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OUTCOMES FROM A STUDY OF VALIDATION OF SHIP SPECIFIC MODELS FOR SHIPHANDLING SIMULATOR

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ABSTRACT

This paper presents some outcomes from a four years (2013 – 2016) long research project investigating validation of ship specific simulation models. In contrast to the other initiatives such as SIMMAN 2008 [1] and SIMMAN 2014 [2], the R&D project "Sea Trials and Model Tests for Validation of Shiphandling Simulation Models" (SIMVAL [3]) investigates model development and validation methods for specific vessels. For these vessels, the yard's documentation of manoeuvring characteristic was available for the researchers. In addition, the project has been given permission to perform different sets of sea trials on selected case vessels. As far as possible, these sea trials were designed to document vessel-specific operations such as low-speed manoeuvres and dynamic positioning. Other papers presenting results from the SIMVAL project will be given in a separate session, Session 12-14, in the Torgeir Moan Symposium at OMAE2017.

INTRODUCTION

The Norwegian R&D project "Sea Trials and Model Tests for Validation of Shiphandling Simulation Models" investigated ways of validating ship-specific manoeuvring models using model tests and sea trials. Numerical models in engineering tools can be used for different purposes such as studies of ship manoeuvring characteristics in deep open waters, or the design of fairways, ports and quays. Simulation models become an integrated part of modern design tools making it possible to include manoeuvring performance as a design parameter. Numerical ship models are also used in training simulators for deck officers and pilots. The verification and validation of simulation models are closely intertwined with access to benchmark data and the accuracy of such data from model tests and sea trials. This project had access to sea trials from a number of ships. The Norwegian partners performed model tests and sea trials on five ships. The foreign partners used four other case vessels.

This paper will present some of the outcomes of the Norwegian part of the SIMVAL project. The first part of this paper offers a brief overview of project content and research objectives. With reference to the findings of SIMMAN 2008 [1], we concluded that manoeuvring models used by research institutes and universities showed significant differences in their predictions of International Maritime Organisation (IMO) standard manoeuvres such as turning circles and zig-zag tests. The paper will also review the findings of efforts to develop vessel-specific simulation models for three Norwegian case vessels, one offshore vessel, one LNG coastal ferry and the research vessel of the Norwegian University of Science and Technology (NTNU). A lack of high-quality test documents from shipyards' sea trials made it impossible to use these for validation studies of the case vessels. Following discussions with the masters of the case vessels, the project drew up vessel-specific test matrices for the collection of operational performance data required by the masters. Low-speed tests were high on their priority list. The final part of the paper discusses how the findings of the project were communicated to the industrial project partners (ship designers and shipping companies). This section also describes how results are being implemented in an operational environment for shipping companies (improved models in simulators for training and pre-studies of critical operations) and design offices (design-phase simulation tools).

[2] Earlier MARINTEK, SINTEF Ocean from 1st January 2017 through a merger internally in the SINTEF Group

NOMENCLATURE

$a_0 - a_4$	Constants in yaw equation
DIR_P	Mean peak direction
H_S	Significant wave height
r	Rate of turn/yaw speed
T_P	Peak period
y	Identification data
$\hat{y}$	Output data from metamodel
δ	Rudder angle
ψ	Course angle

THE SIMVAL PROJECT

Research objectives

The main objective of the project was to develop and apply a method for validation of numerical ship models. Numerical models in engineering tools can be used for different purposes such as studies of ship manoeuvring characteristics in deep open waters, or the design of fairways, ports and quays. Simulation models have become an integral part of modern design tool packages that enable designers to include manoeuvring performance as a design parameter. Numerical models are also used in training simulators for deck officers and pilots. Verification and validation of simulation models are closely intertwined with access to benchmark data and the accuracy of such data from model tests and sea trials. This project had access to the sea trials of several ships. The Norwegian partners performed model tests and sea trials of five ships (NTNU's research vessel "Gunnerus", the gas-powered ferry "Landegode" and three offshore support vessels "Island Condor", "Polarsyssel" and "Westland Mira"). The foreign partners used four vessels (a triple E-class container vessel (Flanders Hydraulics/Ghent University), a small container vessel (Singapore Maritime Academy) and university research vessels belonging to University of Sao Paulo and Tokyo University of Marine Science and Technology).

On three of the Norwegian case vessels, MARINTEK performed a range of model tests using the Hexapod system as a Planar Motion Mechanism – PMM. A new method for analysing model test data was developed to generate input data for MARINTEK's ship simulation tool VeSIM [4]. The project showed the importance of selecting model test parameters (for surge, sway and yaw) representative of critical manoeuvres for each vessel. When the parameters were well selected, the numerical predictions compared well with sea trial results.

Project organisation

The project started in April 2013 and ended in December 2016. The project budget was approximately 18 million NOK. Some preliminary project results were presented at a dedicated validation session at the OMAE 2015 Conference in St. Johns, Newfoundland, in June 2015 [5] – [9]. The Norwegian partners were MARINTEK, NTNU, Rolls-Royce Marine, Island Offshore, Torghatten Nord, Ship Modelling & Simulation Centre (SMSC) (2013-2014), Marine Cybernetics (2014-2016) and Havyard Design & Solutions (2015-2016). The foreign partners were Flanders Hydraulics Research, Ghent University, Tokyo University of Marine Science and Technology, Singapore Maritime Academy, the University of São Paulo and Instituto SINTEF do Brazil (2013-2014)."

Project structure and test timelines

The initial project structure was as shown in Figure 1. A number of different tools (analytical, regression analysis, computational fluid dynamics and captive model tests) were used to develop mathematical ship simulation models. Figure 2 shows the timeline for model tests with the Norwegian case vessels. These models were used to calculate a selection of IMO's Standard manoeuvres [10] for the project's case vessels.

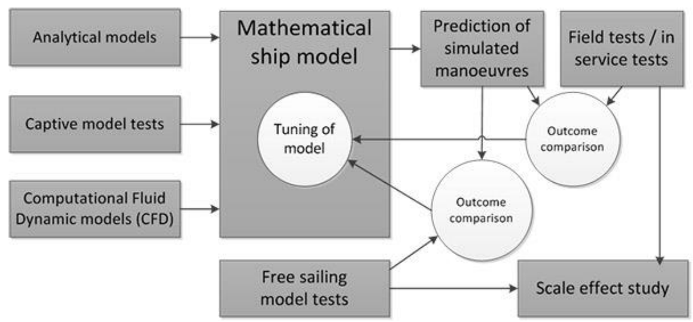

Figure 1: Initial SIMVAL project structure

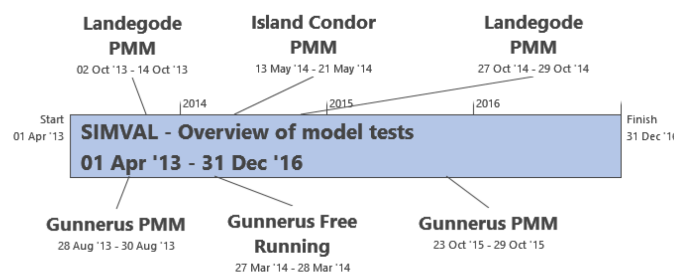

Figure 2: Timeline of model tests of Norwegian case vessels.

In collaboration with industrial project partners, MARINTEK specified the case vessel specific sea trial programmes and data logging systems to be used during dedicated sea trials and for logging in-service manoeuvring parameters. The timeline for sea trials of the Norwegian case vessels is shown in Figure 3.

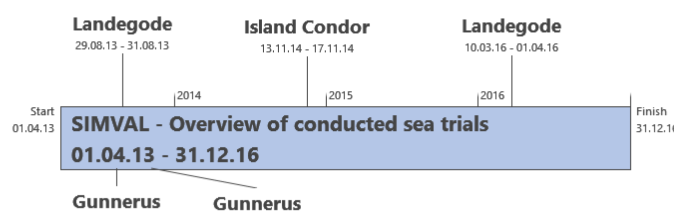

Figure 3: Timeline of sea trials for Norwegian case vessels

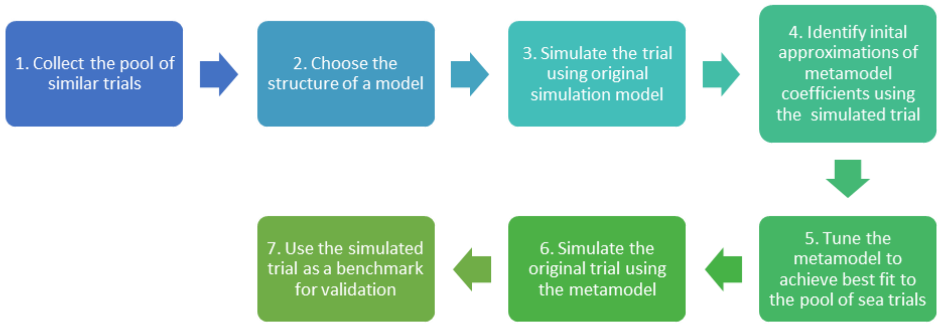

Figure 4. Validation process using metamodels.

PHD AND POST-DOC WORK

The project funded two scholarships. The candidates studied uncertainty in sea-trial data and the possibility of obtaining a vessel's manoeuvring performance from service data. The PhD student investigated how to analyse repeated sea trials for two of the case vessels; RV "Gunnerus" and the LNG ferry "Landegode". His approach was based on system identification and use of metamodels. Figure 4 shows the different steps involved; steps 3 and 4 can be skipped for the simple forms of a metamodel. A metamodel can be explained as a simplified model of a ship for particular narrow range of operation, identified from full-scale experimental data.

However, steps 3 and 4 may be important for more complex models. In Step 5, known environmental effects can be taken into account, such as mean drift due to currents and waves identified for each individual trial. The key differences between metamodel identification and traditional manoeuvring model identification are:

- The structure of a metamodel can differ from the structure of the model that has already been validated. In fact, different metamodel structures can be used for the different types of trials.
- Several similar trials are used to identify a metamodel. Thus, influence of random components due to environmental conditions and other disturbances is minimized by averaging.

A metamodel thus represents the averaged response of a ship to certain control inputs. A demonstration of the method using the LNG ferry "Landegode" as a case vessel will be presented later in this paper: The case investigated is manoeuvring connected to approaching/departing the ferry quay in Moskenes (Northern Norway).

In the Postdoc study application of long term operational data for validation work was investigated contrary to usual method based on use of standardized test manoeuvres defined by IMO. For this purpose, a framework was developed to extract the information of distinctive manoeuvres from the in-service data. An outline of the approach is shown in figure 5.

More information of the work was presented by Abbasi Hoseini [11].

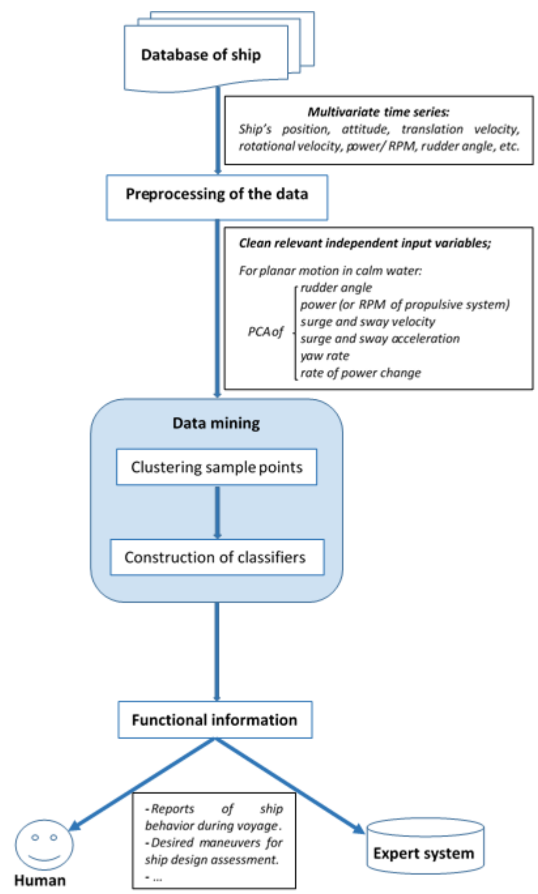

Figure 5: Data processing of in-service manoeuvring data.

DEVELOPMENT, VERIFICATION AND VALIDATION OF VESSEL-SPECIFIC MODELS – NORWEGIAN CASE VESSELS

Some introductory comments

MARINTEK's simulation tool VeSIM [4] was used to predict the manoeuvring performance of five Norwegian case vessels. This paper provides a brief summary of the work done on three of these vessels. In-depth presentations of some of these vessels, will be offered by papers in sub-section 12-14 of this conference (Torgeir Moan Symposium).

A lack of high-quality test documents from shipyard's sea trials meant that it was impossible to use them for validation studies for the case vessels. On the basis of discussions with masters, chief officers and inspectors, the project prepared vessel-specific test matrices to collect operational performance data required by the master and deck officers. Low-speed tests were high on their priority lists. In this paper we only present comparisons for some IMO standard manoeuvres

NTNU's research vessel "Gunnerus"

Most of the initial SIMVAL work was done using this vessel. The application of MARINTEK's Hexapod system as a Planar Motion Mechanism was improved, and we gained a better understanding of how to specify the motion parameter space to be included in captive tests. A major upgrade of the coefficient identification tool IDSIMAN [9] was implemented. This tool was designed to generate naked hull hydrodynamic coefficients for a manoeuvring ship as input to the VeSIM 6 DOF vessel simulation tool. The tool solves an optimisation problem using a non-linear curve-fitting approach in a least-squares sense. When the parameters of the manoeuvring model have been found by IDSIMAN, they can be used to reconstruct the PMM test. If the manoeuvring model matches the physical system well, the structure of the model has been verified. Figure 6 shows how the identified model replicates a PMM dataset. One comparison of model predictions and sea trials for RV "Gunnerus", is shown in Table 1 and figure 7. As can be seen, the simulation model compares well with sea trial results. There is some minor deviation in the 1st and 3rd overshoot angle as shown in figure 7.

Torghatten Nord's LNG ferry "Landegode"

In collaboration with representatives from Rolls-Royce Marine, MARINTEK developed two logging routines. The first one was used during specific manoeuvring tests that were performed outside Bodø, in northern Norway, in August 2013. The second one (developed in 2016) was used for in service logging. The manoeuvring tests included IMO Standard Manoeuvring tests [10] and some tests defined in ISO 13643 [12]. A complete list of conducted test types is shown in Table 2, and an example of comparison between prediction and sea trial is shown in Figure 8. A separate paper on validation analysis for this vessel will be presented in session 12-14 of the Torgeir Moan Symposium [13].

Table 1 Comparison of characteristic manoeuvring parameters from a 10/10 zig-zag trial – prediction and full-scale values [5]

	Prediction	Full-scale
First Overshoot angle (deg)	6.5	7.5
Second Overshoot angle (deg)	6.2	6.5
First Overshoot time (s)	5.6	5.7
Second Overshoot time (s)	6.0	5.4
Half period (s)	27.2	27.2
Full period (s)	50.6	50.0
Approach speed (kn)	8.1	8.2

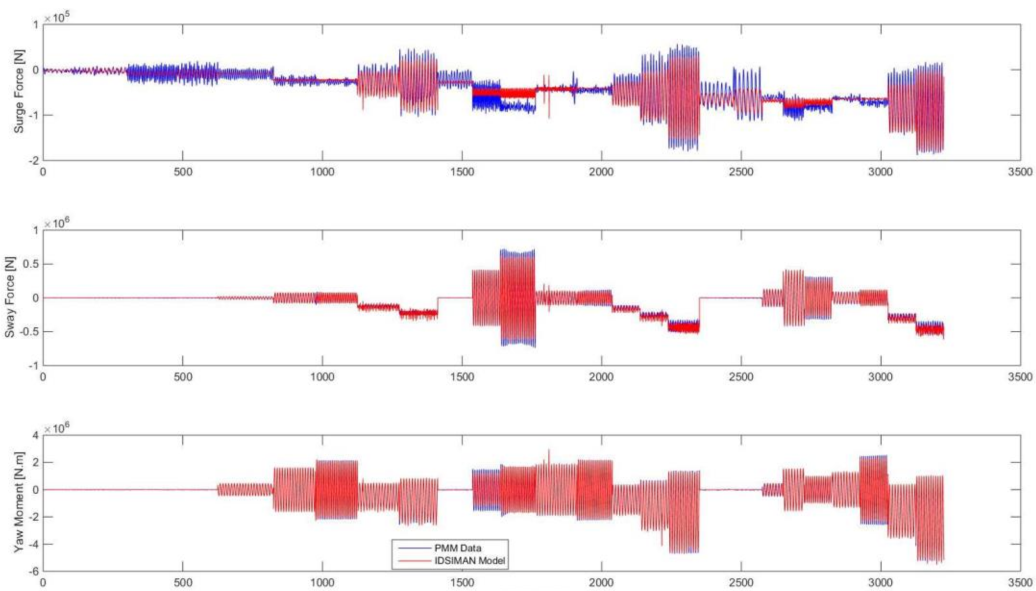

Figure 6: Comparison of force measurements and forces calculated using IDSIMAN coefficient set [9].

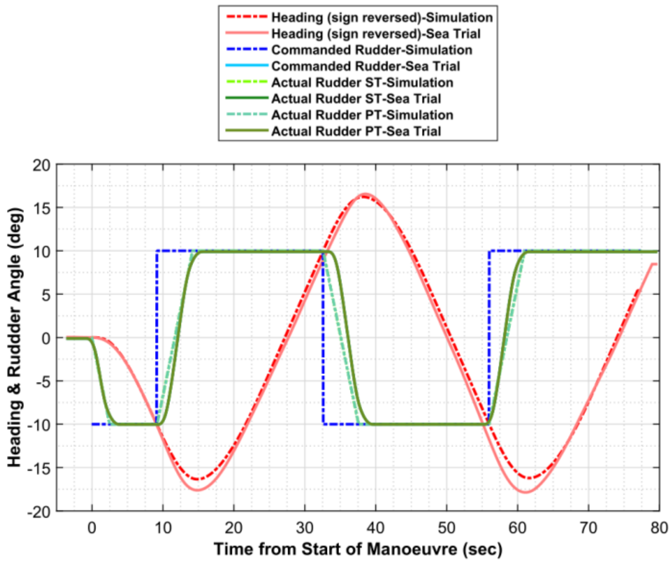

Figure 7: Prediction and full-scale values for RV "Gunnerus" for a 10/10 zig-zag test [5]

Table 2: Manoeuvring tests with LNG ferry "Landegode"

Test types	Standard
Thruster turning tests	ISO 13643 - 2.3 O
Thruster turning tests (forward speed)	ISO 13643 - 2.3 A
Thruster turning tests (astern speed)	ISO 13643 - 2.3 O
Accelerating turn test	ISO 13643 - 2.2 S or P
10/10 Zig-zag	IMO [10]
20/20 Zig-zag	IMO [10]
Turning circle	IMO [10]
Direct spiral test	IMO [10]
Stopping test	IMO [10]

During the sea trial with Landegode, several low speed tests according to ISO 13643 were conducted. Among these, thruster turning tests with zero speed, ahead speed and astern speed. The ferry has two bow tunnel thrusters and one stern tunnel thruster. These tests is to identify how effective the tunnel thrusters rotate the ferry. Accelerating turn test according to ISO 13643 was also performed to investigate the ships turning capabilities. Further, tests to document and understand the use of the flap-rudders were performed where rudder angles were increased from 40° to 67° to see the effect on yaw rate and forward speed.

The in-service data were also used by the PhD student (Gavrilin) to identify parameters for a metamodel for a zig-zag manoeuvre. During the operation, main parameters such as positions, orientation, velocities, propulsion parameters, wind direction and velocity were recorded and stored as one-hour-long time-series with short breaks in between. Most of this information was derived from almost straight course motions and was therefore not of interest for a manoeuvring application.

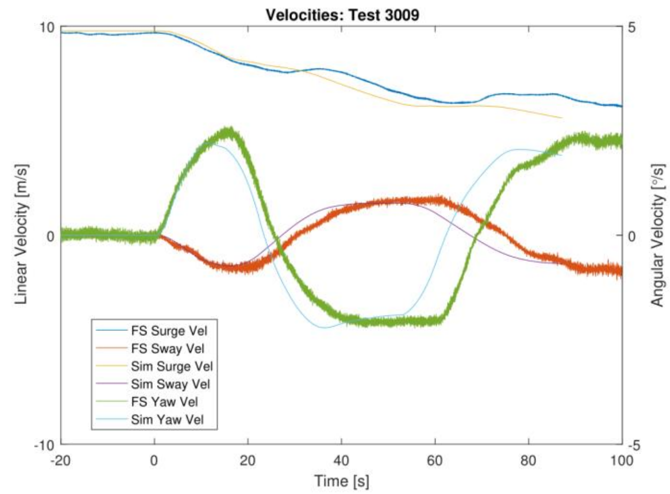

Figure 8: Prediction and full-scale body velocities for LNG ferry "Landegode" during a 20/20 zig-zag test [14].

The first task while processing the data was to find parts of the time-series representing turning motion. The search was performed in four steps:

Step 1. Data cleaning and preparation. All the data were low-pass filtered and resampled in order to end up with the same sampling frequency, using spline interpolation.

Step 2. Searching for the fragments of the time-series, when the ship was turning. A moving average (MA) algorithm with window size 300 samples (30 s) and step size 10 samples (1 s) was used to find where turning rate exceeded a threshold value equal to 0.2°/s.

Step 3. Merging of the fragments. Fragments were merged if the interval between them was less than 90 s. This was done to detect zigzag-like or course-changing manoeuvres. The resulting time-series, further referred to as trials, were saved as individual files.

Step 4. Classification. The ship operated on a fixed route and followed similar path every time as shown on figure 9. The position and orientation were maintained by the autopilot of the ship. Therefore, many of the turning trials detected in the data were nearly similar, with slightly different control input counteracting changing environmental disturbances. The k-means algorithm was used to find similar trials. As a feature vector characterizing each trial, positions of the beginning and the end of a trial (four features per trial) were used. Prior to application of the k-means algorithm, the mean values of the features were removed before the features were normalized, so that the scale was similar for both latitude and longitude.

For zigzag-like trials with small rudder deflection, a nonlinear heading model proposed by Norrbin [15] was selected as a metamodel:

$$\dot{r} = -a_0 - a_1 r - a_2 r^2 - a_3 r^3 + a_4 \delta \qquad (1)$$

As can be seen from figure 9, the track during approach/departure from the ferry quay in Moskenes (Northern Norway) resemble a zig-zag test.

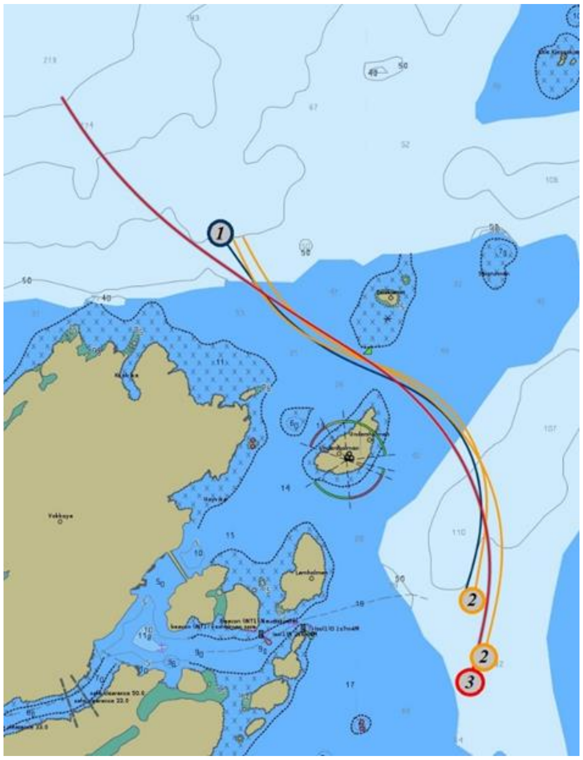

Figure 9 Examples of tracks from each group of trials used for identification of the metamodel of "Landegode".

To check the outcomes cross-validation was performed. The metamodel was used to simulate one additional trial (not used for the identification). Figure 10 compares prediction based on the metamodel with actual time-series of rate of turn for the additional trial. The following metric was used for comparison (y is identification data, $\hat{y}$ is the output of a metamodel):

$$fit = \left(1 - \frac{\|y - \hat{y}\|}{\|y - mean(y)\|}\right) \cdot 100\% \qquad (2)$$

For this case, y was the vector of all yaw rate measurements. By subtracting the mean value of the measurement vector in the denominator, the effect of the variable varying about a non-zero value was eliminated.

It was concluded that the selected metamodel accurately represented the turning dynamics of the vessel for small rudder deviations and a particular surge velocity.

Island Offshore's vessel "Island Condor"

The tests were conducted between November 13th and 17th, 2014 on the journey between the yard at Brevik and Stavanger. No calm-water validation tests could be conducted due to the weather. However, tests in waves were performed. The measurements during the tests with Island Condor were performed using both the vessel's own instrumentation and test specific instrumentation. Table 3 summarises test types and weather conditions during the tests. As can be seen, the significant wave height was less than 3 m while the peak period varied between 6 and 9 seconds. Figure 11 compares calculated and measured parameters for what was specified to be a $20^{o}/20^{o}$ zig-zag test. From analysing the measurements, it was

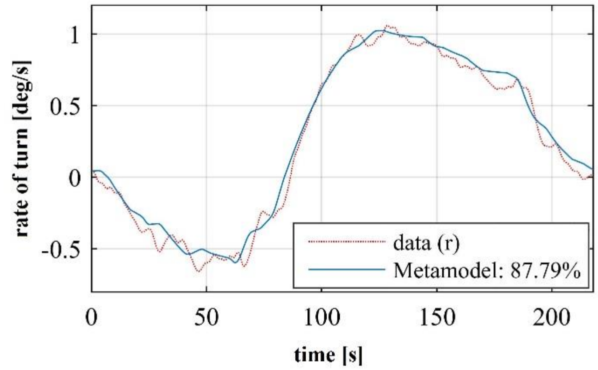

Figure 10. Cross-validation of the metamodel.

Table 3 Manoeuvring tests with offshore vessel "Island Condor"

Test types	Test parameters	Environmental conditions
Turning circle	$\delta=15^{0}$, 20^{0} , 23^{0} STB, $\delta=15$, 25^{0} PT	H_S: 2.2-2.8 m T_P: 6.1-9.4 s DIR_P: 115^{0} - 154^{0}
Spiral test	$\delta=\pm 10^{0}$, $\pm15^{0}$	
Zig-zag test	$\delta/\psi=10^{0}/10^{0}$, $20^{0}/20^{0}$	
Acceleration test	Full ahead (on DP system)	
Stopping test	Full astern (on DP system)	
Thruster turning test	Single and multiple thrusters	
Pure sway test (crabbing)	On DP system (joystick). All thrusters enabled	
DP tests	Various headings	

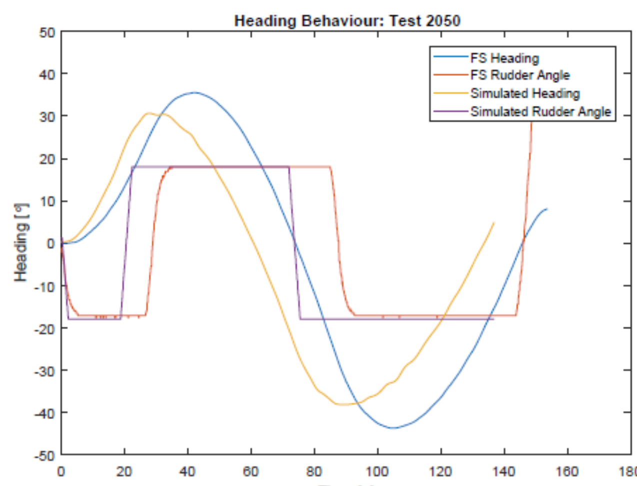

Figure 11: Track comparisons – predicted and full-scale zig-zag parameters for "Island Condor"

found that a rudder angle of 18° was used in the sea trial. This angle was also used in the simulations. As can be seen from this figure, the deviations between measurements and predictions are larger than for the calm water models shown in previous sections of the paper. In order to investigate and make benchmark data for validation, stationkeeping tests with the weather coming from different angles were conducted. As for the ferry, thruster turning tests according to ISO 13643 was done for zero forward speed. A pure sway test (crabbing) was performed with the DP system by use of joystic.

CONCLUSIONS AND RECOMMENDATIONS

MARINTEK's own main outcomes were a new tool for planning of captive model test using our Hexapod system in a towing tank and an improved process for the analysis of captive model test measurements and generation of input parameters to the naked-hull 6 DOF manoeuvring model in VeSIM.

The project increased our knowledge and understanding of the need for high-quality ship-specific simulation models for studies of complex manoeuvres. The importance of model verification and validation were demonstrated through studies of selected case vessels. For improved quality of a numerical simulation model, the parameter space in captive model tests for drift angle, linear and rotational speeds and acceleration ought to be representative of actual vessel operations. MARINTEK's VeSIM tool with a naked-ship non-linear manoeuvring model can be used for studies of vessel performance, operational limits and familiarization with a vessel's manoeuvring characteristics.

Based on project outcomes, we recommend the following items for further investigation:

- Application of in-service measurements for tuning of metamodels adapted to specific operations
- Validation studies for other types/sizes of vessels
- Definition of sufficient space for variations in motion parameters, applied in captive model tests
- Validity of simulation model for vessels manoeuvring in a sea state.

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