Using a Bridge Simulator during the Early Design-Stage to Evaluate Manoeuvrability

Wilfried Abels, TU Hamburg-Harburg, Hamburg/Germany, w.abels@tu-harburg.de
Lars Greitsch, TU Hamburg-Harburg, Hamburg/Germany, lars.greitsch@tu-harburg.de

Abstract

A bridge simulator is a useful tool for receiving information about the behaviour of a ship. Contrary to physical simulation tools, which are able to calculate the characteristics of a ship design, a bridge simulator can show how a ship design will perform within its natural environment. The classical use of a bridge simulator is training the crew. The numerical models are adjusted mostly by results of model and full-scale tests, but such test results are not available during the design stage of a ship. Therefore numerical simulations have to identify the behaviour of the ship, still within the project stage. In the past, a wide range of numerical methods have already been implemented. The coupling of such “First-Principle-Methods” with a bridge simulator will be presented.

1 Introduction

The use of a bridge simulator for training crews is state-of-the-art nowadays. It is a useful tool for testing a ship and training its crew in many different situations. Critical manoeuvres can be analysed without risk for humans and the ship, and it is possible to get a direct feeling for the behaviour of a ship within a nearly real environment. Effects of current, wind and geography can be modelled. In consideration of the intended use, the ship’s performance can be analysed. Such information is not only important for training the crew. Also during the design process of a ship it is necessary to take the later use into account. The problem is to define in which way a ship can realise the future tasks efficiently. Not the hard values of design speed, displacement or the overshoot angle of a zigzag manoeuvre are important, but probably the possibility to transport a specific stowage from port A to port B by realising a fixed time schedule. However, an engineer can only handle hard values as speed and displacement. Numerical design tools are producing such data. Furthermore, only hard values can be part of a contract between a yard and the customer.

This forces the partners to define a set of physical characteristics. First, they have to describe the ship in a way that the future mission of the ship can be realised. Secondly they have to be clear enough that they can be exactly measured during the ships trial trip. A problem is to communicate in which way different characteristic values are influencing the later mission of the ship. An experienced ship designer will have a feeling for the effects of different attributes. However, for example, a captain who wants to use the ship later has a total different background of knowledge. A curve of rudder forces, which has much information for an engineer, does not have significance for him. He has much experience in handling a ship and has a feeling in which way it should behave. Resulting from these differences in background and experiences, the communication between the developer and the user of a ship is sometimes complicated. Each partner has his own view to the object ship. In such a situation, a bridge simulator can be used as a communication platform. The engineer can design a ship in consideration of his technical background, and the customer can analyse the features of a design in an environment similar the later operation scenario. By using such a platform both partners have the possibility to communicate their know-how. If a simulated mission shows that the ship has a problem with manoeuvring through a specific strait, the engineer can optimise the design and test it again within a bridge simulator. It is not necessary to explain in which way changes of specific physical characteristics will change the global behaviour of a ship design. The bridge simulator can show the new behaviour in a direct and easily observable. The problem of using a bridge simulator in such a way is to generate the numerical characteristic of a ship. Traditionally this information is available by analysing the model-scale or full-scale ship. For the task of training the crew this approach is possible, because the real ship is already available, but during the design stage there are no measurements available. Thus the physical characteristics of a ship design have
to be generated by using “First-Principle-Methods”. The challenge is to generate a reliable numerical ship model without having knowledge of the real ship. It is necessary to have design tools able to produce such reliable information. To solve this task, much work has been done already. There are many tools available to analyse different aspects of a ship design. Different types of CFD tools can be used for a numerical evaluation of resistance, manoeuvring, propulsion and other relevant properties. If there are additionally vessels of comparison available, a ship designer can estimate the behaviour of a new design in quite reliably. Today, bridge-simulators are available along with many sophisticated CFD tools. It is state of technology to use a bridge simulator to train the crew on existing ships and to use CFD tools for supporting the engineer during the early design state. As explained above, a bridge simulator would be a useful extension for the early design. Now it shall be discussed and demonstrated, in which way such a scenario can be realised and what kind of problems have to be solved.

2 Integration Approach

The starting point of this project was the Simflex bridge simulator of FORCE Technology in Denmark and the ship design software E4, both these tools are already available. FORCE Technology has been using its bridge simulator for many years already. The ship design software E4 has been developed over a period of 20 years, Krüger (1999). The focus was to build a software framework for ship design. Therefore many different types of numerical methods have been developed and integrated to this system.

![E4-Ship-Design Methods](image)

**Fig. 1: Principle structure of E4 ship design framework**

This framework has the task to support the ship designer especially during the early design, Krüger (2003). This package is not a monolithic software application, but a set of many different tools working on the same database. This concept has allowed different engineers and scientists to include their own knowledge to the E4 framework by developing a special method. There are today different types of “First-Principle-Methods” available, Fig. 1. Especially a method for calculation of rudder forces should be explained more detailed in chapter 3.2.

For simulating the natural environment, the bridge simulator Simflex has been used. This tool has been developed by the company FORCE Technology. In contrast to the ship design system E4, this simulator cannot calculate the physical characteristics of a ship, but it allows evaluating how a ship will behave in a nearly natural environment. Based on these two tools, the task was now to generate a ship model compatible for the Simflex. This model should be generated by using characteristics produced by “First-Principle-Methods”. If these tools are connected together it is possible to demonstrate features of a new ship design already during the early design stage.
To explain this process, it is necessary to know how ships are described within the Simflex simulator. This simulator uses a model based on forces for different parts of a ship. Thus hull, propeller, rudder and other relevant devices are described in separate modules. Corresponding to the global state of the mathematic model, all forces and momentum are calculated for one time step and summarised. One important difference between a bridge simulator and “First-Principle-Methods” is that a bridge simulator has to simulate many more features of a natural environment, whereas design tools have been developed to analyse different aspects of a ship on its own. These features should be calculated in the most accurate way as possible. On the other hand, a bridge simulator is optimised to simulate the global behaviour of a ship. Therefore it is necessary to describe a lot of more details of a ship. A mathematical model of thrusters is necessary to handle aspects of manoeuvring within harbours. The positioning of the bridge is important for the viewpoint of the captain and a ship-ship interactions model have to be calculated to get a feeling for the behaviour of the ship within an area of high traffic. There are many more aspects which have to be simulated by a bridge simulator.

It is not possible to calculate all features of such a bridge simulator with the used design tools. However, often this is not necessary. First, there are many empirical models available, which describe many details sufficiently. And normally not all features are in the focus of interest. Normally simulations are used, because there is a fear that a ship design would not fulfill a special set of requirements. For example, the question is whether a ship will fulfill the IMO manoeuvres during the trial trip, or whether the ship can keep the time-table in spite of a difficult sea area. In such a case it could be that thrusters are not of interest, but manoeuvring aspects of the rudder are very important. Consequently the numerical descriptions of rudder forces have to be very reliable, whereas a more basic description of thrusters is acceptable. The task is to know which aspects of the bridge simulator have to be exact and which can be approximated in a basic way.

![Diagram](image)

**Fig. 2:** Principle workflow for adapting a Simflex ship model to the E4 ship design tool

The simulator Simflex supports this approach well. All parts of the ship are described by separate functions for forces. The complete model consists of a big set of files including one-dimensional or two-dimensional tables. Interpolation within this data returns the needed forces for one time-step. Due to their complexity, it is not possible to generate a complete set of tables, but this is not necessary. In addition to the Simflex simulator, the software tool ShipYard also implemented by the company FORCE Technology allows the generation of a complete ship model based on empirical information. This model
does not include any “First-Principle-Methods”, but it can be used as a start point for the real ship. In combination with information about the real characteristics, this first empirical model can be improved. This approach is already used by FORCE Technology. The difference is only that until now this process of improving was handled by data from full-scale and model-scale measurements.

Fig. 2 symbolised the work flow of generating a Simflex ship model, which can be used for a full-mission simulation based on a ship design. During the early design, a ship model will be developed. It is possible to generate a valid Simflex-Model by using the software tool ShipYard, this tool only needs main dimensions and characteristic parameters as displacement and centre of gravity. In combination with a big empirical database this tool allows to generate a first ship model. Resulting from the empirical approach, such a ship model behaves in a way as is common for such a kind of ship. Special details resulting from differences to a common ship design cannot be mapped, because the empirical database is unable to estimate the effects. In contrast to the ShipYard tool, the E4 framework can be used to calculate effects of special details by using “First-Principle-Methods”. By doing this, a second numerical ship model can be generated, which can be used for a manoeuvring simulation and typical IMO manoeuvres can be calculated. In the same way, Simflex can be used to calculated IMO manoeuvres based on the ship model based on the empirical database.

If the analysed ship design is similar to a common ship design, the empirical ship model could be good enough already, but normally there are differences to the real behaviour of a ship. In the classical use of a bridge simulator this first empirical model will be improved. Results from model tests and full-scale test are used to correct the model by editing the force tables. During the early design phase the reference will no longer be the test results from an existing ship, but the manoeuvring simulation of the E4 framework. If the comparison between the Simflex and the E4 manoeuvre simulation show differences, the Simflex model has to be improved. It can now be analysed where are the differences between the two numerical models and afterwards the Simflex model can be improved. A criteria, whether a Simflex and an E4 ship model is similar or not, will be in this work a comparison between standard IMO manoeuvres. Especially the turning circle manoeuvre will be used to analyse the effects of rudder forces. After this process of generating a ship model behaviour analogue to the related ship design, this model can be tested within the natural environment of the bridge simulator.

3 The prediction of specific manoeuvring behaviour in the early design stage

The demand on the manoeuvring behaviour of a vessel is almost contradictory. On the one hand the vessel should be course stable; on the other hand there should be an adequate turning ability. The standardisation of requirements depending on the main dimension leads to a comparability of different ships in a similar range of size. The surveying of the manoeuvring behaviour by performing defined trial tests is state of the art. The required trial tests, e.g. the turning circle manoeuvre for checking the turning ability and the procedure of zig-zag test for the yaw-checking and course-keeping ability, are described in the IMO Resolution MSC.137 (76). As modifications on the delivered ship are difficult and expensive, it is a great benefit that contemporary design tools are able to predict the performance of these requested trial tests. In E4, there is a well validated method to predict the manoeuvring behaviour of ships before launching. Krüger and Haack (2004). By contrast the use of bridge simulators during the product development process in order to coordinate the “want to have” and the “able to build” between customer and naval architect has so far not yet been achieved in detail. If there is, for example, a demand for clarifying the influence of the number or size of the bow thrusters on the behaviour during crabbing manoeuvres, the model generated by a neural network will be sensitive enough. However, to determine more local and detailed modifications of the ship design by using bridge simulators, even nowadays the generated virtual ship has to be corrected with parameters gained by measurements during the sea trials. At this point our approach to combining the results of local calculations with “First-Principle-Methods” implemented in our ship design environment with the global ship model generated with the neural network of ShipYard, tries to satisfy the increasing demand on the use of bridge simulators in early design. In the following sections we want to give an overview about the abilities of influencing the simulator model exemplary by
modifying the shape of the rudder. The change in manoeuvring behaviour is verified by the performance of IMO standard trial tests.

3.1 The rudder characteristic in the simulator model

Whilst creating a suitable simulator model of the vessel, ShipYard generates a characteristic diagram of rudder force coefficients. Therefore the coefficients of longitudinal and transverse rudder forces and the heeling and yawing moments are given in arrays in dependence on the rudder angle $\delta$ and the flow condition $\xi$ at the rudder, see Fig.3 for an example.

![Characteristic diagram of rudder force coefficients](image)

**Fig.3:** Characteristic diagram of rudder force coefficients

The rudder angles are described in the range of $-60^\circ$ to $60^\circ$; the flow regime, identified as the rudder loading angle $\xi$, in the range of $-180^\circ$ to $180^\circ$. The rudder loading angle $\xi$ is defined as:

$$\xi = \arctan \frac{u_d}{u_e}$$  \hspace{1cm} (1)

Here $u_d$ stands for the mean flow velocity at the rudder outside the propeller slipstream and $u_e$ for the mean flow velocity inside the propeller slipstream. This leads to a four-quadrant diagram, Fig.4. The four quadrants represent the occurring flow regimes for the possible manoeuvring situation. A rudder loading angle between $-90^\circ$ and $-180^\circ$ indicates, for example, a flow regime where the vessel sails astern with astern propeller thrust, either due to negative propeller rotation or as result of negative pitch in the case of controllable pitch propellers. For our work the focus is on the first quadrant with a rudder loading angle range between $0^\circ$ and $90^\circ$ and therein especially on the range between $0^\circ$ and $45^\circ$, because values $\xi > 45^\circ$ indicate the propulsion phenomenon named propeller wind-milling. The flow velocity inside the slipstream is smaller than the flow velocity outside the slipstream. The propeller is influenced by the flow around the ship. Smaller positive values of $\xi$ indicate flow regimes, where the ship sails with reduced speed but high revolution speed of the propeller. Thus there is no equilibrium between the thrust of the propeller and the resistance of the ship. The propeller generates more thrust as needed to propel the vessel.

Influencing the manoeuvring behaviour of the simulator model by changing the shape of the rudder will only be reasonable in a range of flow regimes which can be calculated by the design software. Fig.3
shows the rudder coefficients characteristics in dependence on rudder angle and flow regime. The curves for the flow regimes $\xi = 10^\circ$ to $\xi = 40^\circ$ identify the flow regimes where a sound flow around the rudder should appear.

![Diagram of rudder loading angle](image)

Fig. 4: Rudder loading angle

To convert the rudder forces into coefficients and vice versa, the related reference consist of the stagnation pressure within the slipstream and outside the slipstream and the associated areas passed by the corresponding flow, Petersen and Lauridsen (2000):

$$F_{x,y} = \frac{1}{\gamma} \cdot \rho \cdot c_{x,y} \cdot (A_s \cdot u_s^2 + (A_{rudder} - A_s) \cdot u_a^2)$$  \hspace{1cm} (2)

The rudder area within the propeller slipstream as an important reference value depends on the contraction of the propellers slipstream on the one hand and on the rudder angle on the other hand. The area within the slipstream is defined in a strict geometrical way. For very large rudder angles, the trailing edge of the rudder is no longer within the slipstream. The reference area $A_r$ becomes smaller. A higher contraction of the slipstream as a consequence of a higher thrust load of the propeller also leads to smaller reference areas $A_r$.

The conversion of momentum coefficients into heeling and yawing moments follows the same paradigm as in case of forces. Here the reference value is expanded by the draught in the case of heeling moments and by the length between perpendiculars in the case of yawing moments.

### 3.2 Calculation of the rudder force coefficients in E4

The calculation of the rudder forces within the design software E4 is carried out with a panel method based on the potential flow theory. The propeller slipstream is modelled with a lifting-line method which covers the propeller characteristic more detailed than a simple momentum theory. In dependence on load cases, hull efficiency elements and environmental influences the thrust load of the propeller is represented. The method has been used in daily ship design for many years. The calculated forces are used successful by the E4 method for simulating the standard manoeuvres called IMOMAN.

To modify the characteristic diagram generated by ShipYard to influence the manoeuvring behaviour in terms of the E4 model, the calculated rudder forces must be converted into coefficients in the reversed way ShipYard converts the coefficients into forces. In other words, the calculated forces by the E4 method must be treated like the forces measured in PMM model tests were treated before being put in the database.
of ShipYard. In that case the coefficients are comparable and do not need further corrections. Therefore the contraction and the velocity of the slipstream are calculated using the classic momentum theory. That leads to the velocity of the slipstream far behind the propeller \( u_{\infty} \) in dependence on the thrust loading coefficient \( c_{th} \) (3).

\[
  u_{\infty} = u_a \cdot \sqrt{1 + c_{th}}
\]  

(3)

The radius of the slipstream far behind the propeller \( r_{\infty} \) follows from the law of continuity in dependence on the origin radius of the slipstream in the propeller plane \( r_o \):

\[
  r_{\infty} = r_o \cdot \sqrt{\frac{1}{2} \cdot (1 + \frac{u_a}{V_{\infty}})}
\]  

(4)

For estimating the right contraction of the slipstream at the position of the rudder, the distance between propeller and rudder \( x_{rudder} \) leads to the radius of the slipstream in the rudder plane, *Brix* (1993):

\[
  r_{rudder} = r_o \cdot \frac{0,14 \cdot \left( \frac{r_o}{r_a} \right)^3 + \frac{r_o}{r_a} \cdot \left( \frac{x_{rudder}}{r_o} \right)^{1.5}}{0,14 \cdot \left( \frac{r_o}{r_a} \right)^3 + \left( \frac{x_{rudder}}{r_a} \right)^{1.5}}
\]  

(5)

The velocity of the slipstream at the position of the rudder \( u_r \) results from:

\[
  u_r = u_{\infty} \cdot \left( \frac{r_o}{r_{rudder}} \right)^2
\]  

(6)

With these velocities and the above mentioned areas, a mean velocity at the rudder \( u_m \) is formed:

\[
  u_m = \sqrt{\left( A_s \cdot u_r^2 + (A_{rudder} - A_s) \cdot u_o^2 \right) / A_{rudder}}
\]  

(7)

Finally, the rudder forces calculated by E4 are converted into coefficients by using the reference values mean rudder velocity \( u_m \) and the rudder area \( A_{rudder} \):

\[
  c_{x,y} = \frac{F_{xy}}{\frac{1}{3} \cdot g \cdot A_{rudder} \cdot u_m^2}
\]  

(8)

These rudder force coefficients now have the same reference basis as the coefficients in the ShipYard database. They can be used to modify the characteristic diagram of rudder force coefficients in the ShipYard database of the virtual vessel.

### 3.3 Modifying the steering characteristic of the simulator model

Using the example of a single-screw RO-RO-ferry propelled by a controllable pitch propeller and equipped with a twisted full spade rudder the following shows the ability of the combination of “First-Principle-Methods” and a neural network algorithm for generating virtual ships for a bridge simulator. The twisted rudder of this vessel is designed for high stall angles.

There are scores of dimensions and parameters that the initial virtual ship generated by ShipYard is based on. Unknown parameters are set as default values by ShipYard. Some important dimensions concerning the generation of the rudder model in ShipYard are given in Table I.

Before modifying the data of the vessel generated by ShipYard, there should be a view on the range of investigated model ships that the ShipYard data is based on.
Table I: Main dimensions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length between perpendiculars</td>
<td>$L_{pp}$</td>
<td>190</td>
</tr>
<tr>
<td>Rudder area</td>
<td>$A_{rudder}$</td>
<td>18.24</td>
</tr>
<tr>
<td>Rudder span</td>
<td>$b$</td>
<td>5.70</td>
</tr>
<tr>
<td>Aspect ratio</td>
<td>$A_{rudder}$</td>
<td>1.78</td>
</tr>
<tr>
<td>Propeller diameter</td>
<td>$D_{prop}$</td>
<td>6.1</td>
</tr>
<tr>
<td>Draught</td>
<td>$T$</td>
<td>6.95</td>
</tr>
<tr>
<td>Propeller diameter to draught</td>
<td>$D_{prop}/T$</td>
<td>0.878</td>
</tr>
<tr>
<td>Rudder span to propeller diameter</td>
<td>$b/D_{prop}$</td>
<td>0.93</td>
</tr>
</tbody>
</table>

3.3.1 The database content

The rudder force coefficients in the ShipYard database are derived from model ships. They are originally based on three ships with horn rudders and two ships with full spade rudders. They are categorised as shown in Table II, Petersen and Lauridsen (2000).

Table II: Database content

<table>
<thead>
<tr>
<th>Ship / rudder type</th>
<th>$D_{prop}/T$</th>
<th>$b/D_{prop}$</th>
<th>$A_{rudder}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>tanker, L &gt; 300m, horn rudder</td>
<td>0.463</td>
<td>1.59</td>
<td>1.6</td>
</tr>
<tr>
<td>tanker, L &lt; 200m, horn rudder</td>
<td>0.531</td>
<td>1.44</td>
<td>1.6</td>
</tr>
<tr>
<td>container vessel, L &gt; 250m, horn rudder</td>
<td>0.673</td>
<td>1.39</td>
<td>2.6</td>
</tr>
<tr>
<td>reefer, L &lt; 160m, spade rudder</td>
<td>0.622</td>
<td>1.27</td>
<td>2.2</td>
</tr>
<tr>
<td>reefer, L &lt; 160m, enlarged spade rudder</td>
<td>0.622</td>
<td>1.27</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Comparing these parameters with the values of the ship of interest, it is obvious that the reefer with the enlarged spade rudder is the model ship with the highest accordance. For these kind of ships, typical characteristics of transversal and longitudinal rudder coefficients over the range of flow regimes between $\xi = 0^\circ$ to $\xi = 40^\circ$ are given in Fig.5. In this figure only the smaller tanker and the reefer with the enlarged rudder are displayed. The marked values identify measurements, Petersen and Lauridsen (2000).

What can be gathered from these characteristics is the difference in the interaction between propeller, rudder and hull of the ships. The calculation of the rudder force coefficients with $E4$ over the range of different values of $\xi$ in these extreme off-design states did not lead to suitable characteristics and should be investigated further. Thus the rudder coefficients calculated by $E4$ for the design state (near $\xi = 40^\circ$) has been transferred to lower $\xi$ values after corrections. These corrections are necessary to keep the rudder loading characteristics. There should be further investigations on the possibility to calculate these off-design states.

3.3.2 Comparison of lift and drag coefficients

To compare the calculated rudder force coefficients by $E4$ with the proposed coefficients of the ShipYard database, there should be the focus on the design speed. Fig.6 shows the rudder force coefficients in transversal ($c_v$) and longitudinal ($c_d$) direction. The drag $c_d$ is corrected by the value for a rudder angle $\delta = 0$. This correction is necessary to adjust the calculated drag values to the ShipYard specification where the drag for the zero rudder angle is covered in the hull resistance.

Clearly, the additional lift for rudder angles below $-20^\circ$ and above $20^\circ$ results from the higher stall angle of the twisted rudder. But there is no possibility to calculate rudder forces for angles above the expected stall angle of $44^\circ$ with the used panel method. In these ranges of rudder angles we adopt the ShipYard
values without any corrections. A view to the drag values shows that there is no significant difference between the E4 and ShipYard values.

3.4 Simulation of trial tests

The success of modifying the steering behaviour is evaluated with the standard manoeuvres in terms of the IMO requirement. That supposes that the manoeuvres should be run at at least 90% of the ship’s design speed and with 85% of the maximum engine output. In the case of turning circles, IMO demands a rudder angle of 35°. To demonstrate the effort of modifying the rudder force coefficients of the simulator model, we decided to focus on the turning circle manoeuvre. This IMO standard manoeuvre is valuated by two distances. The first parameter is the so-called advance. This is the distance the vessel travels in the direction of the original course until the heading is changed 90° from the original course. The second parameter, the tactical diameter, is the transversal distance the ship travels until the heading is changed 180° from the original course. The results of the simulated manoeuvres are compared in Table III.

Clearly, there is a significant difference in advance and tactical diameter between the initial model of ShipYard and the manoeuvre calculated by E4. The comparison of the E4manoeuvre and the turning circle of the modified ShipYard model shows that the effect of the model modifications on the turning ability is represented correctly. The tracking points of the initial and the modified manoeuvre of the simulator model in comparison to the E4 model are shown in Fig.7.
Table III: Simulated turning circle

<table>
<thead>
<tr>
<th>Model</th>
<th>SY-Initial</th>
<th>E4</th>
<th>SY-Modified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction</td>
<td>portside</td>
<td>starboard</td>
<td>portside</td>
</tr>
<tr>
<td>Advance [m]</td>
<td>746</td>
<td>735</td>
<td>719</td>
</tr>
<tr>
<td>Tactical diameter [m]</td>
<td>945</td>
<td>941</td>
<td>797</td>
</tr>
</tbody>
</table>

E4-model versus ShipYard-initial

Fig.7: Simulated turning circles

The influence of the modified rudder force coefficients on the simulator model is also evaluated with calculated 10/10 zig-zag manoeuvres. Here the yaw-checking and course-keeping ability of the vessel is verified. This takes place in comparing the so called overshoot angles. These angles are additional headings after achieving the desired heading of 10° and putting the helm in the opposite direction. A look at the results of the calculated zig-zag manoeuvres shows that there are only small differences between the overshoot angles of the initial simulator model and the values calculated by E4. But there also is almost no influence on these values by modifying the rudder force coefficients, because in the range of the occurring rudder angles during a zig-zag manoeuvre there are no differences in transversal coefficients. Further investigations showed that small changes on the turning rate of the rudder engine have noticeable influence on the overshoot angles.

Table IV: Simulated 10/10 zig-zag manoeuvres

<table>
<thead>
<tr>
<th>Model</th>
<th>SY-Initial</th>
<th>E4</th>
<th>SY-Modified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction</td>
<td>portside</td>
<td>starboard</td>
<td>portside</td>
</tr>
<tr>
<td>1st overshoot angle [°]</td>
<td>3.3</td>
<td>3.7</td>
<td>4.0</td>
</tr>
<tr>
<td>2nd overshoot angle [°]</td>
<td>4.8</td>
<td>4.7</td>
<td>9.0</td>
</tr>
</tbody>
</table>

4 Conclusions and further work

The results of this paper show that it is possible to modify a simulator model with a neural network algorithm successfully; the turning ability of a simulator model can be modified by using the forces calculated by a ship design tool. This allows transferring modifications in the rudder design to the simulator model and sailing the ship before launching.

To improve this method of simulating ships in the design phase, there is further work to be done. In analogy to the presented work, the transfer of propeller characteristics will bring improvement in transferring
a specific manoeuvring behaviour to the simulator model. In combination with research on the field of off-design states of propellers and rudders, the virtual trip before launching of the real vessel will be practicable.

5 Acknowledgements

The authors wish to thank the German BMBF for the funding of the project. Without the support of BMBF, the research work would not been possible.

References


PETERSEN, J. B.; LAURIDSEN B. (2000), Prediction of hydrodynamic forces from a database of manoeuvring derivatives, Int. Conf. on Marine Simulation and Ship Manoeuvrability, Orlando