VALIDATION OF MATHEMATICAL MANOEUVRING MODELS BY FULL SCALE MEASUREMENTS

Jeroen Verwilligen, Flanders Hydraulics Research, Belgium.

Guillaume Delefortrie, Flanders Hydraulics Research, Belgium.

Stijn Vos, Flanders Hydraulics Research, Belgium.

Marc Vantorre, Maritime Technology Division - Ghent University, Belgium.

Katrien Eloot, Flanders Hydraulics Research & Maritime Technology Division - Ghent University, Belgium.

BASED ON COMPREHENSIVE CAPTIVE MODEL TESTS, EXECUTED IN THE TOWING TANK OF FLANDERS HYDRAULICS RESEARCH (FHR), MATHEMATICAL MANOEUVRING MODELS FOR INLAND VESSELS OF 110 M X 11.4 M AND 85 M X 9.5 M WERE DERIVED. BOTH MANOEUVRING MODELS WERE EXTENSIVELY APPLIED IN REAL-TIME SIMULATION STUDIES TO DESIGN INLAND WATERWAYS AND CONSTRUCTIONS.

IN ORDER TO VALIDATE THE MATHEMATICAL MANOEUVRING MODEL FHR PERFORMED FULL SCALE MEASUREMENTS ON THE INLAND TANKER *MT ELISE* WITH A LENGTH OF 105 M, A BEAM OF 9.5 M AND A DRAFT OF 2.6 M. THE MANOEUVRING BEHAVIOUR OF THE *MT ELISE* WAS COMPARED TO THE AVAILABLE MANOEUVRING MODELS BY MEANS OF BOTH FREE RUNNING AND CAPTIVE REPLAY (FAST-TIME) SIMULATIONS.

FROM CAPTIVE REPLAY SIMULATIONS THE SHIP-TO-SHIP INTERACTION FORCES DURING HEAD-ON ENCOUNTERS PERFORMED DURING THE FULL SCALE TESTING, COULD BE ESTIMATED.

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INTRODUCTION

In order to support the Flemish government in designing new inland infrastructure such as waterways, ports and locks, Flanders Hydraulics Research (FHR) developed in 2009-2010 two inland simulators (Figure 1). Since then an extensive number of real-time simulation studies [1], [2], [3] have been performed in which the design vessel was an ECMT[1]-class Va (110 m x 11.4 m) or an ECMT class IV (85 m x 9.5 m) vessel.

The mathematical manoeuvring model of the ECMT-class Va vessel was developed by FHR, based on comprehensive captive model tests, executed in the Towing Tank for Manoeuvres in Shallow Water (co-operation Flanders Hydraulics Research and Maritime Technology Division of Ghent University). A manoeuvring model for a 85 m x 9.5 m inland vessel was obtained by scaling the original manoeuvring model.

Taking into account the large variation in manoeuvring behaviour of inland vessels, due to different propulsion and steering systems, FHR wanted to gain more insight into the manoeuvring behaviour of these vessels during actual operations on the Flemish waterways. For this purpose FHR performed full scale measurements on the inland tanker *MT Elise* with a length of 105 m, a beam of 9.5 m and a draft of 2.6 m.

The actual manoeuvring behaviour of the *MT Elise* was compared to the manoeuvring behaviour corresponding to the mathematical models of the ECMT class IV and Va vessels in the simulator. Based on this comparison the mathematical manoeuvring models for application in design studies were adapted in order to keep the results at the conservative side.

This paper only discusses the manoeuvring behaviour in open, but shallow water. Nevertheless the mathematical manoeuvring models of inland vessels developed by FHR do also take into account the effects of ship-bank and ship-to-ship interaction.

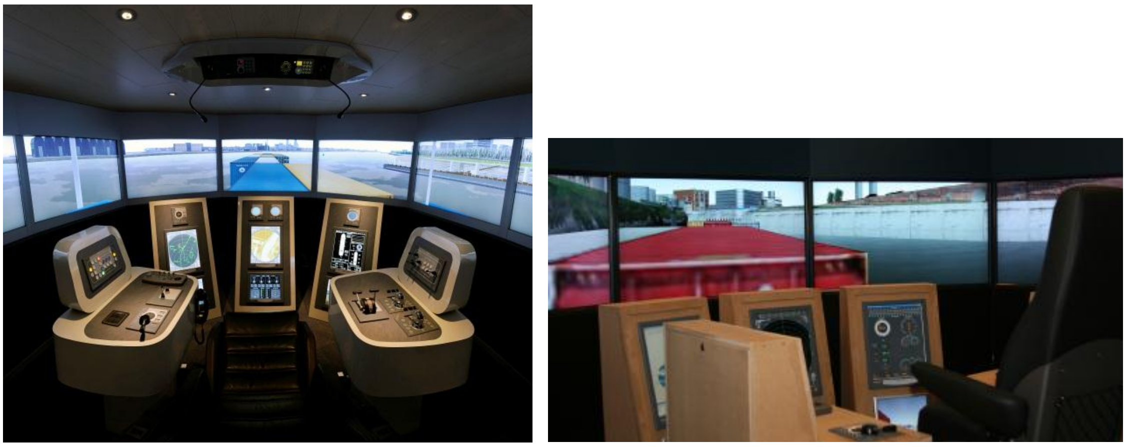

FIGURE 1 – VIEW ON THE INLAND SIMULATORS DEVELOPED BY FHR. LEFT: LENA DEDICATED FOR TRAINING AND EDUCATION. RIGHT: LARA DEDICATED FOR DESIGN AND RESEARCH.

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[1] ECMT: European Conference of Ministers of Transport (French, CEMT: Conférence Européenne des Ministres des Transports).

MATHEMATICAL MANOEUVRING MODELS

EXPERIMENTAL RESEARCH AT MODEL SCALE

In order to obtain a realistic mathematical manoeuvring model for simulation purposes a 1/25 scale model of an ECMT class Va inland vessel was tested in FHR's shallow water towing tank (Figure 2). The ship model was equipped with a ducted propeller with diameter 1.81 m (5 blades, left-handed) and two coupled rudders each with a rudder area of 3.61 m² (max. rudder angle 75 deg). The ship model was tested even keel at drafts of 2.85 m and 3.65 m. Tests were performed at water depths corresponding to under keel clearances 10%, 20%, 35% and 200% of the draft.

Captive model tests were performed at ship speeds varying between -6.5 km/h to 22.7 km/h and with or without propeller action. During tests with positive propeller rate, the propeller was used in a range of 113 to 266 rpm. The rudders (Port/Starboard) were varied between 0/0 deg and -58/-75 to +75/+58 deg.

The comprehensive PMM-testing program (Planar Motion Mechanism) consisted of more or less 300 model tests per combination of draft and under keel clearance.

FIGURE 2 – 1/25 SCALE MODEL OF AN ECMT CLASS VA VESSEL TESTED AT THE TOWING TANK FOR MANOEUVRES IN SHALLOW WATER

MATHEMATICAL MANOEUVRING MODEL

A (3+1) DOF (Degrees Of Freedom) mathematical model of an ECMT class Va vessel has been developed for surge, sway and yaw (horizontal motions) completed with roll. The mathematical model form described in [4] has been used as basis. A modular model is used for combined hull, propeller and rudder forces.

Validation of the mathematical models was based on a comparison between forces and moments measured during additional multi modal captive tests and the corresponding output of the mathematical model, on standard manoeuvres executed during free-running model tests and finally on feedback of a skipper executing real-time simulations on the inland simulator.

A manoeuvring model for an ECMT class IV inland vessel was obtained by scaling the original manoeuvring model developed for a ECMT class Va vessel with the appropriate scale factor.

In Table 1 the available mathematical manoeuvring models are presented. By interpolation of the available manoeuvring models, simulations can be performed at every intermediate draft and under keel clearance.

During the last five years the mathematical manoeuvring model of an ECMT class IV and Va have been extensively used for applied simulation research at the inland simulator Lara and for training and education purposes on the inland simulator LeNa.

TABLE 1 – MATHEMATICAL MANOEUVRING MODELS FOR ECMT CLASS IV AND VA INLAND VESSELS AVAILABLE IN THE SIMULATORS OF FHR

Loa	B	T	UKC
110	11.45	3.65	200%
110	11.45	3.65	35%
110	11.45	3.65	20%
110	11.45	3.65	10%
110	11.45	2.85	200%
110	11.45	2.85	35%
110	11.45	2.85	20%
85	9.5	2.82	200%
85	9.5	2.82	35%
85	9.5	2.82	20%
85	9.5	2.82	10%
85	9.5	2.2	200%
85	9.5	2.2	35%
85	9.5	2.2	20%

FULL SCALE TESTING

On April 3rd 2013 FHR performed measurements on the inland vessel *MT Elise*. During the measurements the vessel was sailing upstream from the lock in Evergem (BE) to the lock in Harelbeke (BE). The trajectory of the *MT Elise* during the full scale testing is presented in Figure 3.

The objective of the measurement was to obtain data for:

- validation of mathematical manoeuvring models of inland vessels;
- validation of roll motion of inland vessels;
- squat (sinkage and trim) during inland navigation;
- validation of simulation models for lock effects.

This paper focusses on the validation of the manoeuvring model.

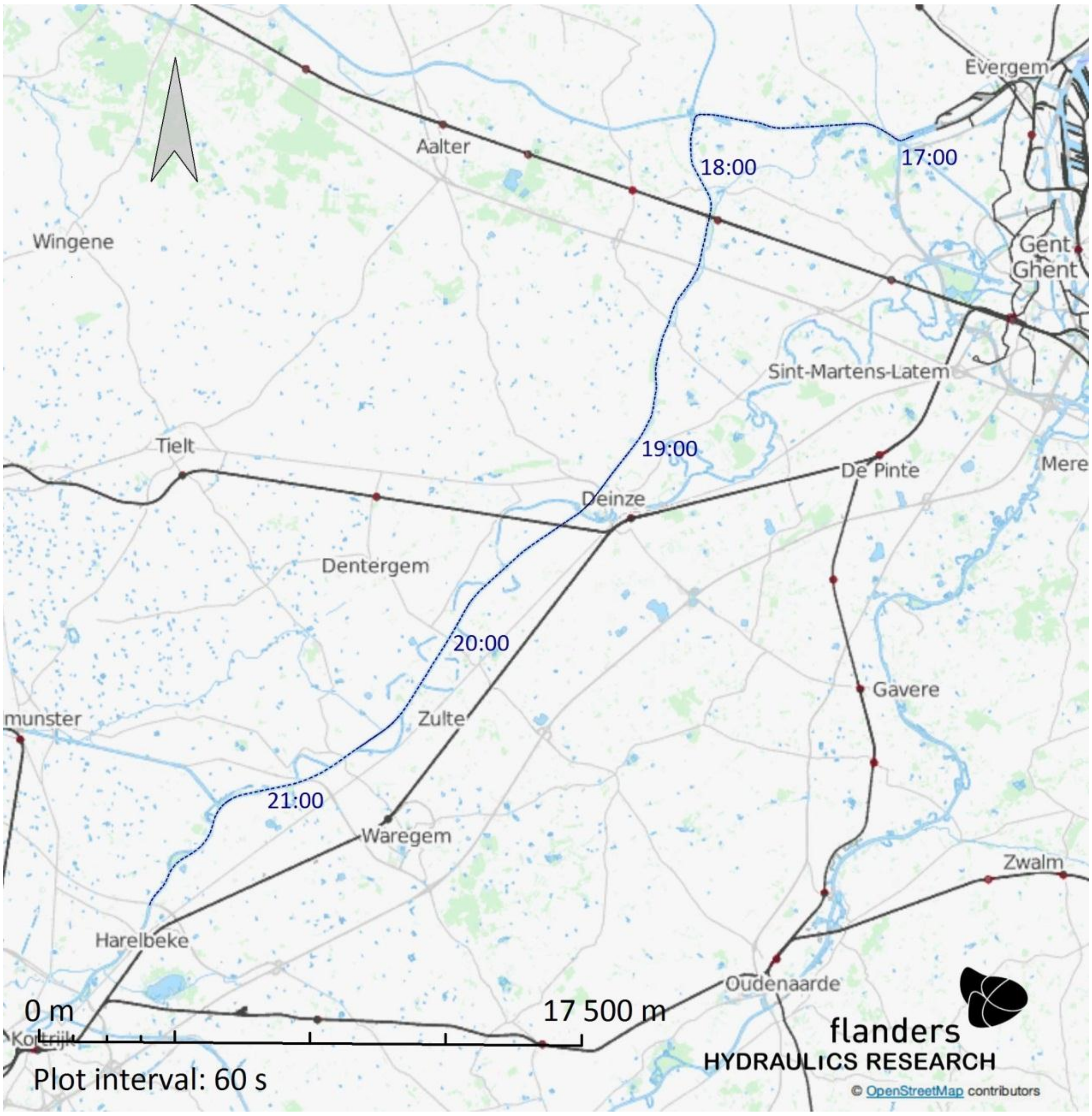

FIGURE 3 – TRAJECTORY OF *MT ELISE* DURING FULL SCALE MEASUREMENTS ON APRIL 3RD 2013

MT ELISE

The inland tanker *MT Elise* (°1958) combines a length of 105 m and a beam of 9.5 m (see Figure 4). During the measurements on April 3rd 2013, the vessel was loaded even keel at a draft equal to 2.6 m. The *MT Elise* is the largest vessel that operates regularly on the Lys Diversion Canal.

The vessel is equipped with one ducted propeller and three rudders. When applying a rudder angle of 90 deg, the three rudders form a continuous plane. The propeller has a diameter of 1.6 m and a maximum propeller rate of 400 rpm, and is driven by a 985 kW (1340 HP) diesel engine. The skipper judged the manoeuvring behaviour of the vessel to be very favourable.

FIGURE 4 – *MT ELISE* SAILING IN THE BEND OF NEVELE

BEND OF NEVELE

The Lys Diversion Canal is a link in the Seine-Scheldt connection that connects the Ghent-Ostend Canal to the river Lys. As the main objective of the measuring campaign was to analyse the manoeuvring behaviour of the vessel, the passage of the Bend of Nevele, combining a course deviation of 79 deg and a bend radius of 230 m, was selected. The Bend of Nevele connects the Ghent-Ostend Canal to the Lys Diversion Canal.

The selected trajectory (see Figure 5) had a duration of 11 minutes. During the first 7 minutes, the vessel did follow a relatively straight trajectory. From 17:47 to 17:50 the vessel performed the bend.

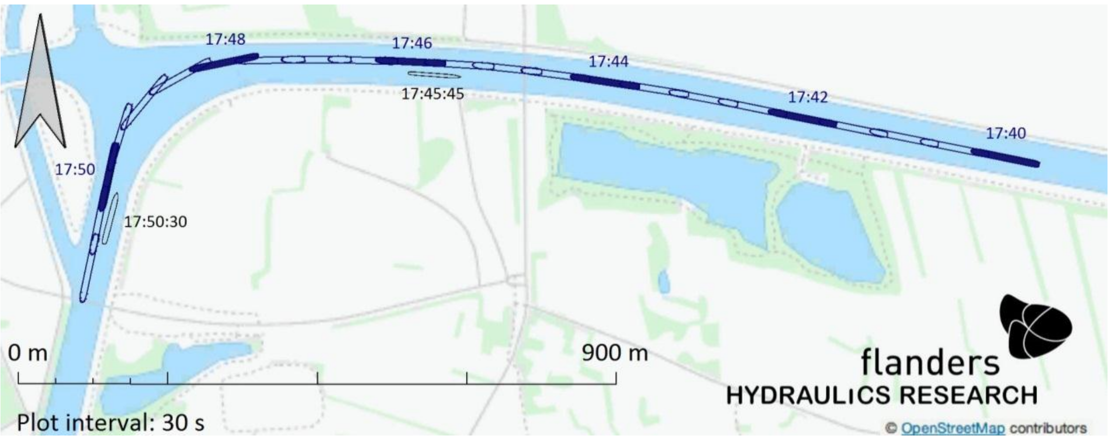

FIGURE 5 – TRAJECTORY OF *MT ELISE* IN BEND OF NEVELE ON APRIL 3RD 2013

MEASUREMENT EQUIPMENT

The measurement equipment consisted of a pair of RTK-GPS antennas mounted on a pre-calibrated inertial measurements unit (IMU). In this IMU the accelerations and orientations were measured in six degrees of freedom by means of accelerometers and gyroscopes. When fed with RTK (Real Time Kinematic) correction signals from reference stations, the measurement equipment has accuracies as indicated in Table 2. The actions of rudders (coupled) and propeller were registered using video cameras and were post-processed to time series. AIS-data (Automatic Identification System) were logged to gather information regarding other shipping traffic in the environment.

TABLE 2 – ACCURACY OF MEASUREMENT EQUIPMENT APPLIED

Parameter	Unit	Accuracy
Horizontal position	[m]	0.010
Vertical position	[m]	0.015
Roll angle	[deg]	0.06
Trim angle	[deg]	0.01
Heading	[deg]	0.05

ENVIRONMENTAL DATA

In order to analyse the under keel clearances and the squat of the vessel, information regarding the bathymetry and the water level are required.

Bathymetric data were supplied by the waterway authority: Waterwegen en Zeekanaal NV – Upper Scheldt Division (Belgium). For the trajectory in the bend of Nevele, most of the available bathymetric data were not older than three years (Figure 6).

Water level measurements were supplied by the Hydrological Information Centre (Flanders, Belgium) for several measuring stations along the trajectory. For the analysis of the Bend of Nevele water level measurements were available 8000 m downstream and 300 m upstream the Bend of Nevele. Local water levels were obtained by geographical interpolation.

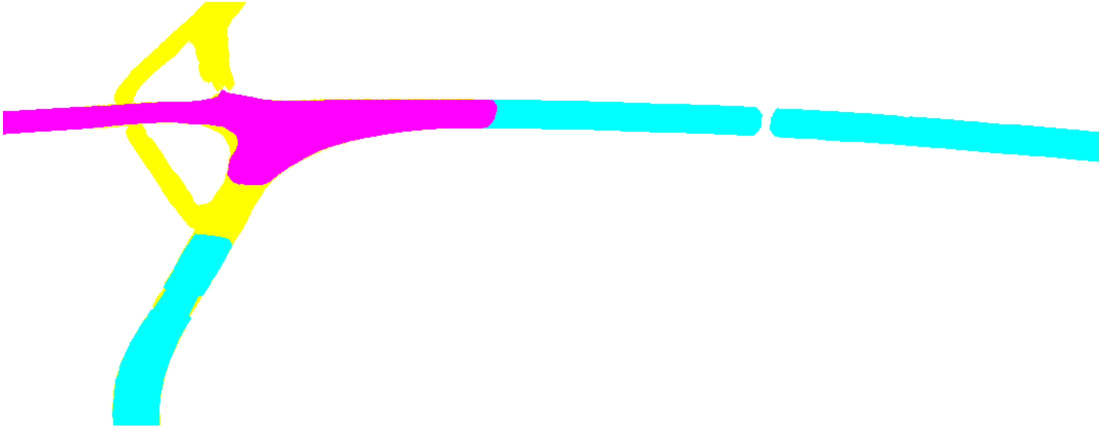

FIGURE 6 – BATHYMETRIC DATA AVAILABLE FOR THE BEND OF NEVELE. YELLOW: SURVEY 2004, BLUE: SURVEY 2010: PINK: SURVEY 2012

RESULTS

The results of the full scale measurements on the *MT Elise* are presented in Figure 7 by means of time series of the most important parameters. The trajectory of the vessel is visualised in Figure 5.

During the relatively straight trajectory in the Ghent-Ostend Canal (17:40 to 17:47) the gross under keel clearance (app. 57%) and the propeller rate (270 rpm) did not vary resulting in a rather constant squat of 0.42 m. Nevertheless the speed of the vessels shows some variation. The speed of the vessel decreased from initially 9.3 km/h (17:42:00) to 8.4 km/h (17:46:30). The speed variations between 17:45:25 and 17:46:05 were resulting from ship-to-ship interaction effects as the *MT Elise* at that time performed a head-on encounter with a 80 m x 5 m inland vessel (see Table 3). The deceleration of the vessel between 17:42 and 17:47 cannot be linked to the parameters presented in Figure 7. It is assumed that the deceleration of the vessel was the result of bank and blockage effects resulting from a more eccentric position in the fairway related to the ship meeting at 17:45:45.

The rudder angles applied between 17:40 and 17:47 show a periodic evolution resulting from the control system of the autopilot of the vessel, that keeps the rate of turn of the vessels within 5.5 deg/min. The average rudder angle required to perform a straight trajectory seemed to be 10 deg to starboard.

From 17:47 on the skipper applied important rudder angles to port side in order to perform the Bend of Nevele. The Bend of Nevele shows high variation in bottom depth resulting in under keel clearances varying between 50% and 100%. By using rudder angles up to 75 deg to port, the vessel reached yawing velocities up to 50 deg/min. As a result of the large rudder angles and rate of turn of the vessel, the vessel decelerated from 8.3 km/h to 7.2 km/h. This combination of deceleration and larger under keel clearances reduced the ship’s squat significantly from initially 0.42 m to 0.12 m at 17:49:20 when the ship speed was minimal. Furthermore during the bend manoeuvre, a bow up trim was observed.

When the vessel had reached the heading corresponding to the Lys Diversion Canal (17:49:30), the rate of turn was reduced to zero and the vessel accelerated again. At 17:50 the propeller rate was increased in order to gain more speed. Between 17:50:10 and 17:50:46 the *MT Elise* met a 80 m x 8 m ballasted vessel with small draft. Both meetings performed with a 80 m long inland vessel (see Table 3) resulted in a similar evolution in trim due to ship-to-sip interaction:

- the moment the bows meet, the trim reaches a maximum (bow up);
- when the bow of the *MT Elise* passes the mid ship of the other vessel the trim reaches a bow down maximum;
- when the bow of the *MT Elise* passes the stern of the other vessel the trim increases again and reaches a maximum (bow up) when the mid ship of the other vessel passes the stern of the *MT Elise*.

TABLE 3 – HEAD ON MEETINGS PERFORMED BY *MT ELISE*

Vessel name	L_{OA} [m]	B [m]	T (est.) [m]	SOG [km/h]	Bow-Bow [hh:mm:ss]	MS-MS [hh:mm:ss]	Aft-Aft [hh:mm:ss]
Malta	80	5	2.5	9.1	17:45:25	17:45:45	17:46:05
Unitas	80	8	1.0	11.9	17:50:11	17:50:30	17:50:46

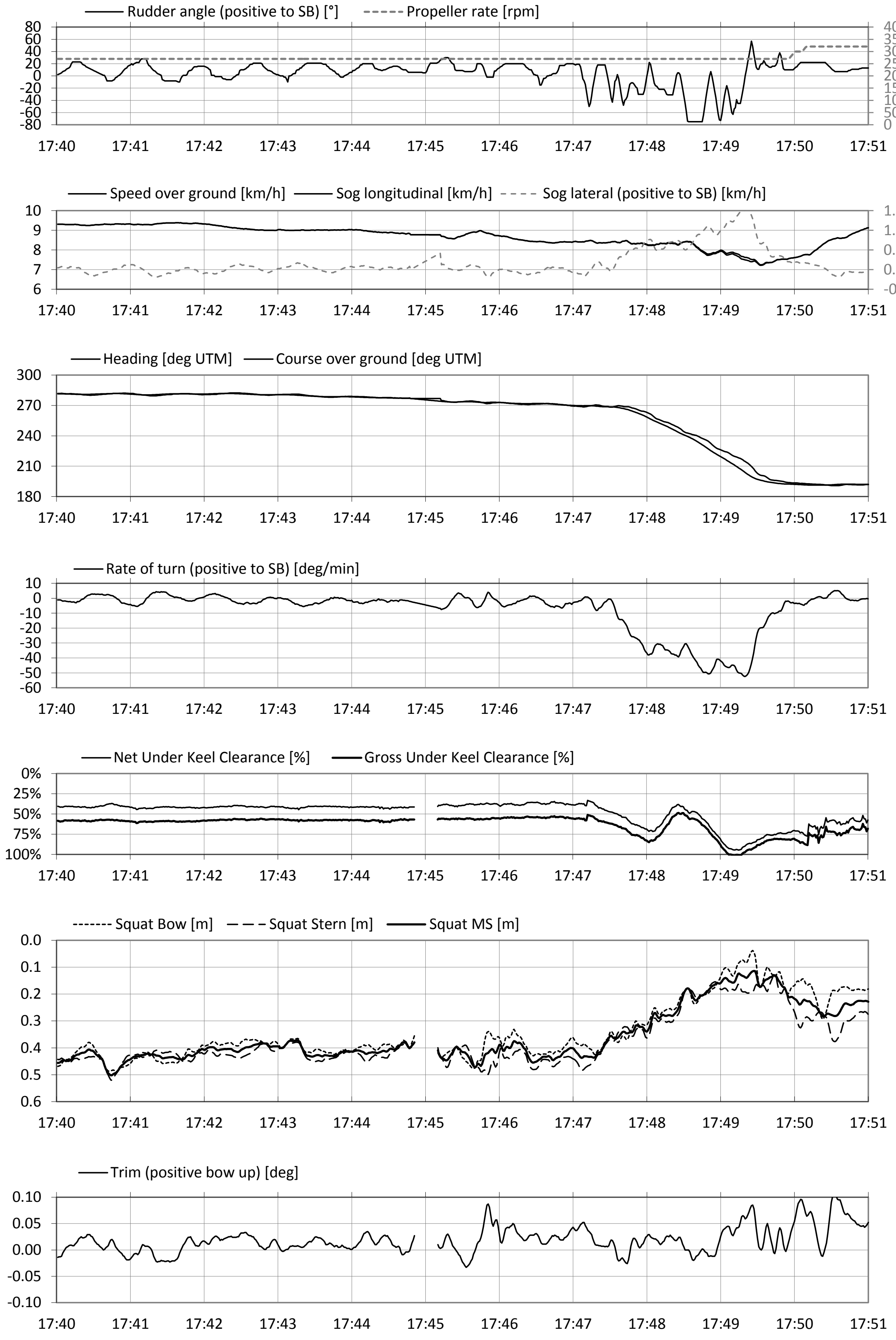

FIGURE 7 – TIME SERIES OF THE MOST IMPORTANT PARAMETERS MEASURED ON THE *MT ELISE* DURING THE TRAJECTORY IN THE BEND OF NEVELE

COMPARISON FULL SCALE TESTING WITH MATHEMATICAL MANOEUVRING MODEL

The main objective of the full scale measurements on the *MT Elise* concerns the validation of the mathematical manoeuvring models for ECMT-class IV and Va vessels.

Table 4 compares the main dimensions and UKC's of the ECMT class IV and Va vessels available in the simulator with those tested in situ on the *MT Elise*. It should be noticed that the *MT Elise* has intermediate dimensions with a length close to the length of the ECMT class Va vessel and a beam equal to the beam of the ECMT class IV vessel. The draft of the *MT Elise* falls within the range of drafts for which there are manoeuvring models available for the ECMT class IV vessel but is smaller than the smallest draft available for the ECMT class Va vessel.

The manoeuvring behaviour of the *MT Elise* was compared to the manoeuvring characteristics of the ECMT class IV vessel at a draft of 2.6 m and to the ECMT class Va vessel at a draft or 2.85 m.

TABLE 4 – COMPARISON OF DIMENSIONS AND UKC'S OF SIMULATOR VESSELS AND *MT ELISE*

	Sim IV	**Sim Va**	**MT Elise**
L_{OA} [m]	85	110	105
B [m]	9.5	11.4	9.5
T [m]	2.2 – 2.85	2.85 – 3.6	2.6
UKC [%]	10 - 200	10 - 200	50 - 100

FAST TIME SIMULATIONS

The comparison between full scale measurements on the *MT Elise* with the manoeuvring behaviour corresponding to the mathematical manoeuvring models was performed by means of fast-time replay simulations (further called 'replay simulations'). Two types of replay simulations can be distinguished.

A first type of replay simulations concerns free replay simulations (or free running replay simulations). In this type of simulation the time evolutions of propeller and rudder usage are used as an input to the simulator vessel and the vessel sails freely in the environment. The simulation environment applied in free replay simulations is not horizontally restricted, as one cannot predict the trajectory of the simulator vessel. In free replay simulations the force balance is respected. The most important output of free replay simulations are the followed trajectory, speed and rate of turn.

A second type of replay simulations concern captive replay simulations. During captive replay simulations not only the usage of propeller and rudder are an input to the manoeuvre, but also the vessel performs a predefined trajectory by forcing the horizontal accelerations. As for captive replay simulations the trajectory of the vessel is prescribed, also local restrictions such as banks or other shipping traffic can be added to the simulation environment. The output of captive simulations concerns time series of the net horizontal forces and moment that are computed by the mathematical models.

SCALING OF PROPULSION AND STEERING

At first free replay simulations were performed in order to compare the manoeuvring behaviour of the *MT Elise* to the selected manoeuvring models. Before this could be done the time series for rudder and propeller needed to be adapted in order to have a similar general manoeuvring behaviour. The reason for this is that the propulsion and steering equipment of the ship model tested in the towing tank and the vessel tested at full scale showed significant differences. In order to transform the rudder angles and propeller rates applied on the *MT Elise* to suitable input values for free replay simulations two conditions were set:

- During the straight trajectory the average ship speed should be equal for the measurement and the simulation. This is achieved by applying a correction factor to the propeller rates measured.
- During the straight trajectory the average rate of turn of the vessel should be equal for the measurement and the simulation. This is achieved by applying an offset to the rudder angles measured.

The calculation of the scale factor for the propeller rates and rudder angles was done by performing free replay fast-time simulations in an iterative way so that both the condition regarding ship speed and rate of turn were met. The resulting scale factors are presented in Table 5. It was already mentioned that despites the straight trajectory of the *MT Elise* from 17:40 to 17:47 the vessel applied an average rudder angle of 10 deg to starboard (positive). The offset rudder angle to be applied on the Sim IV and Sim Va in order to achieve identical average speeds is 6.57 and 7.01 degrees to port respectively.

TABLE 5 – SCALE FACTORS FOR PROPELLER RATE AND RUDDER ANGLE IN ORDER TO REACH A SIMILAR GENERAL MANOEUVRING BEHAVIOUR FOR THE SIMULATOR VESSELS (AT UKC 55%) AND THE *MT ELISE* DURING THE TRAJECTORY BETWEEN 17:40 AND 17:47

	Scaling RPM [%]	**Offset rudder angle [deg]**	**Average speed [km/h]**	**Average rate of turn [deg/min]**
MT Elise	-	-	8.98	-1.52
Sim IV	100	0	10.71	19.79
Sim Va	100	0	15.07	22.00
Sim IV	73.3	-6.57	8.98	-1.52
Sim Va	48.9	-7.01	8.98	-1.52

FREE REPLAY SIMULATIONS

In Figure 8 and Figure 9 the most relevant parameters to analyse the manoeuvring behaviour of the simulator vessels corresponding to ECMT class IV and Va, respectively, at different UKC's are presented together with the registrations on the *MT Elise*. The application of rudder and propeller is presented in Figure 7.

Based on these graphs the following conclusion can be drawn:

- Small rudder angles (< 20 deg) as applied during the straight trajectory (17:40 to 17:47) correspond to much larger rate of turn of the simulator vessels than was measured on the *MT Elise*.
- In the simulator models the rate of turn stagnates at a rudder angle larger than approximately 40 deg, which was not the case for the *MT Elise*. The maximum rate of turn reached in the bend of Nevele was similar for the simulator vessels than for the *MT Elise*.
- The reduction in longitudinal speed while turning the vessel is much larger for the simulator vessels than was noticed on the *MT Elise*.
- The ratio between lateral speed and rate of turn was similar for simulator vessels and *MT Elise*.
- The results of the ECMT class Va simulator vessel correspond better to the manoeuvring behaviour of the *MT Elise* than it was the case for the ECMT class IV simulator vessel.

Simulator vessels applied for design studies preferably have somehow conservative manoeuvring characteristics. Based on the comparison in Figure 9 it was concluded that the manoeuvring behaviour of the simulator vessels at small rudder angles was better than for the *MT Elise*. It was agreed to tune the manoeuvring models of the simulator vessels in such a way that the manoeuvring behaviour at small rudder angles was reduced and the manoeuvring behaviour at large rudder angles was increased. This purpose was achieved by tuning the lift and drag coefficients of the rudder in such a way that the absolute mean rate of turn of the simulator vessels corresponded better to the *MT Elise*. The absolute mean rate of turn is defined as the average of the absolute values of the differences between two consecutive extremes in the rate of turn time series and is considered to be a measure for manoeuvrability of the vessel. The absolute mean rate of turn values were derived separately for the straight trajectory (based on 11 extremes) and the Bend of Nevele (also based on 11 extremes) and are presented in Table 6. The absolute mean rate of turn reveals the significantly better manoeuvring behaviour corresponding to the original manoeuvring model of the ECMT-class IV vessel than was measured on the *MT Elise*. After tuning the manoeuvring models the manoeuvring behaviour of the ECMT-class IV vessel was still slightly better than that of the *MT Elise* (this can be justified by the larger length of the *MT Elise*) while the manoeuvring behaviour of the ECMT-class Va vessel was similar to the one of the *MT Elise* at small rudder angles and slightly worse at large rudder angles (this can be justified by the smaller dimensions of the *MT Elise*).

TABLE 6 – ABSOLUTE MEAN RATE OF TURN FOR THE SIMULATOR VESSELS (AT UKC 55%) CORRESPONDING TO THE ORIGINAL AND TUNED MANOEUVRING MODELS AND THE *MT ELISE*

Vessel	**Absolute mean rate of turn 17:40 – 17:47 deg/min**	**Absolute mean rate of turn 17:47 – 17:51 deg/min**
MT Elise	6.2	17.2
Sim IV (original)	19.9	51.8
Sim Va (original)	11.5	19.6
Sim IV (tuned)	10.2	23.5
Sim Va (tuned)	6.5	12.8

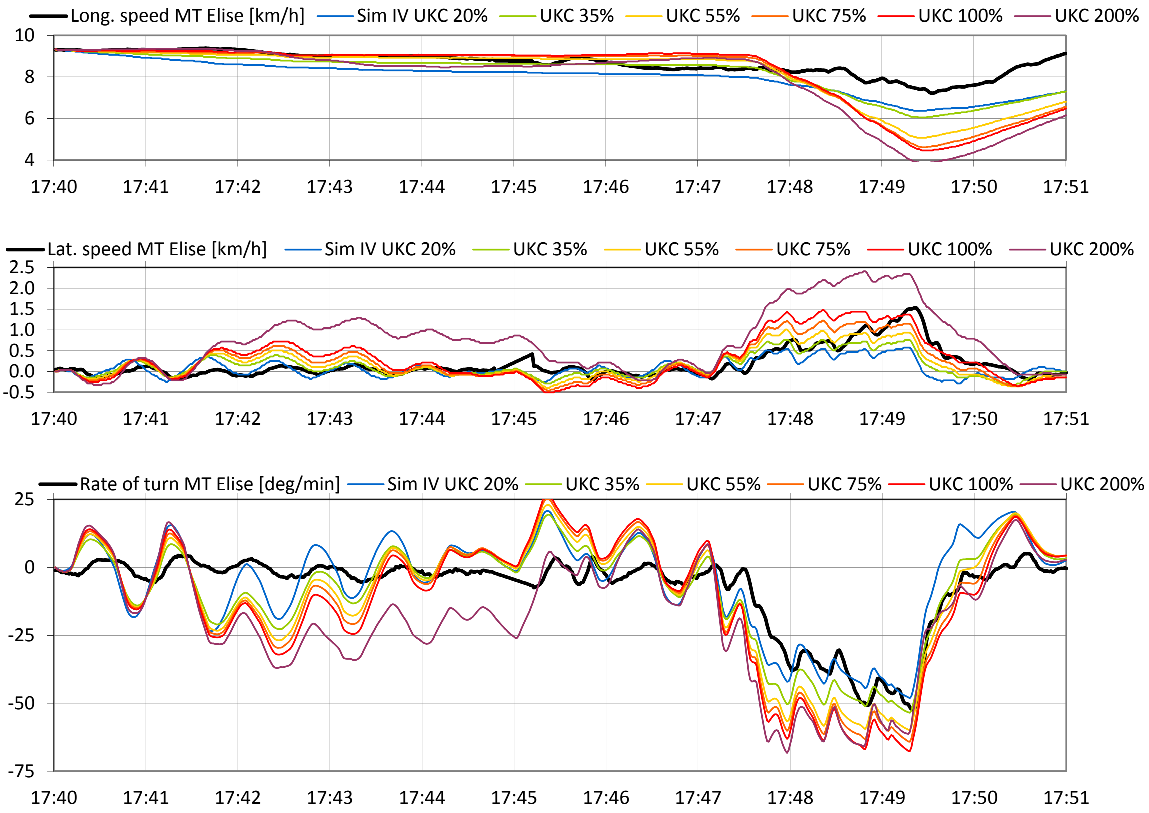

FIGURE 8 – RESULTS OF FREE REPLAY SIMULATIONS WITH ECMT CLASS IV AT DRAFT 2.6 M

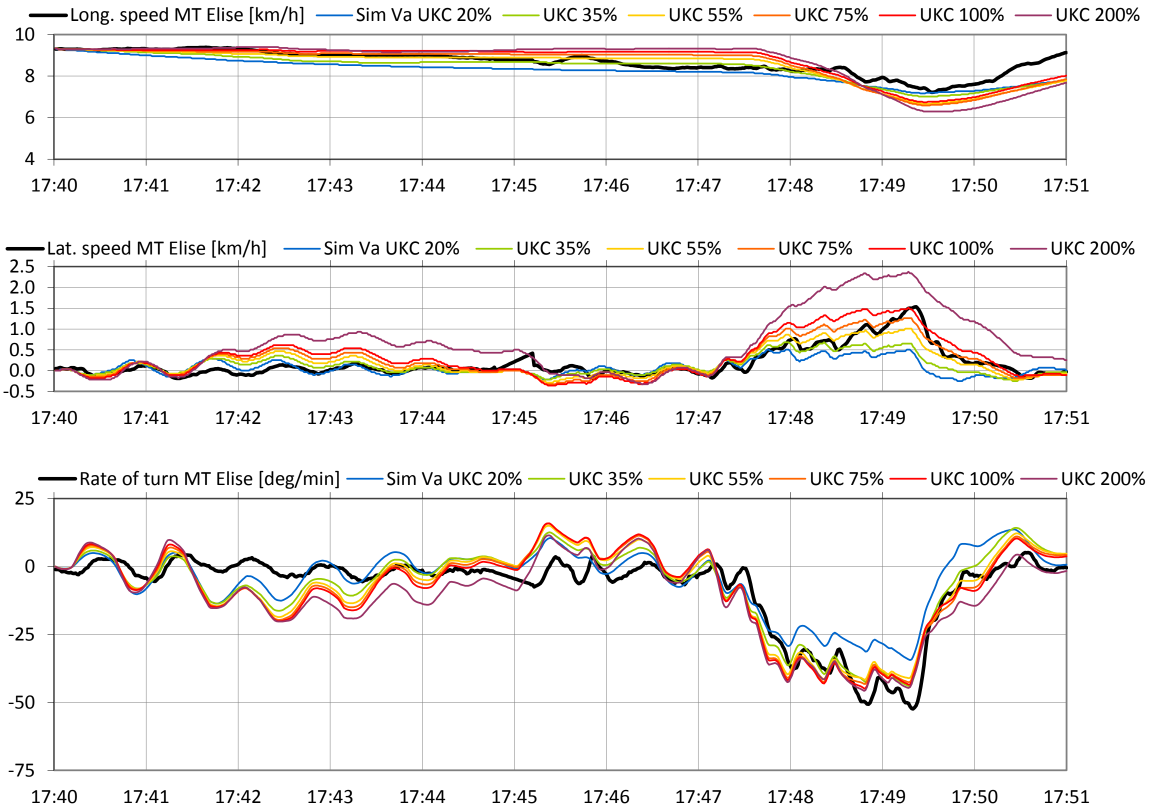

FIGURE 9 – RESULTS OF FREE REPLAY SIMULATIONS WITH ECMT CLASS VA AT DRAFT 2.85 M

CAPTIVE REPLAY SIMULATIONS

During captive replay simulations both usage of controls (propeller and rudder) and the ship motions are used as an input to the simulator vessel. As a result the force or moment balance calculated in the mathematical manoeuvring model will not be respected. The net force or moment calculated by the mathematical manoeuvring model is a measure for the:

- discrepancy between manoeuvring model and actual behaviour of the vessel;
- forces and moments resulting from external effects (such as wind, banks, ship-to-ship interaction, tug assistance, etc.) that are not taken into account in the manoeuvring model.

As the yaw motion (or rate of turn) is the most relevant degree of freedom for manoeuvring, the results of captive replay simulations will be presented by the net yawing moment.

During the straight trajectory when small rudder angles were applied, the net moment is in phase with the rudder angle (Figure 10). This implies that the manoeuvring models calculate larger yawing moments than those corresponding to the ship motions of the *MT Elise* (the manoeuvrability is over estimated). In the Bend of Nevele large rudder angles and high rate of turn were applied. When using large rudder angles the net yawing moment is in counter phase with the rudder angle. These observations correspond to the conclusions regarding manoeuvring behaviour drawn based on free replay simulations. The smaller net yawing moment when applying the tuned manoeuvring models instead of the original manoeuvring models illustrates the good correlation between the tuned manoeuvring models and the manoeuvring behaviour of the *MT Elise* (especially for Sim IV).

The major advantage of captive replay simulations is that in case of a reliable manoeuvring model that accurately predicts the ship behaviour in open shallow water, the net horizontal forces or moment correspond to external effects that are not taken into account in the manoeuvring model. During the full scale measurement on the *MT Elise* two ship meetings were performed (Table 3). The yawing moment resulting from the ship-to-ship interactions can be derived from the net yawing moment resulting from the captive replay simulations (Figure 10). Based on the captive replay simulation with the tuned manoeuvring model of the ECMT class IV vessel the yawing moments resulting from the meeting with the Malta (17:45:45) are:

- bow repulsion of app. 60 tonm when the bows meet;
- bow attraction of app. 75 tonm when the mid ship meets the bow of the other vessel;
- bow repulsion of app. 120 tonm when the stern meets the bow of the other vessel;
- bow attraction from the moment the mid ship meets the stern of the vessel until the sterns meet, with a maximum of app. 100 tonm.

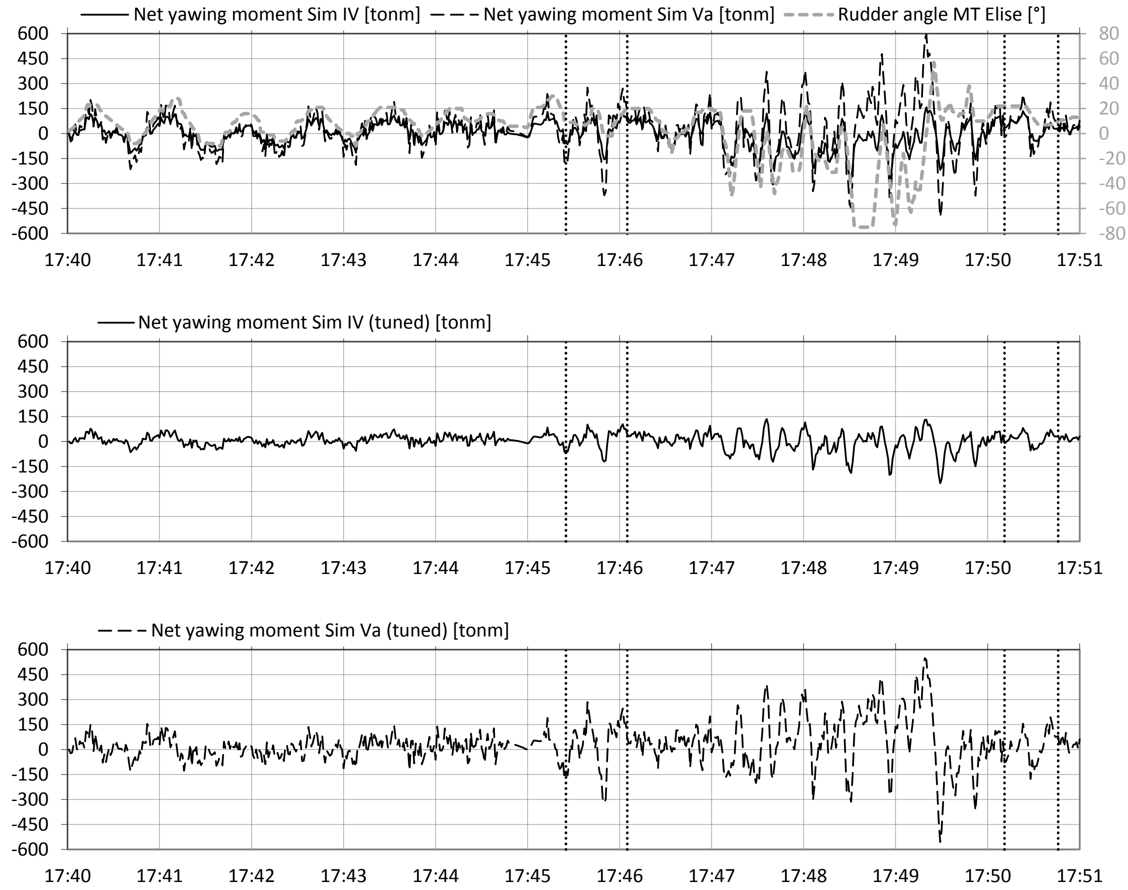

FIGURE 10 – NET YAWING MOMENT DURING CAPTIVE REPLAY SIMULATIONS WITH THE ORIGINAL (TOP) AND TUNED (MID AND BOTTOM) MANOEUVRING MODELS OF SIMULATOR VESSELS SIM IV AND SIM VA AT UKC 55%. INDICATION OF START (BOW-BOW) AND END (AFT-AFT) OF HEAD ON MEETING

CONCLUSIONS AND FURTHER RESEARCH

In order to validate the mathematical manoeuvring models of inland vessels developed by FHR, full scale measurements on a similar inland vessel were performed. The comparison between manoeuvring models and actual ship behaviour was made based on both free running and captive replay simulations.

Free running replay simulations seemed to be a valuable tool for evaluating the manoeuvring behaviour in open (shallow) water. This kind of simulations was applied to tune the mathematical model in order to achieve a manoeuvrability for the simulator vessels corresponding to the full scale observations.

Unlike free running replay simulations, captive replay simulations can be applied in order to analyse the effects of horizontal restrictions on the manoeuvring behaviour of a vessel. The capability of captive replay simulations to assess the ship-to-ship interaction forces during head on meetings is demonstrated. The same technique can be applied to estimate the forces and moments experienced by the vessel resulting from e.g. bank effects, lock effects, tug operations or contact forces. The quality of the results of captive replay simulations strongly depends on the accuracy of the mathematical manoeuvring model.

As ship-to-ship interactions correspond to a relatively small time scale and data from other shipping traffic can be collected in an easy way (by means of AIS-data), and also taken into account the rather large efforts to test these effects on model scale, ship-to-ship interactions are assumed to be the most interesting hydrodynamic effect to analyse by means of captive replay simulations of full scale measurements. FHR has the intention to apply this technique to analyse the ship-to-ship interactions on container vessels on the river Scheldt.

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