full scale trial (ballast draft)		Simulation (loaded draft)		Simulation (loaded draft)	
		PORT	STARBOARD	PORT	STARBOARD	PORT	STARBOARD
Advance/L_{PP}	[-]	2.622	3.006	2.46	2.36	2.63	2.51
Transfer/L_{PP}	[-]	-1.842	1.582	-1.55	1.30	-1.45	1.15
Tact. Diam./L_{PP}	[-]	-3.716	2.508	-3.54	2.91	-3.41	2.73
Initial speed	[knots]	18.9	20.0	19.3	19.3	19.3	19.3
Final speed	[knots]	4.5	5.9	6.4	5.6	6.3	4.4

The non-dimensional (divided by the ship length) values for the advance, the transfer and tactical diameter at 35 deg rudder angle are satisfactorily comparable for the eqp_fidelio_becker1 table and the full scale trials and simulations. The values from the turning circles with the eqp_fidelio_becker2 table are resulting in a more course unstable ship which has been judged on the 29th of August as too far from the real ship due to the unstable behaviour (e.g. drifting while approaching the lock).

Table 17 gives the simulation results for 20% UKC and the same starting conditions as for 200% UKC.

Table 17 – Turning circle at 20% UKC: characteristics for sea full and half ahead speed, rudder angle 35 and 65 deg for simulations at loaded condition

			Simulation, 35 deg, 1.75 rps		Simulation, 35 deg, 1.08 rps		Simulation, 65 deg, 1.75 rps	
			PORT	STAR-BOARD	PORT	STAR-BOARD	PORT	STAR-BOARD
Eqp_fidelio_becker1	Advance/L_{PP}	[-]	3.95	4.47	3.83	4.34	6.96	5.57
	Transfer/L_{PP}	[-]	-3.25	3.71	-3.19	3.62	-6.04	4.61
	Tact. Diam./L_{PP}	[-]	-6.45	7.34	-6.26	7.12	-11.14	8.59
	Initial speed	[knots]	19.0	19.0	11.7	11.7	19.0	19.0
	Final speed	[knots]	10.8	10.9	7.4	7.5	6.1	6.1
Eqp_fidelio_becker2	Advance/L_{PP}	[-]	3.17	3.6	2.97	3.41	6.60	4.72
	Transfer/L_{PP}	[-]	-2.03	2.46	-1.94	2.37	-5.87	3.62
	Tact. Diam./L_{PP}	[-]	-4.23	5.06	-4.01	4.84	-10.96	6.93
	Initial speed	[knots]	19.0	19.0	11.7	11.7	19.0	19.0
	Final speed	[knots]	6.1	7.4	4.3	5.3	6.1	5.0

3.3.3 Zigzag manoeuvre

The results of the zigzag manoeuvres at 200% UKC and 20% UKC are respectively summarised in Table 18 and Table 19. The difference between the first and second overshoot angle during the full scale trial is not seen in the simulation where you have especially for the Fidelio_becker1 model almost the same values. For other ships the zigzag manoeuvre gives typically almost identical overshoot angles to starboard and port during full scale trials so that the simulation models are considered to be realistic.

Table 18 – Zigzag manoeuvre at 200% UKC: characteristics for sea full ahead speed (1.75 rps propeller rate), comparison of full scale trial (ballast draft) and simulation (loaded draft)

			Full scale trial (ballast draft)		Simulation (loaded draft)	
			20/20	10/10	20/20	10/10
Eqp_fidelio_becker1	Initial speed	[knots]	19.5	19.8	19.3	19.3
	RPM (initial/final)	[rpm]	102.4/98.7	102.5/101.6	105/105	105/105
	First overshoot angle	[deg]	18	11	18.5	10.1
	Second overshoot angle	[deg]	9.4	7.7	17.3	12.3
Eqp_fidelio_becker2	Initial speed	[knots]	19.5	19.8	19.3	19.3
	RPM (initial/final)	[rpm]	102.4/98.7	102.5/101.6	105/105	105/105
	First overshoot angle	[deg]	18	11	20.4	12.3
	Second overshoot angle	[deg]	9.4	7.7	17.8	14.1

Table 19 – Zigzag manoeuvre at 20% UKC: characteristics for sea full ahead speed (1.75 rps propeller rate), simulation (loaded draft)

		Eqp_fidelio_becker1		Eqp_fidelio_becker2	
		20/20	10/10	20/20	10/10
Initial speed	[knots]	19.0	19.0	19.0	19.0
RPM (initial/final)	[rpm]	105/105	105/105	105/105	105/105
First overshoot angle	[deg]	2.5	0.8	4.2	1.4
Second overshoot angle	[deg]	2.2	0.7	3.4	1.2

3.3.4 Crash stop and inertia test

The crash stop and inertia test from the simulation at loaded draft are presented in Table 20 for 200% of the ship's draft as under keel clearance. For the other under keel clearance a new calculation should be made with the last available executable.

Table 20 – Crash stop and inertia test at 200% and 20% UKC, simulation (loaded draft)

		200 % UKC		
		Time [s]	Track reach[8] [m]	Head reach [m]
Using engine full astern (-1.25 rps)	Full sea speed	647	2800	2182
	Full speed	542	1805	1626
	Half speed	495	1457	1362

[8] The track reach is the total distance travelled by the ship, while the head reach is the longitudinal distance according to the original course of the ship.

4 Data of the 200 m Car and Truck Carrier

4.1 General information

The ship characteristics are given by the shipping company for the MS Tosca (Figure 3) with a length over all of 199.9 m (Table 21). This ship is equipped with a single fixed pitch propeller and a classic rudder.

Table 21 – Characteristics of the MS Tosca

Length over all	[m]	199.9
Length between perpendiculars	[m]	192
Beam	[m]	32.26
Depth (upper deck)	[m]	34.7
Draught (design)	[m]	9.5
Draugth (scantling)	[m]	11.0
Longitudinal position of centre of gravity at fully loaded condition	[m]	91.0m from A.P.
Displacement	[tons]	33,179
Dead Weight tonnage (at maximum draught)	[tons]	22,700
Block coefficient	[-]	0.55
Engine type	[-]	Mitsubishi 7UEC60L SII-ECO
Power	[kW]	11,915
Number of revolutions, propeller	[rpm]	101.4
Service speed	[kn]	20
Number of propellers	[-]	1
Diameter of propeller (D)	[m]	6.5
Number of blades	[-]	5
Pitch ratio of propeller (P/D)	[-]	1.0062 (at 0.7R)
Area ratio of propeller (A_E/A_0)	[-]	0.5605
Number of rudders	[-]	1
Rudder type	[-]	Semi spade
Maximum rudder angle	[deg]	35
Rudder area	[m^2]	40
Bowthruster	[kW]	(27 tons)
Sternthruster	[kW]	-
Frontal wind area	[m^2]	1100
Lateral wind area	[m^2]	6000

4.2 Manoeuvring information

Besides the general information in 4.1 for the development of a mathematical manoeuvring model the manoeuvring characteristics from HB07-0001-0002 - MANEUVERING CHARACTERISTICS.PDF must be examined. No sea trial data are made available within this project.

Figure 3 – MS Tosca (source marinetraffic.com)

Based on the manoeuvring characteristics of the MS Tosca, characteristics of the following trials can be found:

- telegraph – speed table;
- turning circle;
- crash stop and inertia test.

An important remark while considering the data shown on the manoeuvring characteristics is that the source of the information (estimated/measured) is not stated. A normal loaded condition corresponds with a draft of 9.5 m and a normal ballast condition with a draft of 8.2 m.

4.2.1 Telegraph – speed table

The telegraph – speed table shown in Table 22 gives the speed values at loaded and ballast condition. As can be seen no difference in speed is reported for dead slow to full ahead for loaded and ballast condition although such a difference is generally expected. Probably the speed values are estimated for the loaded condition, copied for the ballast condition and only for sea full ahead the normal ballast condition value is adjusted to the results from the acceleration test.

Table 22 – Telegraph – speed table of the MS Tosca

		Loaded	Ballast
Telegraph	Propeller rate	Speed	Speed
	[rpm]	[knots]	[knots]
SEA FULL AHEAD	101.4	20.0	20.2
FULL AHEAD	70	14.0	14.0
HALF AHEAD	51	10.0	10.0
SLOW AHEAD	34	6.5	6.5
DEAD SLOW AHEAD	30	6.0	6.0

4.2.2 Turning circle manoeuvre

The turning circle manoeuvre characteristics are reported for normal loaded and ballast condition for deep water (water depth is at least twice the ship's draft) and sea full and slow ahead (Table 23). As for the telegraph-speed table the differences between loaded and ballast condition are small with slightly lower values for the ballast condition. For slender container ships FHR measured an increase of the course stability (and thus larger advance and tactical diameter values) with decreasing draft. This is not seen for the car carrier at 9.5 and 8.2 m draft so that together with the negligible difference between the turning circle characteristics it is supposed that the results in (Table 23) are estimated.

Table 23 – Turning circle to starboard: characteristics for normal loaded and ballast condition, rudder angle 35 deg

		Loaded		Ballast	
		Sea Full Ahead	Slow Ahead	Sea Full Ahead	Slow Ahead
Propeller rate	[rpm]	101.4	51	101.4	51
Advance/Lpp	[-]	3.38	2.8	3.28	2.6
Tact. Diam./Lpp	[-]	4.15	3.28	3.67	3.09
Initial speed	[knots]	20	10	20.2	10
Final speed	[knots]	7.1	3.5	7.1	3.5
Time 90 deg	[s]	90	144	84	132
Speed 90 deg	[knots]	12.8	6.4	12.8	6.4
Time 180 deg	[s]	186	300	180	282
Speed 180 deg	[knots]	8.8	4.4	8.9	4.4
Time 270 deg	[s]	312	498	294	474
Speed 270 deg	[knots]	7.1	3.5	7.1	3.5

4.2.3 Zigzag manoeuvre

There is no information available from the manoeuvring characteristics for the zigzag manoeuvre.

4.2.4 Crash stop manoeuvre

The data from the crash stop manoeuvre using engine full astern and with minimum application of rudder are shown in Table 24.

Table 24 – Crash stop and inertia data from the wheelhouse poster

	Loaded condition		Ballast condition	
	Time (s)	Distance (m)	Time (s)	Distance (m)
Full sea speed	450	2481.7	420	2352.0
Full speed	408	1685.3	372	1629.8
Half speed	366	1222.3	336	1166.8
Slow speed	324	777.8	300	759.3

5 Development of the 200 m Car and Truck Carrier

Based on the information made available by the shipping company a mathematical manoeuvring model is developed for a 200 m car and truck carrier in deep and shallow water. The methodology for the development of the MS Tosca is the same as for the Fidelio. The manoeuvring characteristics of the developed simulation model of the ship Tosca were evaluated as not being realistic and no further examinations have been made to improve the simulation models. In this chapter only the partial development of the simulation model is described.

5.1 Scaling of the mathematical model

The scaling of the mathematical manoeuvring model of the Tosca is based on the 265 m car carrier Odyssea from the simulator database with characteristics as shown in Table 9. The block coefficient of the Odyssea is only 0.476 and a little smaller than the block coefficient of the Tosca (Table 22).

The scaling factors for the length λ, for the beam β, for the draft τ and for the ratio of the speed coefficient ν are:

$$\lambda = \frac{requested\ length}{original\ length} = 0.777$$

$$\beta = \frac{1}{\lambda}\frac{requested\ beam}{original\ beam} = 1.290$$

$$\tau = \frac{1}{\lambda}\frac{requested\ draft}{original\ draft} = 1.112$$

The scaling factor for the propeller rate is calculated using the Excel file opschaling_motor.xls and is represented by

$$\upsilon = \frac{(u/n)_{requested}}{(u/n)_{original}} = 1.2624$$

The rudder efficiency must also be scaled through the scaling parameter α_1 which gives a ratio of the rudder area of the requested and the original area:

$$\alpha_1 = \frac{1}{\lambda^2}\frac{requested\ rudder\ area}{original\ rudder\ area} = \frac{1}{\lambda^2}\frac{40\ m^2}{62.64\ m^2} = 1.058$$

For the scaling according to the draft the power σ for deep (300% UKC) and shallow (20% UKC) water must be determined based on the values in Table 25. For the available water depth to draft ratios the values 1.1 for shallow and 2.0 for deep water have been taken.

Table 25 – Relationship between σ and the water depth to draft ratio h/T

h/T	1.0	1.1	1.2	1.3	1.4	1.5	2.0	2.5	3	>3.5
σ	1.00	1.05	1.10	1.13	1.17	1.20	1.40	1.60	1.80	2.00

Table 26 – Multiplication factor and value for the propeller coefficient at astern telegraph and 300 and 20% UKC

Coefficient	Factor	Unit	Value
BEWCO%XNNM	0.4		-3.75762E+05

The block coefficient from the Tosca is 0.55 and differs from the coefficient 0.476 of the Odyssea and of the scaled simulation model. Therefore the mass and mass moment of inertia will be adjusted with the ratio of the block coefficients or 1.155.

The coefficient BEWCO%XNNM for backwards propeller turn was adjusted to the value summarised in Table 26.

5.2 Fast time simulation through manoeuvring trials

Using the scale factors as described in 5.1 gave not comparable results for the turning circle manoeuvre as reported in the data of the 200 m Car and Truck Carrier (Table 28) so that new scalings have been executed as shown in Table 27.

Table 27 – Scaling factors depending on different scalings

Scaling factors	Scaling 1	Scaling 2	Scaling 3	Scaling 4	Scaling 5
λ	0.777	0.777	0.777	0.777	0.777
β	1.29	1.29	1.29	1.29	1.29
τ	1.112	1.112	1.112	1.112	1.112
ν	1.2624	1.2624	1.2624	1.2624	1.2624
α	1.058	0.6	0.45	0.25	0.32

Table 28 – Turning circle to starboard at 200% UKC: characteristics for sea full ahead speed (1.69 rps propeller rate), rudder angle 35 deg, comparison of manoeuvring characteristics and simulation (loaded draft)

		Scaling 1	Scaling 2	Scaling 3	Scaling 4	Scaling 5	Data
Advance/Lpp	[-]	2.6	3.13	3.43	4.14	3.83	3.38
Transfer/Lpp	[-]	1.13	1.5	1.68	2.12	1.92	
Tact. Diam./Lpp	[-]	2.53	3.26	3.63	4.4	4.08	4.15
Initial speed	[knots]	19.96	19.96	19.96	19.96	19.96	20
Final speed	[knots]	6.24	10.30	11.82	13.93	13.16	7.1

As the MS Tosca was finally not confirmed by the captain of Wallenius the fast time simulation results have not been reported. If this vessel has to be used for a simulation study or for training the simulation models have to be adjusted to the latest information available for this type of ship and compared with the real behaviour of a chosen vessel.

References

[1] **Delefortrie, G.; Vantorre, M.; Eloot, K.** (2007). Leveren van wetenschappelijke bijstand voor het uitvoeren van proeven en het opstellen van wiskundige manoeuvreermodellen voor 8000 TEU containerschepen voor de toegang tot de Vlaamse havens: deelopdracht 2. Opmaken van de wiskundige manoeuvreermodellen voor de verschillende ladingstoestanden en kielspelingen en validatie van deze modellen. Verslag en bijlagen. WL Rapporten, 749. Waterbouwkundig Laboratorium/Universiteit Gent: Antwerpen. Vol. 1 (verslag); Vol. 2 (bijlagen) pp.

[2] **Delefortrie, G.; Vantorre, M.; Eloot, K.** (2007). Leveren van wetenschappelijke bijstand voor het uitvoeren van proeven en het opstellen van wiskundige manoeuvreermodellen voor 8000 TEU containerschepen voor de toegang tot de Vlaamse havens: eindrapport. WL Rapporten, 749. Waterbouwkundig Laboratorium/Universiteit Gent: Antwerpen. 8 + CD-ROM pp.

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