Ship Assist in Fully Exposed Conditions – Joint Industry Project SAFETUG II

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SYNOPSIS

SAFETUG II, as the continuation of SAFETUG I, focused on a number of outstanding issues: firstly improving the tug design, primarily by looking at reducing the roll motions through changes in the design. Furthermore, the issues of winch design and line optimisation were addressed in connection with offshore assist operations and human operator criteria. In particular the following issues will be presented in this paper:

Tug design

- Performing systematic model tests to obtain specific information on the tug roll damping and motion response;
- Validating the accuracy of available sea-keeping tools on motion predictions for tugs, especially regarding roll;
- Improving available sea-keeping tools to better calculate tug roll motion response at operational sea states;
- Calculating the effect of various design parameters such as hull type, main dimensions and appendages (including propulsion equipment) on roll damping and operational downtime of tugs;
- Capturing the effect of design parameters on operational performance as trends.

Offshore operations

During berthing operations in high waves, the towline dynamics can play an important role in the operability. Using time domain simulations, the impact of different line types and the effectiveness of various dynamic winches can be assessed. A suitable time domain model was constructed and a set of reference scenarios investigated.

Human performance during tug operations

An experiment was set up to examine the effect of motion on the performance of tugboat captains. The experiment was conducted in two simulators, one fixed-based and one with an advanced six-dof motion platform. The participating captains sailed a set of two different operational scenarios under various sea-state conditions. During each scenario, various experimental observations were measured in different areas of interest, such as workload measurement, to assess if and how motion affects the workload and performance. This part of the paper describes the set-up of the experiment and compares the performance of the tugboat captains for the different simulator systems.

INTRODUCTION

The aim of the SAFETUG project is to enable the operation of tugs in exposed conditions, both in offshore low-speed assistance and in high-speed escort assist. The Joint Industry Project (JIP) started in 2005 with an industry group of 29 participants, a unique cross-section of all involved in tugs, from end users, mainly oil majors, to propulsion equipment manufacturers and all in between. The project continued in 2008 as SAFETUG II with 31 participants, a 1.5m euro budget and now includes a wide representation of the class societies. Again the group represented a relevant cross-cut through the industry, creating a unique platform for research into common subjects and with lively discussion. It brings together the total spectrum from operations-based requirements, to design of basic hull properties to major equipment and to practical operational aspects The list of current participants is given in *Table 1*. The project approach of SAFETUG I is summarised in Section 1.

Oil companies
BP
Chevron Texaco
ConocoPhillips
ExxonMobil
GdF Suez
Petrobras
Shell
Total

(Tug) operators
Lamnalco
MOD UK
Smit Int
Svitzer
Tidewater
Neste Oil
SBM

Yards (Design and Build)
Bharati
Damen

Class societies
BV
LR
ABS

Design and Build Equipment
WorldWise Marine
Robert Allan Ltd
Vuyk Engineering
SIPORT XXI
Rolls-Royce

Markey
Trelleborg
Voith
Wärtsilä

MARIN

RCAC

Table 1: List of participants in SAFETUG II.

SAFETUG II had the following objectives:

- Deliver a downtime calculation tool (software) to assess berthing operations;
- Review a number of observed trends in design parameters and explore the limits further. Present the impact of design changes in trend lines;
- Perform focused systematic model tests to find out specific values such as roll damping (at least the aspects which turn out to be important as a result of the parameter study);
- Establish objective human factor criteria on motion behaviour looking at downtime of tugs.

Important deliverables were a simulation tool for the offshore operations to establish the operability envelopes in waves; a trendline report identifying and quantifying the relevant design parameters affecting the performance (human factor and assist capability); criteria and operational advice for practical operations. Case studies were part of the project.

These objectives were a logical continuation of the SAFETUG I capability studies into tugs operating in waves in either escorting or offshore assist conditions. Apparent gaps in the first part were the tug design for purpose (waves) issues and the improved modelling of the winches, the first to enable better tug designs for operation in waves, the second to rationally specify winch capabilities under these same conditions. In addition to these main objectives, studies were done into tug wake-hull interaction, active roll damping devices, fender technology and a future communication platform (tug operations, *Wikipedia*).

This paper focuses on a description of the approach of SAFETUG II. The massive detailed data on tug design data, human factor criteria and results as presented in the example case studies on berthing can only become available in around two years' time given the JIP agreement.

1. OPERATION-RELATED TUG DESIGN ISSUES

Harbour and offshore tugs spend the majority of their time in transit and assist (stand-by, direct or indirect) operations. By the end of SAFETUG I, criteria for evaluations of conditions had been defined in four categories (zero-level, short-term, normal and long-term). These categories are arranged according to the level of stress involved for the tugmaster. Stand-by operations belong to long-term (Category IV) with little movements and low stress levels. Direct/indirect assist operations belong to short-term (Category II) and the tug is exposed to harsh environments and operations at the same time. The aims of the tug motion group within SAFETUG II was to determine the dominant design parameters on operability criteria based on the different operations the tug can fulfil and to determine the trend lines for various design parameters with respect to operability.

A three-stage study was foreseen to achieve the aims of the tug motion group. The first phase was a pre-model test phase where the focus was on calculating the effect of various design parameters on downtime. From the previous tests during SAFETUG I and the first results of these tug design variation calculations, it is concluded that the transverse accelerations are a key driver in tug operability. In addition to transverse accelerations, longitudinal accelerations, water on deck and possibly slamming are also affecting operability. Roll, sway and yaw contribute to transverse accelerations with often roll as a main component. Roll damping is difficult to assess numerically and needs often experimental data to improve accuracy. Complicating factors are the non-linear behaviour of roll and, especially for tugs, the considerable influence of appendages and propulsors.

The second phase was a model test phase where the focus was on the most important parameters that are determined from the previous calculations, parameters that are not easily computable, such as roll damping and motion behaviour in waves. However, the aim of these experiments is not to increase the calm water escorting envelope, but rather a concise information gathering on the dominant parameters regarding our knowledge about tug motions in waves. The focus is on transverse plane (roll, transverse accelerations) because vertical plane motions (heave, pitch, vertical accelerations) are mainly affected by main dimensions and factors like weight distribution.

During sea-keeping operability studies in the design stage, one would like to know which roll damping to expect for the anticipated main dimensions, hull lines, appendages and propulsor-configuration. The trend lines that are derived during the project will assist designers, consultants and operators to have an insight into which parameters are important for tugs. To fill the gaps in calculation of roll behaviour, model tests were performed for a variety of configurations. Parameters that influence the roll-related operability are:

- operating mode (eg standby, transit, [in]direct assist);
- speed;
- wave conditions;
- location of crew areas and bridge;
- roll reduction devices (eg anti-roll tanks, fin stabilisers);
- hull shape (eg round bilge or hard chine);
- main dimensions (L/B and B/T ratio);
- weight distribution and stability (k_{XX}, k_{YY} and GM);
- appendages (eg skegs, bilge keels, sponsons);
- propulsor type (ASD, tractor-type [Voith, Z-drive]).

Taking the list above, it becomes clear that the full test matrix is potentially infinite and thus choices have to be made. In order to make an informed choice, the roll damping contributions and their leading parameters are summarised in *Table 2* below:

Contribution	Leading parameter(s)	Notes
Potential damping	B/T ratio	Sometimes referred to as wave damping.
Hull friction	Wetted surface	Limited contribution for tugs (only relevant for large bilge keel radius non appended vessels).
Eddy damping (vortex shedding from the bilge)	Bilge radius Hull type (Round bilge/Hard Chine) B/T ratio	Dominant at zero speed, reduced when sailing. Proportional to roll velocity squared.
Lift damping from hull	Speed, B/T ratio	Linear with speed.
Bilge keel damping	Bilge keel length & height Distance to COG	Increases vortex shedding at the bilge & bilge keel drag.
Skeg damping	Aspect ratio Distance to COG	Cross flow drag at zero speed and lift (depending on shape). Linear with speed.
Propulsor damping	Propulsor type Distance to COG	Cross flow drag at zero speed and lift (depending on shape). Linear with speed.

Table 2: Roll damping contributions for a tugboat.

The third phase of the study was focused on the analysis and review of the performed experiments and design considerations for overall motion reduction. Based on the results, a numerical study was carried out to obtain trend lines on operability with varying designs which constitutes one of the main outcomes of this project.

1.1 Summary of model tests

1.1.1 Tested tug designs

To cover the scope of variations that need to be performed, the parent hulls from SAFETUG I were taken as reference designs. The objective was to focus on data in order to fill in gaps in the calculation model to be used to derive the final trend lines. The parent tug designs are an azimuthing stern drive tug (ASD) and a tractor tug with VSP (Voith Schneider Propeller). Their properties are given in *Tables 3* and *4*. In total, eight ASD tug design variations and nine tractor tug design variations were tested. A summary of the variation matrix is presented in *Figure 2 (next page)*. *Figure 1* shows various configurations of the tested tug designs.

ASD Particulars	MAGNITUDE	UNIT
L_{PP}	36.00	m
L_{WL}	33.84	m
L_{OS}	33.84	m
B	12.94	m
T_F	4.95	m
T_A	4.95	m
∇	1245.17	m^3
GM_t	1.81	m

Table 3: Principal particulars of parent ASD tug.

Tractor Particulars	MAGNITUDE	UNIT
L_{PP}	37.50	m
L_{WL}	37.50	m
L_{OS}	37.50	m
B	13.82	m
B	14.00	m
T_F	6.75	m
T_A	6.75	m
∇	1244.89	m^3
GM_t	3.50	m

Table 4: Principal particulars of parent tractor tug.

B/T ratio

Two B/T ratios were tested for both ASD and tractor tugs. The B/T-ratio variation is made in such a way that both tug design variations have equal B/T-ratio (B/T = 3.2) with unaltered displacement, block coefficient and L/B-ratio. Note that L/B-ratio will not be varied, as it is believed that B/T is dominating roll behaviour, which is in line with the results of the tug design variations calculations. *Figure 3 (following page)* shows the L/B-ratio plotted against B/T-ratio for various types of existing tugs. The dotted line in the graph shows the envelope that encapsulates the majority of the tug

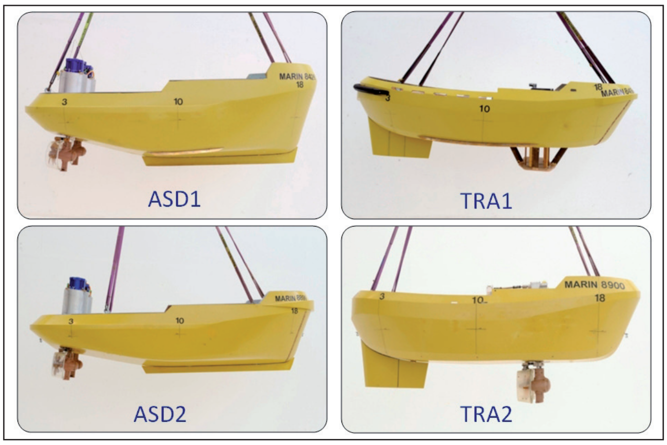


Figure 1: Variations of tested designs.

designs and is the boundary of the numerical study in the third phase of the project.

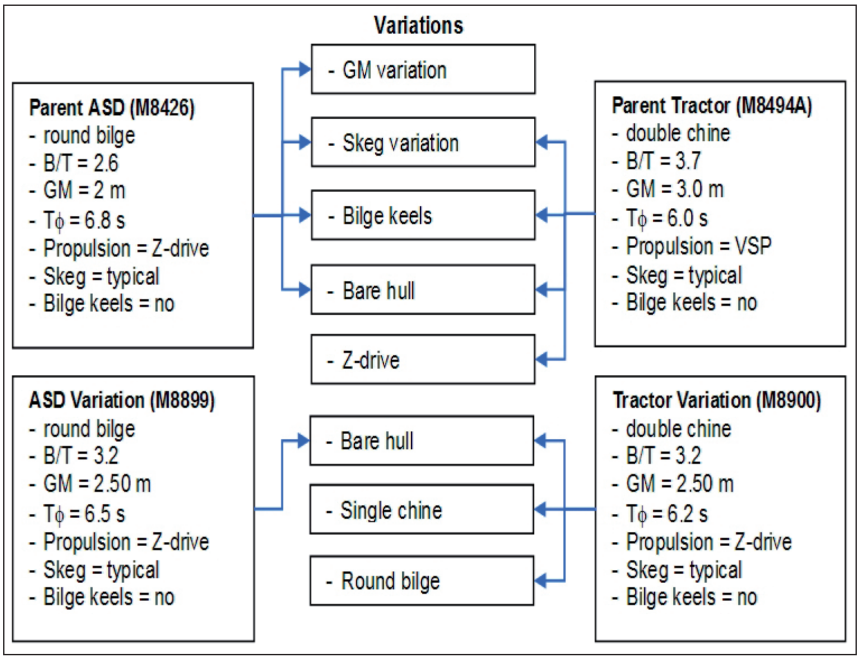


Figure 2: Performed parameter variations per ship model.

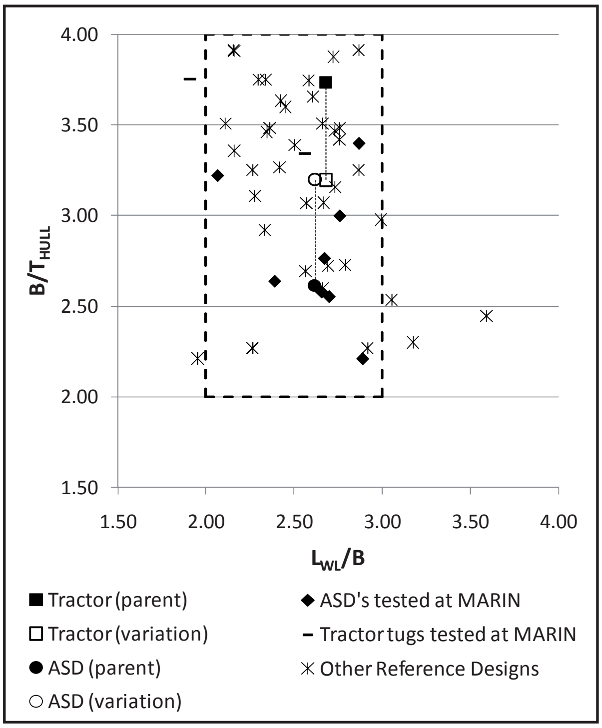


Figure 3: Tested tugs v existing tug designs.

GM variation

GM has a large influence on roll behaviour, not only for the shift in the natural roll period, but also on, for instance, the roll excitation changes. The effect will be shown for the ASD tug, where the target GM will be increased from 2m to 2.75m, resulting in an estimated T_ϕ of 6.2s. This GM is equal to the GM of both B/T ratio alternatives. The effect of stability can be predicted fairly well numerically, therefore one variation is deemed sufficient.

Skeg variation

The skeg area, aspect ratio (AR) and distance to centre of gravity (COG) have an effect on the roll damping. Because the skegs of the ASD and tractor tug are quite different, skeg variations are performed for both tugs. The skegs are designed in cooperation with Robert Allan Ltd and Damen Shipyards.

For the ASD the skeg area will be doubled from 15.6m² to 31.2m². As a secondary result, distance to COG will be slightly increased. For the tractor tug, the alternative skeg will have equal area but the aspect ratio will be doubled. This alternative will not be practical. However, designwise this is very interesting because of the doubled aspect ratio and considerably larger distance to COG.

Bilge keels

Bilge keels are not always applied on tugs; however at low speeds they increase roll damping considerably. The parent ASD was adopted with bilge keels with a length of 25 per cent L_{PP} and a height of 400mm. After this variation, the bilge keels were replaced with a pair 800mm high. The tractor tug had bilge keels along 45 per cent of the length with a height of 450mm.

Propulsion type

As propulsion has considerable effect on roll behaviour, the VSP was exchanged with a Z-drive propulsor on the tractor tug. This enables comparison not only between VSP and Z-drive but also direct comparison between the parent tractor and the tractor variation with B/T=3.2 (this variation is also equipped with Z-drives).

Hull type

The roll damping at zero speed was obtained for all four appended hulls as well as for the bare hull. These variations were used to obtain hull damping without appendages (bilge keels and skeg) and without propulsion. For the tractor variation (B/T=3.2) the effect of chine shape was evaluated by comparing different configurations as shown in *Figure 4*.

1.2 Scope of tests

Tests in calm water and irregular seas were performed for all variations defined in the test matrix in *Figure 2.* The tests in calm water consist of roll decay tests and forced roll tests at zero and forward speed. These tests were used to obtain roll damping.

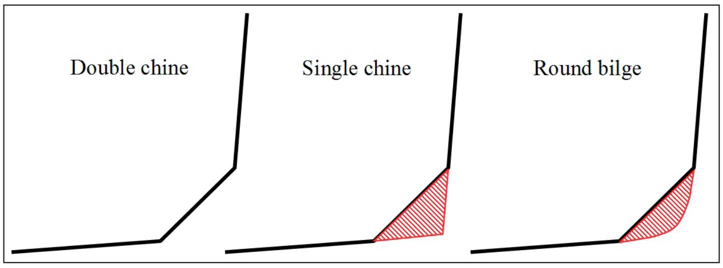


Figure 4: Variations in bilge shape (midship section).

However, they have relatively high uncertainty and should be accompanied by tests in waves to verify the results.

The tests in irregular seas were performed in beam seas at the peak of the roll response ie in a resonant roll condition. For tugs this condition also generally gives the highest roll excitation (worst combination of peak period and wave heading) owing to the large GM. This heading is beneficial because of the decoupling of roll and yaw. A second advantage is that RAOs are directly obtained from the tests in irregular seas because spectral analysis is possible in beam seas.

As roll is dependent upon both speed and wave height, tests in irregular seas were performed at 0kn and 5kn speeds and at 1.5m and 3m wave height. In contrast to pitch and heave, roll is non-linear with wave height, due to increased damping at increased roll motion/velocity. Consequently, the roll does not double but will be slightly less than double when the wave height doubles.

The focus is on tests at zero speed because it is felt that tugs are operating mostly at zero or very low speeds. Secondly, the lift damping is zero which results in larger roll (the most demanding condition).

1.2.1 Forced roll setup

Instead of roll decay tests, forced roll tests are a more sophisticated method of assessing non-linear roll damping. The roll of the ship is excited by rotational acceleration and deceleration of a weight rotating around an axis in ship-length direction, generating negative damping. The rotation inertia of a heavy electrical servo engine is used to induce a stationary roll motion that is required for the forced roll tests (see *Figure 5, below)*.

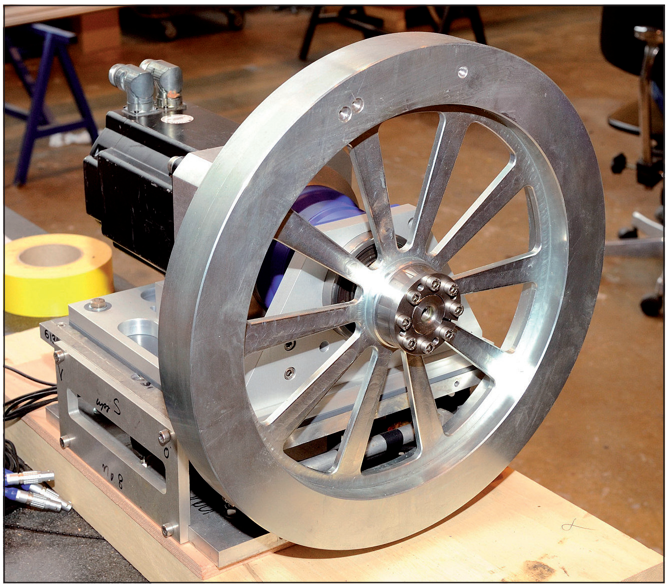


Figure 5: Forced roll rotating motor.

During the tests the system is forced to a roll motion through a feedback loop in which the acceleration (or deceleration) of the engine is proportional to the angular velocity of the model. Thus, the tests are automatically done at the resonance frequency of the system. The equilibrium of the evoked (negative) linear damping and the non-linear damping of the hull determines the resulting roll angle. Manipulating the gain makes it possible to adjust to a target roll angle.

With this approach, a pure roll moment (without introducing a sway motion) is introduced into the ship. Reaction forces of the rotating motor/mass are then measured.

1.2.2 Environmental conditions

Tests were performed in a selection of long-crested, irregular seas coming from three directions (stern quartering, beam and bow-quartering seas). The wave conditions were calibrated prior to the test in order to have full control of wave height, period and spectral shape (Pierson Moskowitz-type spectrum). Note that the calibrated wave period is equal to the natural period of roll of the first model variant tested. (Subsequent variations might have slightly different roll period owing to differences in added mass). In order to obtain reliable statistics, the test duration in irregular seas was approximately 30 minutes full-scale time.

1.3 Results derived from the test campaign

Trends can already be observed from test results. A typical result showing the effect of bilge keels on roll motion is presented in *Figure 6* and transverse acceleration reduction is presented in *Figure 7.* The sea state observed has a significant wave height of 1.5m. Owing to the non-linear behaviour of roll, the response does not increase linearly with wave height.

The effect of hull geometry has significant influence on the roll characteristics. Effects of appendages (especially bilge keels) and their usage (eg outward operating Z-drives) on roll motion is found to be significantly important for tugs. At zero speed there was no influence observed on roll motions and transverse accelerations while varying skeg area, aspect ratio or adding end plates.

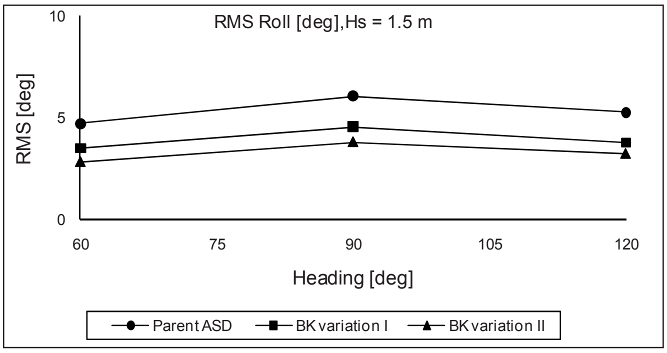


Figure 6: Effect of bilge keels on roll motions.

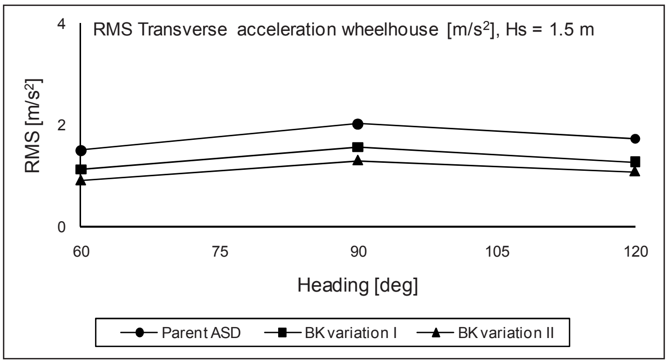


Figure 7: Effect of bilge keels on transverse accelerations.

Roll damping analysis from the tests provided a good basis for computations required for the trend lines study. Tests in waves were used as verification of computations.

2. OFFSHORE OPERATIONS

2.1 Introduction

As part of SAFETUG I, various aspects of tug operability during berthing operations were investigated:

1. The assisted vessel reflects waves which can increase or decrease the local waves the tug experiences.
2. Interaction between the thrust wake and the tug's hull can reduce the effective BP.
3. The local wave field degrades the effective BP owing to, for example, wave wake interactions and thruster ventilation.
4. The tug's thrust wake can hit the hull of the assisted vessel. This reduces the effective pull.
5. Dynamic effects in the towline and the winch can affect the effective pull and can limit operability: snap loads in the towline can cause it to break.

In the SAFETUG I reporting empirical data was provided to assess the impact of points 1-4. To assess the dynamic towline effects, time domain simulations can be used. As part of SAFETUG II, BerthSIM was developed. This is a time domain simulation model for a tug, the winch and the towline. In addition, a set of reference cases was investigated, this time using a domain simulation model.

In the next sections, firstly an overview of the modelled tugs will be presented, followed by a description of the relevant winches and towlines. Finally, the reference cases are discussed.

Tugs
Two types of tugs are commonly used for berthing operations:

- Voith Water Tractor (VWT);
- Azimuthing Stern Drive (ASD).

For each tug type, three tugs with varying length over width ratios are included in BerthSIM.

2.2 Winches and towlines

In high waves the tug motions are large, causing variations in the towline load. In extreme cases the line can become slack, after which a snap load typically occurs. The slack line events can reduce the mean pull on the supported vessel, the snap loads can cause the line to break.

A proven method to limit the slack line events and snap loads is to reduce the line stiffness by means of a stretcher. The stretcher can accommodate the tug motions with relatively little variation in the towline tension. However, there is a downside to this approach: when the tug is set back by the waves, the stretcher is stretched. The stretcher stores energy, which is released again when the tug is already moving towards the supported vessel. If the stiffness is reduced too much this can cause catapulting of the tug.

A recent development is to use a dynamic winch to regulate the line tension. When the tug is set back by the waves the line tension increases, and this is countered by paying out line. When the tug moves towards the supported vessel, the line tension will drop, and this is countered by retrieving line.

One of the goals of SAFETUG II was to gain insight into how effective dynamic winches are at increasing the operability of berthing operations. To make predictions on the impact of a dynamic winch, both the mechanics and the control system need to be accurately modelled. Three different dynamic winches were included in BerthSIM. These were developed by two specialist companies. Seatools developed models for two types of hydraulic winches: one with a passive control system and one with an active control system. Markey developed a model of one of their electric winches.

2.2.1 Hydraulic winches

In this section some background is presented on the two hydraulic winch models. The modelled hydraulic winches are primary controlled: the rotational speed of the winch can be varied by means of adjusting the stroke of the pump. Both hydraulic winches consist of the following components:

- The winch drum (cable storage, slow rotating shaft);
- A gear transmission;
- Hydraulic motor(s) to drive the winch;
- A power pack to drive the winch based on a pump with variable displacement volume.

Additional components were added to improve power requirements:

- An active(water cooled) hydraulic brake (dynamic brake);
- An energy storage or boost facility.

Both hydraulic winches are equipped with a control system. The difference between the two hydraulic winches is how this control system works. For the active winch, the control system is based on a measurement of the line load. The measured load is used as an input to a PID control system. This aims to automatically maintain constant tension within the limitations of the winch. Render and recover tensions may be set independently.

For the passive winch, the control system is based on the hydraulic pressure. A render and recover pressure can be set. This type of control system is less complicated than the active control, but is more likely to be less accurate.

2.2.2 Electric winch

In this section some background is presented on the electric winch model. The following components are included:

- The winch drum;
- A gear transmission;
- The electrical motor;
- A water-cooled brake.

While rendering, the electrical motor can be used as a break. Rendering at higher loads can be done using the water-cooled brake. The control system of the winch uses a measurement of the line load. The measured load is used as an input to a PID control system. This will aim automatically to maintain constant tension within the limitations of the winch.

2.3 Reference simulations

The BerthSIM time domain simulation model can be used to assess the operability for specific berthing scenarios. Within the SAFETUG II, JIP generic berthing scenarios were simulated. These simulations served two purposes:

- Testing and validation of the BerthSIM software;
- Obtaining generic insights on the limits lines, stretchers and winches.

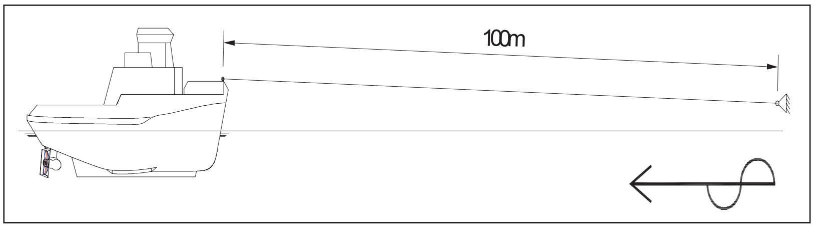


Figure 8.

Two series of simulations were done. The first series are BP tests in waves. For a range of wave heights from 0.5m to 5.0m, the tug was set to deliver 400kN mean pull. The simulations were repeated for a stiff line, stiff line with stretcher and all three dynamic winches. The results of these simulations provide insight into:

- Up to which wave height the mean pull of 400kN can be delivered for each line type and winch;
- Up to which wave height the snap loads can be limited within safe working loads;
- Up to which wave height slack line events can be prevented.

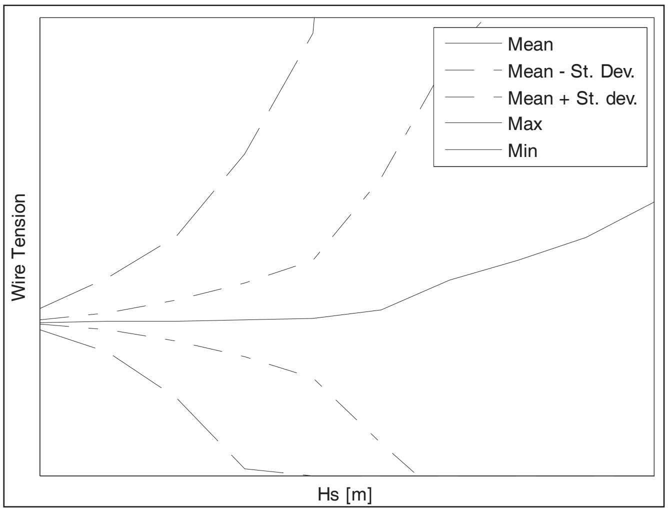


Figure 9: The results for the towline with stretcher.

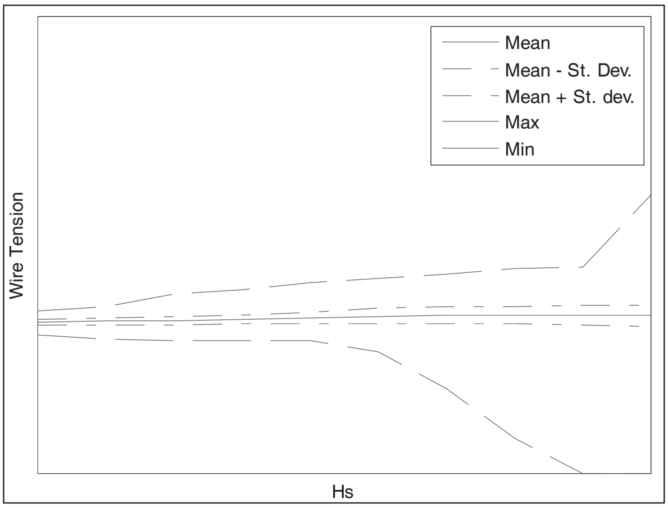


Figure 10: The results for one of the dynamic winches.

As an example, the results for a towline with stretcher and one of the dynamic winches are shown in *Figures 9* and *10*. From these we can conclude the following:

- The dynamic winch can prevent slack line events up to higher wave heights than the stretcher can;
- The variations in the line load are smaller for the dynamic winch than for the line with stretcher;
- The peak line loads increase with the wave height. For the line with stretcher the increase is larger than for the dynamic winch.

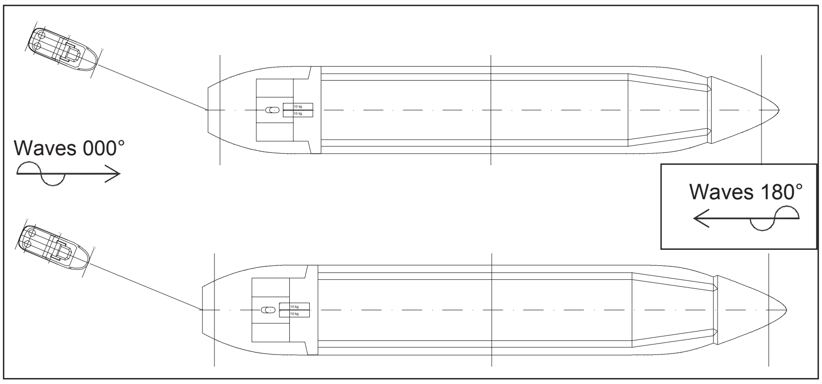


Figure 11.

In the second series of simulations, wave shielding and reflection from the supported vessel were included. As part of SAFETUG I, model tests were done for the same cases. The tug is pulling on the stern of an LNG carrier, under a 22.5 degree angle. The combination is subjected to 3m bow and stern waves (*see Figure 11, above*). The results of these simulations can be compared against the basin test results for validation. Furthermore they give an insight into the operability in a typical berthing scenario.

3. HUMAN PERFORMANCE DURING TUG OPERATIONS

The application of motion simulation is currently not common within simulator-based research on human performance in tug operations and training of tugboat captains. It was expected that simulation of physical ship motions would provide important cues that would enhance bridge simulator training and performance. During this experiment the effect of physical motion simulation on tugboat captain training and performance in bridge simulators was examined. The experiment was also executed in order to define the real-life motion criteria for the design of new generation tugboats and their operational application.

3.1 Simulator facilities description

The TNO Desdemona simulator in Soesterberg has a cabin with a basic bridge mock-up which can only accommodate one subject at a time. Inside the cabin a 210 degree scenery is projected. This cabin is mounted in an advanced 6-dof motion platform. In the cabin the tug captain was seated in a chair with a five-point safety belt. The tug captain was provided with a headset for communication with the experiment leader. Furthermore, the experiment leader could monitor the tug captain by means of a video system. *Figure 12*, below shows the TNO Desdemona simulator.

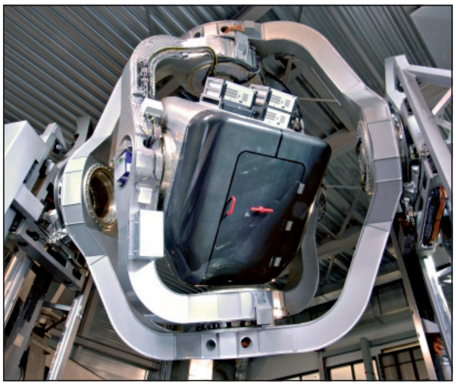


Figure 12: The Desdemona simulator.

The MARIN Small Bridge simulator in Wageningen has a full-scale and fully equipped bridge.

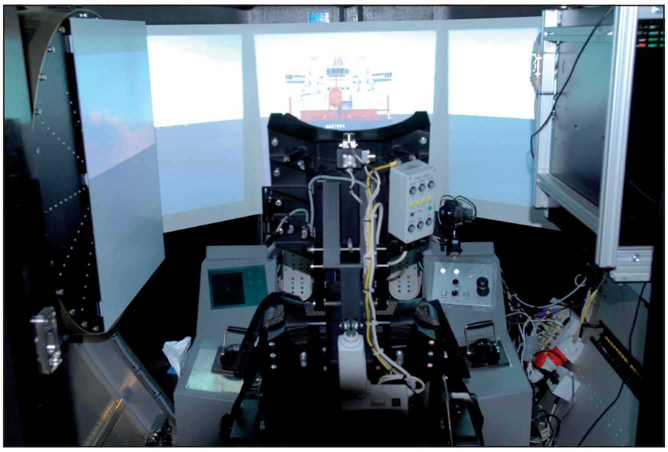


Figure 13: The MARIN Small Bridge simulator bridge.

This simulator is a fixed-based simulator with a 210 degree projected scenery and additional 150 degrees rear view. The tug captain was provided with standard bridge communication system for communication with the experiment leader. Furthermore, the experiment leader monitored the tug captain by means of a video system.

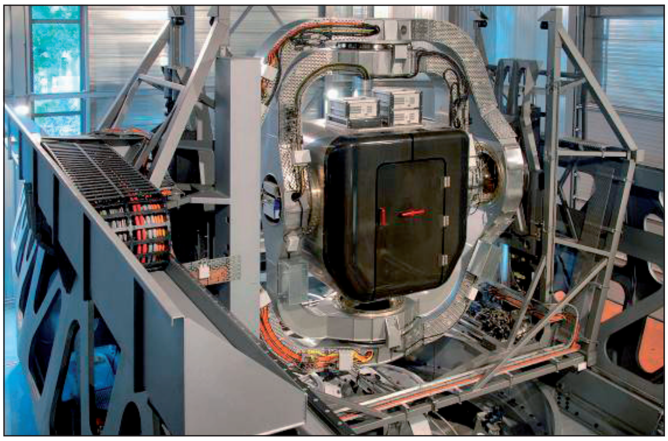
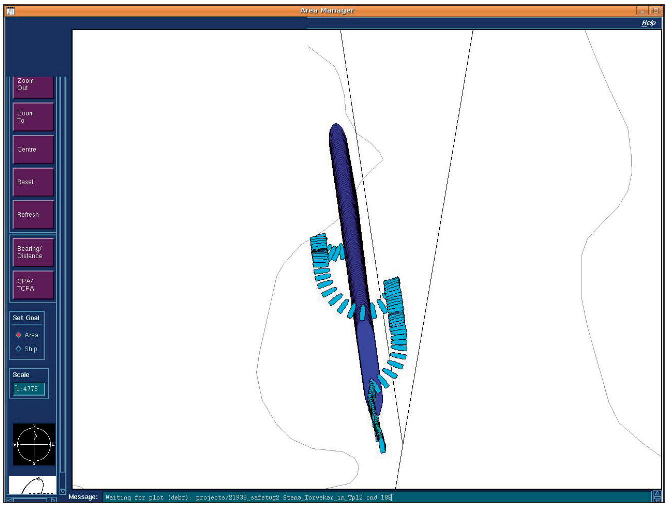


Figure 14: The mock-up of the MARIN Small Bridge simulator.

3.2 Global experiment description

The experiment was conducted in two different simulators, the fixed based MARIN Small Bridge Simulator located in Wageningen and the ***TNO Desdemona*** simulator, an advanced six-dof motion platform located in Soesterberg. The participating tug captains sailed a set of two different tugboat operational scenarios under various sea-state conditions up to 4 m significant wave height. These two scenarios were:

- Approaching a tanker from behind to pick up a line: the tugboat is sailing on a short distance behind a tanker. This tanker sails a fixed speed and heading. The task is to approach the tanker from behind as close as possible and maintain this position for 15 minutes to pick up a line.
- Direct or indirect towing at the stern of a tanker: the tugboat is attached by a line to the stern of a tanker. The tanker sails a fixed speed and heading. The first task is to employ a towing strategy to realise a maximum steering force and maintain this position for 10 minutes. After that, the task is to change the tugboat position and employ a maximum steering force to the other side and maintain this position for another 10 minutes, Finally, the task is to change the towing strategy to realise a maximum braking force. This state must also be maintained for 10 minutes. See the track plot below as an example.



```
Message: Waiting for plot (debr): projects/21938_safetug2 Stena_Torvskar_in_Tp12.cnd 185
```

Figure 15: Track plot.

Each set of scenarios was repeated at least three times; once in the MARIN Bridge Simulator and twice in the ***TNO Desdemona*** simulator (once with physical motion and once without physical motion).

During each scenario various experimental observables were measured in different areas of interest. This included the distance of the tug to the tanker during, following and the line length and line forces during escorting. One other area of observation was workload measurement to assess if and how motion simulation affects the workload in operating a tugboat. For this purpose a secondary task to the primary task of following or escorting was given during the execution of each scenario:

- A peripheral detection task: the tug captain was given a special headset with a red LED. The LED flashed randomly during the run. The tug captain was asked to press a foot switch as soon as he saw the LED turn red;
- Miss (flash, but no foot switch pressed) or false alarm (foot switch pressed, but no flash) was counted and reaction times were logged.

Figure 16.

Furthermore, the simulator instructors monitored and evaluated all sessions. Moreover, in advance and after each scenario the tug captains were asked to fill out questionnaires regarding their background, ship handling qualities and manoeuvers executed, how they experienced the actual simulator capabilities and workload in performing their tasks.

3.3 Results

During the simulations the captains indicated that they had a better situational awareness on the fixed bridge with a 360-degree view and a more realistic bridge mock-up. On the other hand, the simulation results showed that the performance on the six-dof Desdemona platform was slightly better, although the reaction times for the secondary task on the motion platform were significantly higher than on the fixed platform situation. It was clear from the questionnaires that the captains appreciated the added motion and used it to find the limits in the performance of the tug.

Assisting in 3m significant wave height was not a problem. It was found that it was not possible to end up in a stable situation when assisting in 4m significant wave height, but the limits that were found are the operational limits of the tug (model) and not of the performance of the captain in relation to the motions (accelerations).

During change of position relative to the tanker or change of towing strategy, however, full attention was given to the manoeuvre and not to the secondary task. During these short periods the flashing LED was completely ignored. Once a stable situation was reached, the captains picked up the secondary task again almost without miss or false alarm.

Within the context of this study the limits for safe operations related to the human factor were not reached.