A tug captain should also acquire knowledge of the following:

- The capabilities and limitations of tug types while rendering assistance and in particular of the tug he has under command, which should also include the capabilities, limitations and efficient use of the propulsion and steering control systems of the tug, also in case of a single lever control system, and how to respond to propulsion and steering control system failures.
- How to make use of the capabilities of his tug in the safest and most advantageous way when passing or releasing towlines, when coming alongside or departing from a ship's side and when rendering assistance, taking into account all the risks involved related to tug or tug type.
- Proper towline handling and appropriate towline lengths.
- The most effective positions for various tug types, taking into account when, where and how tug assistance is required such as for compensating influences of wind or current, and with respect to particulars of the passage towards a berth and berth location.
- Safety regulations and measures, for instance the need to maintain watertight closed condition of spaces below when a tug is rendering assistance.

As with pilots, the knowledge gained contributes to safe and efficient tug use. Some towing companies have good training manuals, which include several of the aspects mentioned above. It should be noted that theoretical-practical training gives a basic insight, but the required experience can only be acquired 'on the job'.

Additional training aspects

With the exception of the basic manoeuvring characteristics of ships, all the important training aspects have been discussed in the foregoing chapters of this book.

Training for pilots and tug captains has been dealt with separately up till now, but as they should work as a team, training should include more time together. A very important objective of training should be the creation of good understanding and cooperation between pilots and tug captains. Not only between pilots and tug captains but also amongst tug captains, because they have to coordinate manoeuvres in such a way that the most effective tug forces are delivered to a ship. When, for example, two tugs are assisting a ship and one makes a mistake, the effect of the other tug may also be spoiled. To achieve good cooperation it is essential to include the following elements in all training courses:

- Effective communication between pilot and tug captain; attention to this aspect has already been paid in paragraph 4.7.
- Optimum information exchange between pilot and tug captain and between the tug captain and his crew regarding tug placement, destination, intended manoeuvres, propeller use, towline use, etc.

How can basic training be given?

The knowledge of experienced pilots and tug captains is a requirement for successful basic training, which can be given as follows:

- By a classical course, making use of overhead transparencies, slides and/or videos.
- By a classical course and the use of simulations. Simulators can be used to give participants insight into various aspects of ship handling with tugs. For some training objectives, desktop simulation programs are appropriate, or in some cases remote controlled tug models, whether or not in combination with manned ship models, otherwise full mission bridge simulators can be used.
- For junior pilots part of the training should be undertaken on board tugs, while trainee tug captains should accompany pilots on board ships for a time.

Several of the training subjects for pilots and tug captains are similar. Combined training is therefore very effective, particularly when part of the training is given on a full mission simulator. However, the contents of basic training may differ between ports because of the differences in level and background of pilots and tug captains. The background of pilots may also be such that they have already gained considerable experience in tug assistance, especially in ports where pilots are recruited from local tug captains. Whether completely or partly combined training should be given for pilots and tug captains, therefore, should be considered locally.

Regardless of basic training, regular meetings between pilots and tug captains, common practice in a large number of ports, are very useful to discuss problems encountered daily and suggestions of ways of solving them.

8.2.2 Training for specific situations and conditions

This kind of training is sometimes required for problematic areas in the port or port approaches or for difficult environmental conditions such as strong currents or fog. Restrictions in force for certain port areas, harbour basins or berths with respect to tidal currents or wind are sometimes considered too stringent, especially from an economic point of view, and relaxed regulations are issued. For pilots and tug captains the situation then becomes more difficult due to the greater influence of wind and/or current and training will familiarise them with the new and more severe conditions and smaller margins. In most cases such training follows a feasibility study, often carried out on a ship manoeuvring simulator

in close co-operation with pilots.

Training is aimed at a specific situation, and so attention is focused on a specific location in the port, the particulars of that location, the environmental conditions, certain class and type of ships and the tug assistance required. Training is then given in the right ship and tug manoeuvring procedures involving the required bollard pull and tug placement with the objective of being able to handle ships safely in the given situation. Bollard pull and tug placement may be varied during the course, trying to establish the optimum method of tug assistance.

8.2.3 Training for a planned new port, harbour basin or berth

In most cases the training for this kind of situation is based on the findings of a feasibility study of that particular port or port area. It includes the range of environmental conditions, the planned water depths, the type and size of ships and tug assistance. For a planned new port the type of tugs may still be unknown. This type of training does not differ much from the one above, but is aimed at a totally new situation.

Such training provides the possibility at an early stage to familiarise pilots and tug captains with the new situation. Again, the right ship and tug manoeuvring procedures, the required tug bollard pull and optimum tug placement are subjects to be exercised.

8.2.4 Training for specific ships coming to a port

Training for specific ships is mostly training for ships with such size, windage or draft that they are marginal regarding port dimensions, water depths and/or environmental conditions. Training may follow a previous study which determined the maximum environmental conditions and required bollard pull. The aim of training is to familiarise pilots and tug captains with handling the specific ships in the port, arriving and/or departing procedures under maximum allowable conditions, whereby ship and tug manoeuvres are practised with the required bollard pull and correct tug placement.

8.2.5 Training for a new type of tug to be used in a port

A new type of tug has consequences for tug captains as well as pilots. Tug captains should be trained to handle the new type of tug, in particular when the propulsion system differs from the one with which the captains are familiar. Voith, the manufacturer of the cycloidal propulsion system, employs an instructor. However, this is not always the case with azimuth propulsion suppliers. It takes time before a tug captain gets used to a new propulsion system. After sufficient experience is gained when free sailing, the tug captain can start assisting ships. It also takes time to become fully familiar with tug capabilities and limitations when rendering assistance. According to a spokesman of a port that bought azimuth tractor tugs, it took approximately one month under the supervision of a capable instructor to convert an experienced tug captain to be fully competent in omnidirectional propulsion.

A new type of tug performs differently. When the previous tug has, for instance, been a conventional tug and the new one is a tractor tug, the capabilities of the new tug are much greater and limitations fewer. This influences tug assistance as previously provided. The method changes, particularly if the tug is used to its full advantage. As a consequence, a new type of tug influences manoeuvring procedures on board ships. A new type of tug therefore also influences a pilot's job.

Training for a new tug type should therefore not only be training in tug handling. Pilots should be involved together with the tug captains. Training should comprise the total procedure of shiphandling based on the new type of tug and its capabilities and limitations, taking into account port characteristics, ships calling at the port and environmental conditions.

Training may also follow a simulator study, to determine the effect of a new tug type on accessibility of the port. This type of training also applies to escort tug operations, dealt with in the next chapter.

8.2.6 How the specific training courses can be given

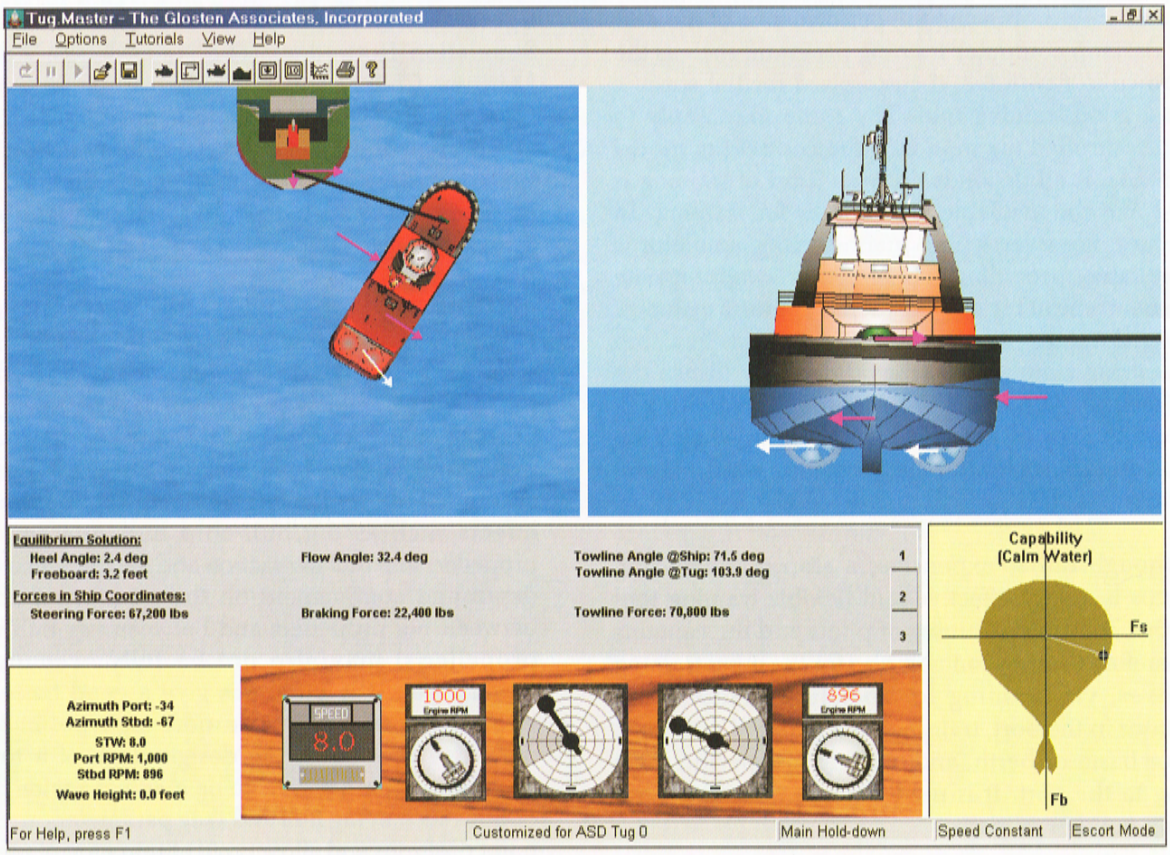
Combined training

Apart from training for a new tug type, the training situations mentioned always concern optimum shiphandling with tugs and mostly under more severe conditions and/or with small margins. In practice pilots and tug captains have to work as a team and both have to become familiar with specific situations, conditions and ships. It is best, therefore, that both pilots and tug captains who have to work in the area concerned or have to handle specific ships participate in such training courses. They will learn from each other through discussions during the course, which contribute to training objectives.

The same applies to training in the specific shiphandling capabilities of a new tug type. A new tug type concerns both pilots and tug captains. Such training may include pilots becoming familiar with the new tug itself, which can be achieved by training 'on the job' on board. Whether combined training of pilots and tug captains can be arranged depends on the local situation, as mentioned earlier.

The use of ship manoeuvring simulators

Training for shiphandling of a new tug can be carried out classically, making use of overhead transparencies,



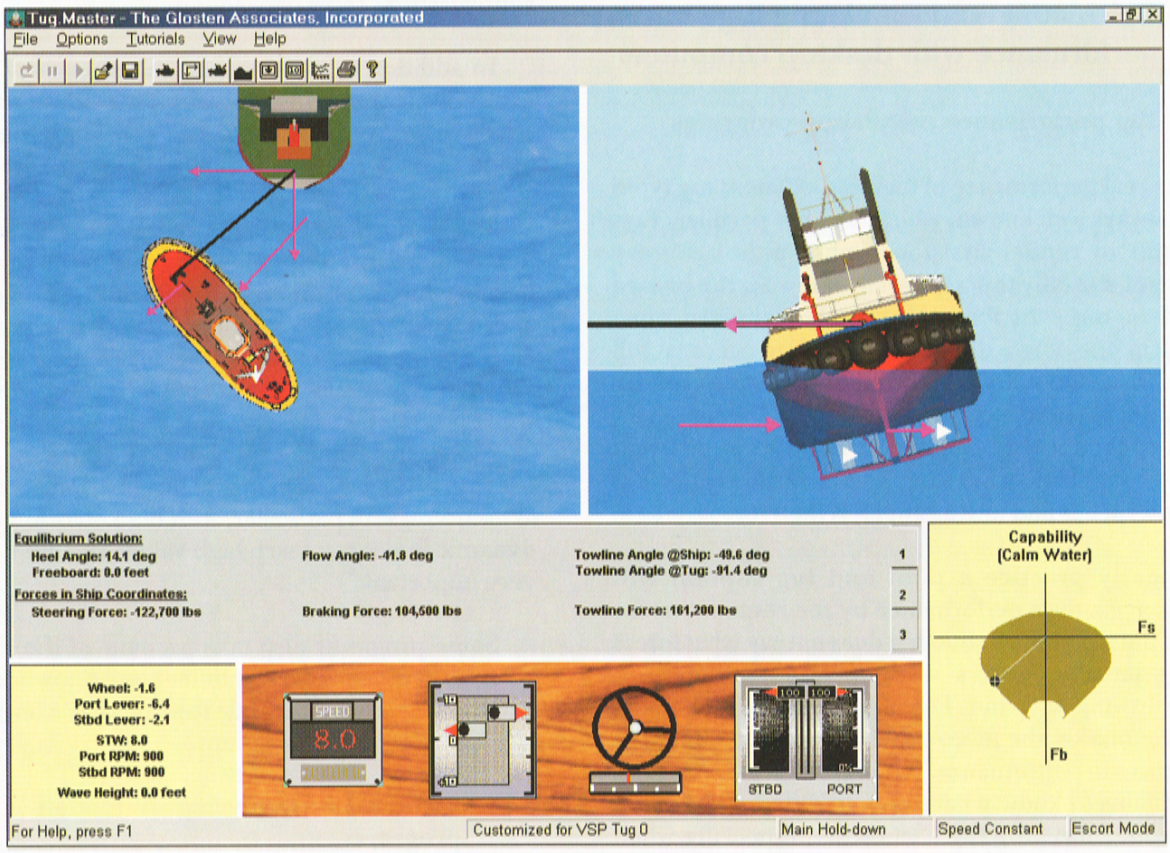


Figure 8.2 Desktop computer program Tug.Master, developed by The Glosten Associates, Seattle, USA. The program that calculates equilibrium solutions for a stern tug towing on a line, e.g. an escort tug, can be customized for a particular tug and be used as a performance prediction program and as a training tool.
A number of ASD and VS-tugs can be simulated. The tugs can be controlled by keyboard and mouse. Speed, wave height and towing point (VS tugs) can be varied. Detailed information on forces, moments, freeboard, heel and towline angle are displayed. CTUGSIM is a similar program for conventional tugs.

slides and videos, showing the performance of the new tug. A desktop computer training program, such as the one shown in figure 8.2, if customised for the specific tug, is a good training tool. The same may apply to remote-controlled tug models if the correct tug model is available. It all depends on what kind of training is needed and the available possibilities for training. In most cases, however, a ship manoeuvring simulator is most suitable, providing the simulator is appropriate for the new type of tug and the method of tug assistance. Combined training of pilots and tug captains in a ship manoeuvring simulator teaches them how to use the tug in the most advantageous way for shiphandling in the specific area of the port, taking into account all relevant aspects, such as for instance ships, wind, current and waves

Although rather expensive, a ship manoeuvring simulator is a very effective and flexible training tool for such a combined training of pilots and tug captains and therefore the most suitable also for the other training objectives, viz. training for specific situations and conditions in the port, training for a planned new port, harbour basin or berth, and training for specific ships coming to the port. It is used for those purposes in a growing number of ports.

8.3 Calculating and simulating tug performance with desktop computers

8.3.1 Tug performance calculation programs

The real performance of tugs and different tug types is not always well known, which is rather peculiar. Tugs are built to render assistance and, although very important, the only thing generally known is the bollard pull of the tug – the forces that can be delivered when pulling in one of two directions, ahead or astern, at full power in a stationary situation. Tugs have to render assistance, as far as possible, in all towing directions and not just when a ship is stopped but also at different speeds. Insight into what a tug's performance really is at different speeds and towing angles is therefore required.

In daily practice a pilot and tug captain will experience a tug's performance by the response of the ship to the tug's efforts. But that does not say what forces the tug actually delivers when operating at the ship's side or towing on a line. The more tug types that come onto the market the more should be known about the differences in performance. It is important for pilots and tug captains to know what tugs and different tug types can do, but also for a tug fleet owner, especially when ordering a new tug. A choice has then to be made between different tug types.

Tug performance calculation programs have been developed by a number of companies and simulation institutes. To name a few, The Glosten Associates (see figure 8.2), USA; Damen Shipyards and Marine Simulation Rotterdam, The Netherlands; Australian Maritime College and Maritime Simulation Centre the Netherlands. These simulation programs produce a graphic representation of a tug's performance at different speeds and towing or pushing angles. Indirect towing methods can be included and some programs account for waves as well.

These tug performance calculation programs are generally based on a force-equilibrium-simulation, a static state, taking into account such characteristics as tug hull, skeg, rudders, propulsion devices, towing point/pushing point locations, stability and tug maximum list, maximum engine load and assisting methods. Not accounted for are the difficult to determine interaction effects such as tug hull/ship hull interaction, tug propeller/ship hull interaction and the influence of water depth and confinement on these factors. Interaction between tug propellers and between tug hull and tug propeller(s) may also not be fully accounted for. Nevertheless, the programs give a good basic insight into performance of one or more tug types in different operating modes. In the design stage of a tug these programs allow a review to be made of a wide range of options such as tug hull and skeg parameters and towing point positions and allow rapid elimination of unsuitable configurations to be carried out.

In addition to performance calculations of various tug types, some of these programs allow the most effective tug positions and tug configurations to be tested.

Tug performance can be represented in so-called polar diagrams, showing the maximum towing or pushing forces at different speeds and towing angles and/or the most relevant pushing angles. In paragraph 4.3, a number of these performance diagrams were shown when discussing tug capabilities and limitations.

These programs have become more important because of the development of purpose built types such as escort tugs. In particular, with high escorting speeds, dynamic forces can reach high values and are therefore very important.

Some programs also take account of the dynamic behaviour of tugs and the influence on towline forces and heeling moments, while towline characteristics are also included in the program.

8.3.2 Fast-time manoeuvring simulation programs

A number of fast-time manoeuvring simulation programs exist in which tug assistance may play a role in one way or another. Such programs can, for instance, be used to investigate whether a certain ship, following a planned route, can enter a port under given

environmental conditions. A tug controller mode can be selected, which merely calculates the tug forces required. As the tugs themselves are not simulated but only the forces available, limitations of tugs or differences in tug types are not taken into account at that stage. These programs are mainly used for initial port design or, for instance, to approximate the limits of environmental conditions in order to reduce the number of runs to be executed when further research is carried out on a full mission bridge manoeuvring simulator. Simulator time and costs on a bridge manoeuvring simulator can thus be reduced.

More sophisticated fast-time manoeuvring simulation programs generate tug forces based on available data of tug type performance, including differences in assisting methods, tug types, speed and environmental conditions. These programs are mainly used for the evaluation and design of tanker escort configurations. Together with the ship simulation program and tug control program, which is responsible for the assistance strategy, the total ship-escort tugs system is simulated after an engine failure, rudder jam or collision course. The results are evaluated with respect to track and/or course control capabilities of the ship-tugs system after these events occurred. Advanced versions of these programs also take into account the times needed for tugs to arrive and/or become effective.

8.3.3 Real-time simulation on desktop simulators

Some real-time simulation programs on desktop simulators, also called part task simulators, provide an opportunity to control a ship by engine and rudder, while several tug types can be chosen to assist. Tugs can assist in different modes, e.g. at a ship's side or towing on a line. These programs can be used for different research purposes such as port lay-out, required tug assistance or bollard pull, maximum wind and current conditions.

Pilots can make use of these simulation programs for certain basic training objectives or to get an insight into how to deal with a new or problematic port area or the handling of a new type of ship. They can try out alternative strategies or tug configurations, extreme wind and/or current conditions. Simulations can often be replayed in real time and fast time. The programs give a good idea of the different possibilities in a given situation and are much cheaper than using a ship bridge manoeuvring simulator.

For most training objectives, manoeuvring on real-time desktop simulators differs greatly from the real world. Manoeuvring is done on the information from a display, which provides a so-called bird's eye view. Reality on board is different, particularly when manoeuvring in confined waters. In such situations a pilot reacts to information mainly obtained from an outside view. This provides a pilot with actual and instant information regarding ship's position, speed, distance off, heading and influence of current and wind. In addition, a pilot on board a ship not only has a totally different but a much more limited view than when manoeuvring using a display. His perception is different, and consequently he may react differently for ship manoeuvres and tug assistance required. Furthermore, cooperation with tug captains, an important factor when manoeuvring in confined waters, is hardly possible.

Bridge manoeuvring simulators, which are dealt with in paragraph 8.5 and following, have an outside view and reflect reality on board ships in a better way, while cooperation with tug captains is possible. In this chapter most attention is therefore paid to this research and training tool, and in particular to the simulation of tugs.

8.4 Simulation by remote-controlled tug models

Particularly in the USA there is an increasing use of simulation by remote-controlled models for training and for performance studies of different tug types or various tug designs. This has become feasible through the construction of very realistic operational models by the model builder Ron Burchett in Canada. Existing ASD-tugs and VS-tugs, for instance, are built in a scale of 1:24 with their specific propulsion systems, with realistic controls, correct stability, working winches and fenders. Models of conventional tugs, ships and barges have been built as well. The largest problem with scale models is the accelerated time factor. Ship or tug models behave exactly like real ships, only much faster, viz. if the model scale is 1:25, five times faster (square root of the scale). A tug model approaching a ship at a certain speed will do so at five times that speed in reality. The same applies to wind and current speeds. A wind speed of e.g. 10 knots working on the model is in reality a wind speed of 50 knots.

The control systems of the model tugs mentioned have an adjustable built-in time delay for propeller and steering control. This does not alter the fact, however, that all speeds observed are five times as high as in reality for a model scale of 1:25. Also the feeling differs from reality, the tug captain is not on board his tug, but is operating a model at some distance, which might affect realism of tug handling.

When taking into account these effects, tug models can be a tool for tug performance studies and for training, such as with regard to tug manoeuvring and ship assist capabilities and tug limitations. With respect to this, using radio controlled tug models in combination with manned ship models (Port Ash, Australia) is an even better training tool. A disadvantage of training with models, in addition to what have been mentioned, is the limited number and type of models and the inflexibility in conditions and circumstances

8.5 Tug simulation using bridge manoeuvring simulators

Bridge manoeuvring simulators, also called full mission bridge simulators, are equipped as a ship's bridge with all the usual instruments – control handles, wheel, radar, communication facilities, chart table, and so on. The outside world is projected on a screen, normally based on computer generated image (CGI) techniques.

The angle of outside view can be up to 360° and on several simulators it is possible to switch between a view ahead from the centre of the wheelhouse to a view from the starboard or port wing. Simulators with a smaller angle of outside view, say 225°, can usually also switch towards a stern view.

Ship models are often represented in three degrees of freedom: surge, sway and yaw. Roll can also be simulated whether by visual presentation or by a hydraulic system. Some simulators equipped with a hydraulic system can, in addition to roll, also simulate pitch and heave, thus representing six degrees of freedom.

Simulator institutes may have up to three or four full mission simulators, which can interact, as explained in section 8.5.2. Not all these simulators are usually equipped in the same way. The main bridge simulator may have a 360° view and a hydraulic system, while other simulators may not have a hydraulic system and just a 225° out-of-window view or even less.

Research projects on full mission bridge simulators are mainly conducted for areas of a port with limited space and where frequent manoeuvring takes place. This is the area of the local experts – pilots and tug captains. Simulator institutes have accumulated a significant amount of nautical knowledge but cannot have in-house all the nautical experience of the local pilots and tug captains. The experience of these experts is indispensable for accurate simulation. In these areas margins are often so small that one cannot afford any inaccuracies. This practical experience is necessary in order to assess whether the simulation is correct, the simulated tugs operate as they do in reality, the simulated manoeuvres can be carried out in reality and so on. Pilots and tug captains must assess the simulation from their point of view to get a realistic simulation and to obtain results which are achievable in practice. The same applies to training courses, whether basic training is given or following on from a former research project.

A number of training objectives have been mentioned. They mainly concern the accessibility of an existing or newly developed port or port area. The accessibility or entrance criteria for a port or port area are determined by the type and size of vessels in relation to the port dimensions, environmental conditions, the number and type of tugs available and on pilots' and

Photo: MarineSafety International Rotterdam

Figure 8.3 Bridge layout of a full mission bridge simulator. The field of view is 360°

tug captains' experience. As larger vessels try to make use of an existing port infrastructure, the accessibility of a port can only be guaranteed by improvement in manoeuvring procedures, increased experience of the pilot and tug captains and improvements in the type, bollard pull and/or number of tugs used to assist a vessel. The opposite is also possible. By increased experience and improvement of manoeuvring procedures or of tug assistance, it is possible that larger vessels can enter a port or a certain port area under given environmental conditions.

The effects of improvement can be established by operational research carried out on a full mission bridge simulator. In addition, improvements associated with experience can be achieved by training pilots and tug captains on full mission bridge simulators. Full mission simulators may also be used for research and training in escorting as will be mentioned when discussing interactive tug simulation.

The whole simulation process on full mission bridge simulators is not discussed in detail, but attention is given to some essential aspects of tug simulation in general and of interactive tug simulation in particular in order to achieve tug simulation which reflects the practical real world situation as much as possible.

8.5.1 Requirements for correct tug simulations

Regardless of how tug and tug assistance are actually simulated, to ensure adequate research and training, correct simulation of the following factors is essential:

- The *force* (magnitude and direction) that the tugs can exert on an assisted vessel under different conditions, situations and speeds.
- The *space* assisting tugs need to operate under different conditions, situations and speeds. For tugs towing on a line the required space depends on the tug dimensions and towline length used. This space is in addition to the space required by the vessel.
- The *response time* of the tugs.

These factors must be accurately simulated and should be considered and/or validated carefully before a research or training project starts, depending on the specific tugs and tug assistance simulated. It is, to a large extent, these factors that determine, for a given vessel and environmental conditions, the minimum required manoeuvring space for ship and tugs. In other words the minimum required horizontal dimensions for a port, harbour basin or fairway.

Tug captains and pilots with significant experience in a port know what they might expect during assistance to a vessel. They position a tug where it is needed before the need occurs. Both tug captains and pilots anticipate expected situations. This anticipation, based on experience, is also a factor of major importance and must be taken into account in evaluating operations with tugs.

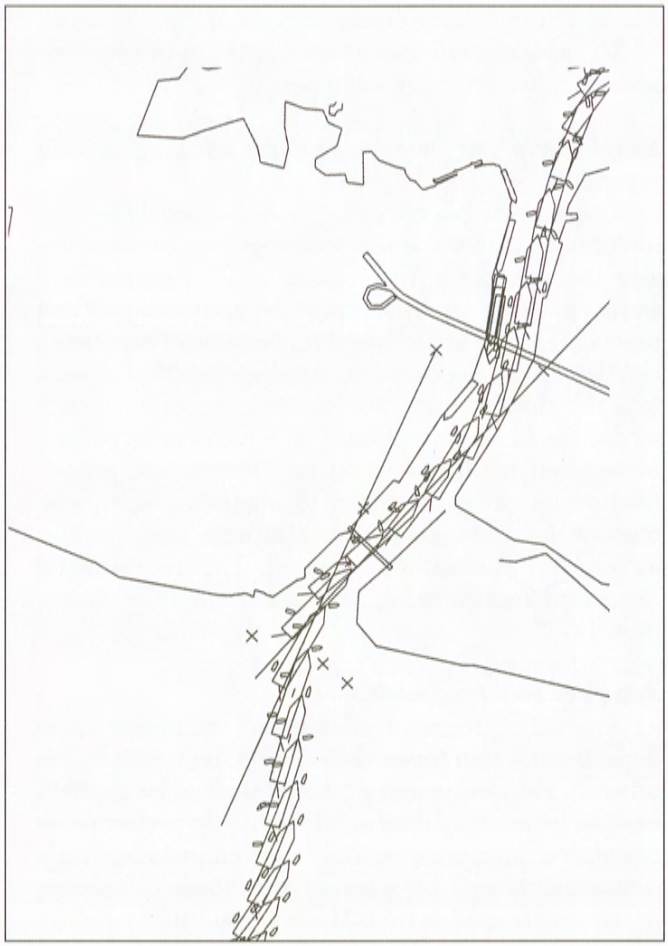


Figure 8.4 Simulation track plot of a loaded tanker entering a port from the sea. Tug positions with towing and pushing directions are shown. The study was carried out by MarineSafety International Rotterdam

How tug simulation can best be achieved depends on how tug assistance is simulated. Developments in and various methods of tug simulation are reviewed, including their limitations.

8.5.2 Development in tug simulation towards interactive tugs

Tug simulation was introduced into shiphandling simulators many years ago. The procedures have changed from simple vector tug models to more sophisticated models over the years as the use of tugs has become an essential part of shiphandling simulations.

Simple vector tug models

In a vector tug model, the tug is simulated by a force vector, indicating magnitude and direction of applied tug force. With the most simple one, the influence of ship's speed is disregarded. It is clear that this system has many shortcomings: no simulation of correct speed and towing direction dependent tug forces, no simulation of the space required by the tug, incorrect

reaction time, and no considerations of the limitations of the tugs, etc. All these factors will, in one way or another, affect the simulation results.

Simple vector tug models combined with tug captain experience

The same simple vector tug model is used. However, to compensate for the shortcomings, tug captains are asked to assist during the simulation. They should have experience in the specific part of the simulated port and practical experience in handling the type of tugs being simulated. The tug captains introduce practical aspects into the simulation. Based on their experience they advise the simulator operator on which tug forces can be applied realistically, on tug limitations, proper towline length with regard to manoeuvring space, reaction times and other practical aspects. They can also anticipate the situation expected. This represents a significant improvement in the use of simple vector tug models.

Advanced vector tug models

Applied tug forces are ship speed and towing angle dependent: a step forward. Different tug types can be selected. For towing and pushing forces to be applied, use can be made of data obtained by tug performance calculation programs, which may even include a tug's limitations caused by waves. Other force calculating programs are used as well. There are still shortcomings in response times and tug limitations and the required tug space may not be fully taken into account. Tug captains often participate to improve the simulation, based on their experience.

Several simulator institutes have developed a more sophisticated form of vector tugs, which manoeuvre automatically into stand by, connect or assist mode, activated by simple commands on the computer screen of the operator.

Tugs simulated on a monitor (bird's eye view) and operated by tug captains

The tug captains have their own control handles for course and speed control of the simulated tug, so that they directly manoeuvre the tug. They might even have a tug wheelhouse with the required instruments and control handles. The tugs can make fast the towline, pull and let go the line if necessary. This system comes closer to reality. The problem is that the tugs on a monitor are so small that slight changes in tug position and in heading can hardly be observed in time and the tug captain's reaction may come too late.

Interactive tug simulation

Modern computer techniques make interaction between full mission simulators possible (see figure 8.6). Some or all tugs and the assisted ship can be run on separate bridge simulators, all interacting. The limitation on the number of interactive simulators is more a question of the cost of the facilities than of technology.

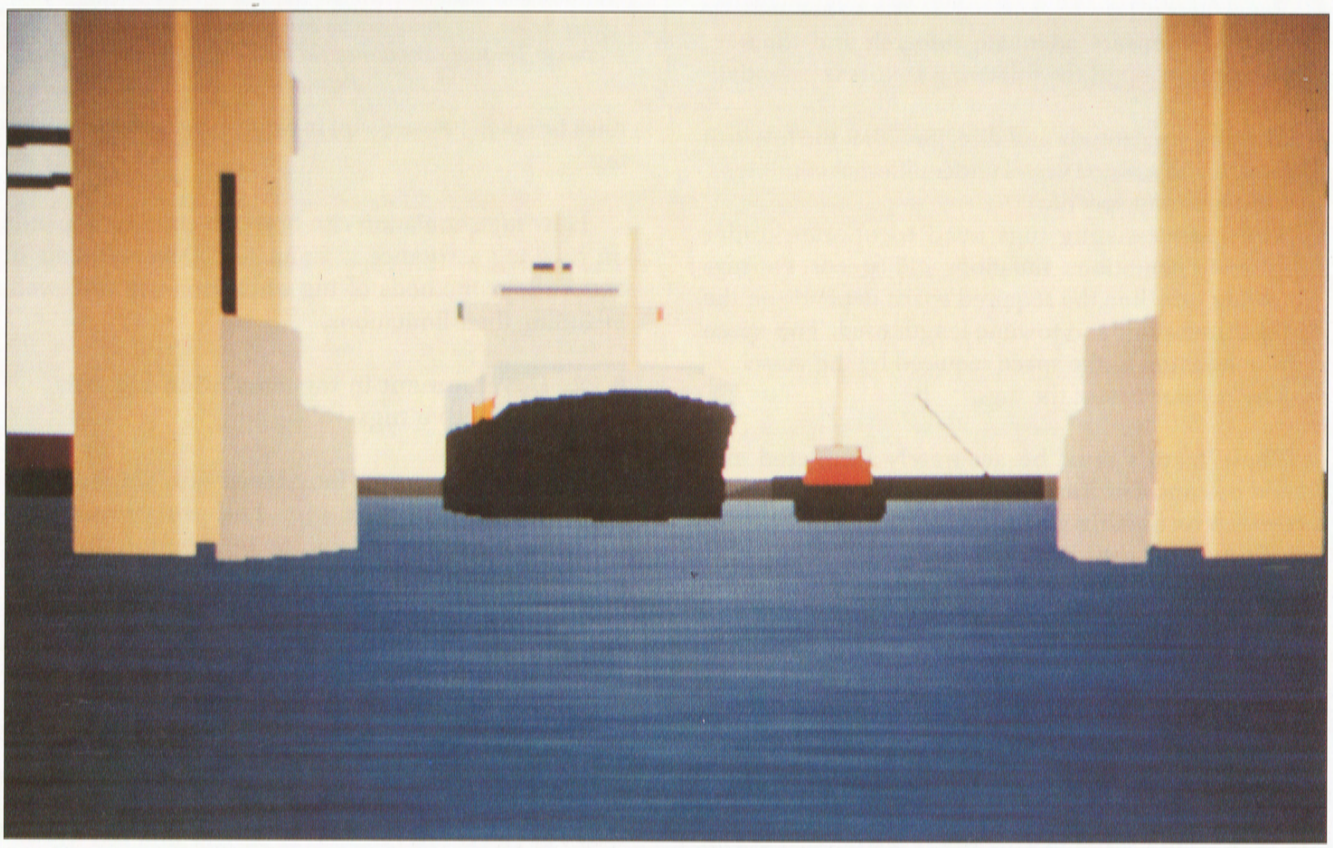


Photo: Hamburg Maritime Research

Figure 8.5 Simulated ship and assisting tug passing a bridge. The tug is controlled as a vector tug by an operator under the supervision of a tug captain

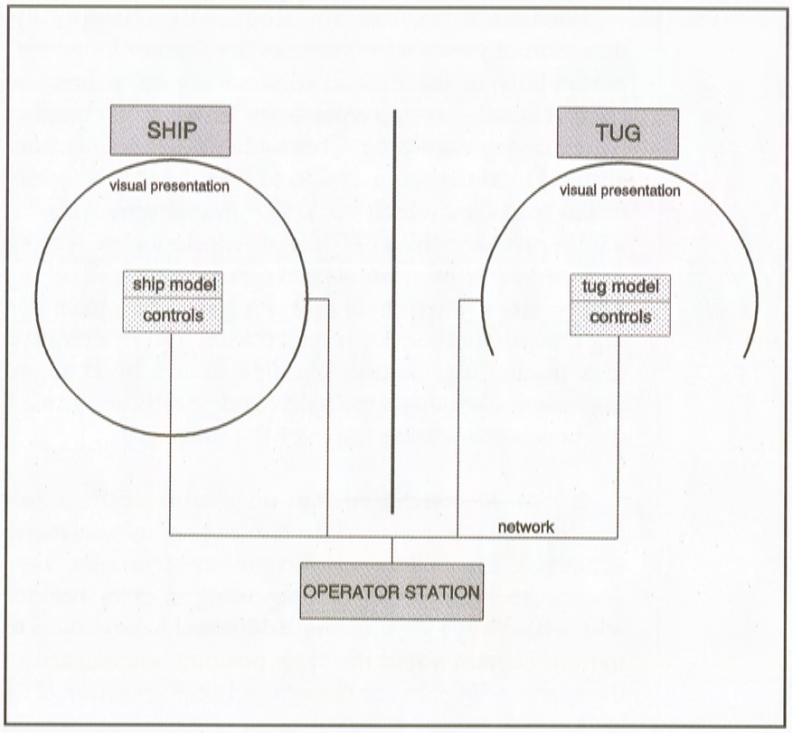


Figure 8.6 Schematic diagram of an Interactive Tug Operations Simulator

Tug captains have their own tug, with wheelhouse, bridge instruments, propulsion and/or rudder controls, communications and an out-of-window view. Different tug types can be simulated, all with their specific characteristics. With a well tuned simulation system the exerted tug forces, tug force directions and required manoeuvring space come close to reality. The shortcomings of vector tugs can thus be overcome. Reaction times are as in reality, because the tug captain is running his own tug. Besides, tug captains bring their own experience with them. They are able to see each other, when not obstructed by the vessel, on the out-of-window view for further enhancement of the operations.

A further advantage of interactive tug simulation is that tug captains now actively participate in study and training projects, giving greater satisfaction, which will contribute to the study and training results.

When simulating a ship assisted by a number of tugs, one or more tugs may be simulated on an interactive tug simulator, while other tugs may still be simulated by vector tugs. This can be for several reasons such as the costs of the required number of bridge simulators being considered too high or manning problems of the interactive tugs.

Simulation of interactive tugs is much more complicated and handling the tugs should be as close as possible to real world operations. This requires attention to a number of important aspects related to the practical handling of simulator tugs, which is discussed below.

8.5.3 Important aspects for interactive tug simulation

Visual presentation and orientation of control handles

For the simulation of interactive tugs one has to consider the following with respect to visual presentation, especially for tugs towing on a line:

- A pilot refers the assisted ship's position relative to the surrounding area, such as banks, buoys, moored vessels and other conspicuous points. A tug captain refers tug's position and speed, heading, distances off to the surrounding area, and the assisted ship's position.
- For the pilot the view of the surrounding area is important. For a tug captain the surrounding area is important, but of equal importance is the view of his towline. The view of his towline gives the tug captain the main information about the tug's position in relation to the assisted ship and its performance.
- The out-of-window view, including the view of the tug's fore or after deck, should always be in accordance with the way propulsion and rudder or thruster controls are operated. There should be no misunderstanding which direction the tug will move when control handles are used

The foregoing has consequences for the horizontal angle of the out-of-window view. The required minimum angle of view depends on the type of tug and the method of tug assistance, as will be shown by some examples in figure 8.7. A 225° field of out-of-window view will be assumed, which is common for many bridge simulators.

The captain of tug no. 1 in figure 8.7 must look forward in the direction of movement as well as aft at his towing line and at the assisted ship. A 225° field of view is not sufficient for him; he needs almost a 360° field of view. He also needs it for making fast, as can be seen when following the tug along positions a, b and c. The tug captain will lose the ship from sight when between position b and c. He cannot position the tug to secure the towline.

The captain of tug no. 2, a conventional or an ASD/reverse-tractor tug, can operate with a view of 225°. A tractor tug, no. 3, normally operates with the stern towards the ship. A field of view of 225° in the direction of the tug's stern will be sufficient. An out-of-window view of 225° is also enough for tug nos. 4 and 5. However, when the ship also has to move astern, then the direction of ship movement and of the towline are opposite. The tugs will then need almost a 360° out-of-window view. In narrow spaces and during berthing

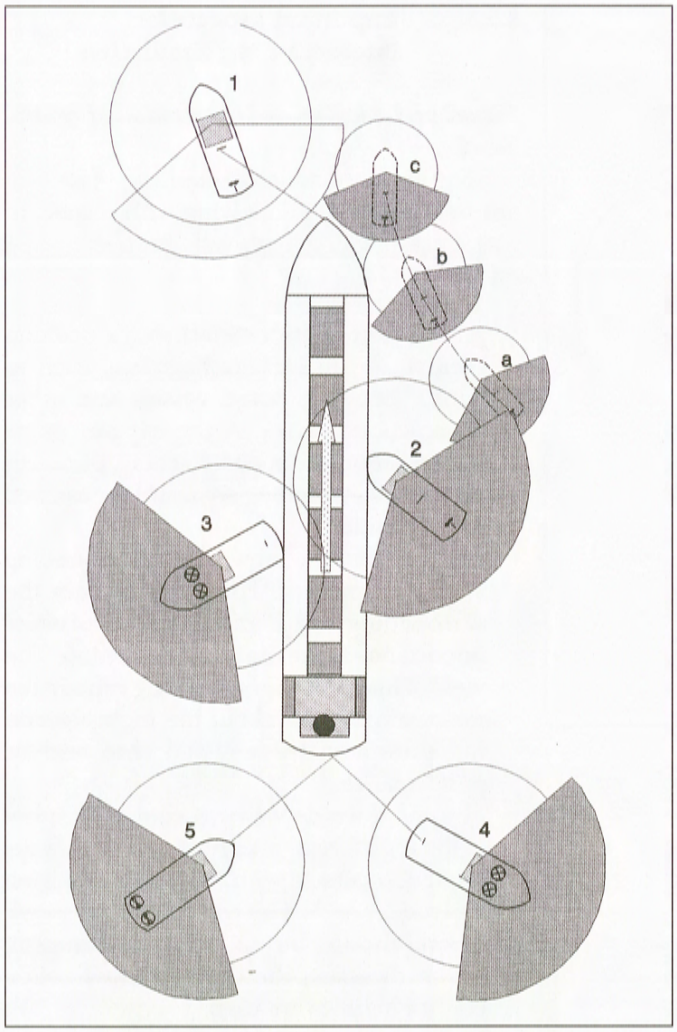


Figure 8.7 Field of view required for interactive tugs
The captain of tug 1 needs an almost 360° out-of-window view. An out-of-window view of 225° for the captains of the pushing tugs 2 and 3 is sufficient. The same is the case for tugs 4 and 5 when the ship moves in the indicated direction. When the ship would move backwards these tugs also need an almost 360° field of view

operations a 360° field of view is often needed for all assisting tugs.

There is another aspect which should be taken into account with a 225° out-of-window view, and that is the handling of the propeller, rudder or thruster controls. As mentioned at the beginning of this paragraph, on several simulators it is possible to switch between a view ahead to a view to starboard, to port or to astern.

In figure 8.8 the simulated tug's wheelhouse is shown with the projection screen. When, for instance, a conventional tug is simulated and the tug's bow is seen on the screen the tug moves forward when forward propeller thrust is applied. When the tug captain wants to have a stern view, the afterdeck is projected on the screen, the propeller control handles maintain their positions and when they are moved into the direction of the projected stern, ahead thrust is still applied and the tug moves forward instead of what should occur, viz. astern.

Because a tug captain frequently changes his direction of view and sometimes for a rather long time, particularly in the case of tugs towing on a line, the control handles are often positioned in a wrong direction which is very confusing. Control handles not operating according to the tug as projected on the screen easily cause mistakes which spoil the manoeuvre. This is another reason why a 360° out-of-window view is often required for correct simulation of tugs towing on a line. Furthermore, when changing the tug simulator from one tug type to another, for instance from a stern drive tug to a tractor tug, control handles should be changed accordingly because a stern drive tug mostly assists over the bow and a tractor tug over the stern.

It can be concluded that an almost 360° out-of-window view is essential for the tug captain in many situations. The lack of a sufficient out-of-window view is sometimes compensated for by using an extra monitor with a bird's eye view, giving additional information to the tug captain about the tug's position with regard to the surrounding area or the assisted ship's position. The monitor has some disadvantages as has already been mentioned.

Simulator institutes having a full mission bridge simulator with a 360° out-of-window view, could consider using a 225° field of view for certain training and research projects for the simulation of the assisted ship and a 360° field of view for one simulated tug.

From the foregoing it can be concluded that when using interactive tugs the following is generally required regarding the angle of out-of-window view:

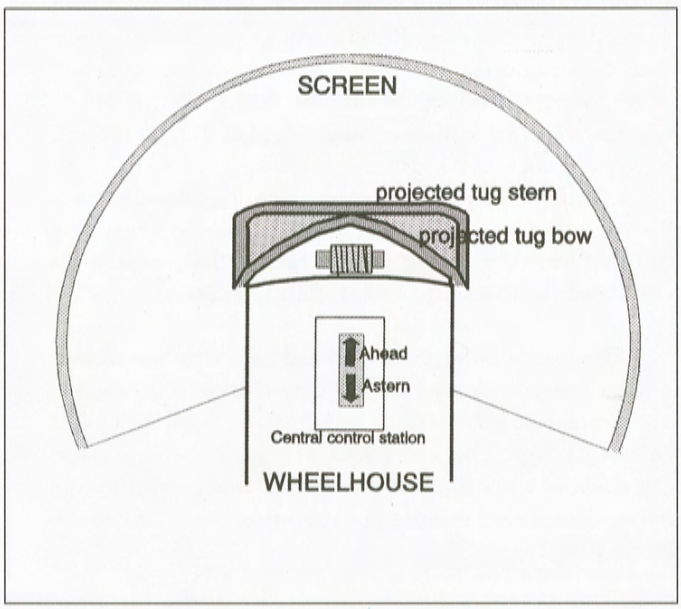


Figure 8.8 Relationship between direction of view and control handles for an interactive tug with a 225° out-of-window view. When the tug's bow is projected on the screen control hamdles are correctly positioned. When the stern is projected control handles are 180° wrong. Therefore, control hamdles should be in accordance with the tug's projection on the screen

- An angle of view of approximately 225° is often sufficient for tugs operating at the ship's side and for tractor and ASD/reverse-tractor tugs when towing on a line and the directions of towline and ship's movement are roughly the same. In narrow spaces and for berthing manoeuvres, however, a 360° field of view is mostly needed.
- An out-of-window angle of view of almost 360° is required for conventional tugs towing on a line and for other tug types when towing on a line and the directions of towline and ship's movement are opposite.
- If using a 225° angle of view for the tugs, an additional monitor can be used to compensate to a certain extent for the lack of sufficient out-of-window view.
- Handling of controls should always be in accordance with the way the tug is projected on the screen.

The captain of an interactive tug should be able to make a good assessment of the tug's speed and position, the ship's speed and position, the towline direction and the towline force. In addition to the requirements for the angle of out-of-window view, the following aspects are important for visual presentation of any interactive tug simulation:

- The assisted ship's side, bow and stern should not be of uniform colour, but accentuated (textured) to give a sense of relative motion to the tug captain.
- Tug movements are much faster and more frequent than movements of the assisted ship. The update frequency of the out-of-window view should be sufficiently high to give a smooth picture.
- The towlines should be made visible in the out-of-window view and towline forces should be clearly displayed in the tug's wheelhouse since on most simulators no visual information can be obtained by the tug captain as to whether the towline is slack or under tension.

Tug performance in wave conditions

Although with three degrees of freedom, tug movements due to waves are not represented, the effects may be taken into account with respect to the forces on tug and ship. Limitations of the tug due to movements and/or the high dynamic towline loads caused by waves may not be taken into account on all interactive simulators. When a bridge simulator is used for interactive tug simulation which also represents roll, or a bridge simulator with a hydraulic system representing heave, roll and pitch, and these limitations are taken into account, simulation of tug performance in wave conditions becomes very realistic. This is an important factor for research and training in these conditions, for example for escort tugs. Such simulation projects may include studies regarding the required tug type for escorting, necessary bollard pull, achievable towline forces and the related training for tug captains and pilots.

Other practical aspects

Apart from the requirements for correct modelling of the tug with regard to hydrodynamic aspects, stability, freeboard, manoeuvring characteristics, location of towing point or pushing point, propeller thrust and engine load, and so on, in addition to the earlier mentioned requirements, there are a number of other important practical aspects which should also be taken into account, namely:

Photo: Author

Figure 8.9 Heeling angle is an important factor in tug limitations. Twin screw tug 'Smit Siberië' (l.o.a. 28·6m, beam 8·7m, bollard pull 35 tons)

- *Heeling angle*
  A tug captain reacts to visual information and also to the tug's angle of heel. The heeling angle is an important factor regarding tug limitations. Heeling angle due to towline forces as well as steering forces should therefore be simulated as well as possible.
- *Engine noise*
  A tug captain also reacts to engine noise. For instance, a tug captain reduces power to avoid overloading the engine. This can occur when a tug has to brake a ship's speed. Engine noise should therefore be simulated for interactive tugs.
- *Control handles*
  The handling of propeller, rudder or thruster controls

of the simulated tug should be similar to the real tug.

- *Towline/fender characteristics*
  Towline and/or fender characteristics should be well simulated. The characteristics and capabilities of the tug's towing equipment, such as a towing winch, should also be taken into account.
- *Wind indicator*
  For simulations where wind plays an important role, the tug captain should have a continuous good insight into the relative direction of the wind working on the assisted ship, either by an appropriate wind indicator or by means of a monitor showing clearly the relative wind direction for the ship.

When all the above aspects are taken into account, the interactive tug is the most suitable tool for research and training projects. However, full mission bridge simulators are not yet able fully to reflect the real world. Further study and improvements are necessary on such subjects as mentioned in paragraph 8.7. Practical input will still be necessary during the coming years.

8.5.4 Method of tug simulation to be used

Although tug simulation has some limitations and further improvements are required, in several training and research projects it has been proven to be a very suitable tool. Regarding the kind of tug simulation to be used the objectives of the training or research project have to be considered. Account has to be taken of the capabilities and particularly the limitations of different tug simulation possibilities. For certain situations this could result in a decision to use vector tugs instead of interactive tugs, while for other research and training projects only interactive tugs will meet the requirements.

A full mission bridge simulator is a rather expensive tool for research and for training. When, in addition to the simulated ship, bridge simulators are used for interactive tugs, two, three or even more simulators may run at the same time, raising the costs considerably. So costs may be a limiting factor in the use of interactive tugs.

The number of simulators might be such that not all assisting tugs can be simulated by interactive tugs. In addition to the interactive tugs, vector tugs will then be used. Furthermore, each interactive tug needs at least one but usually two captains, and they may not all be available. Some tugs then have to be simulated by vector tugs.

There is another aspect which applies to a number of ports. Tug captains are not always in a position to enable them to participate in research or training projects. In these cases the only solution mght then be to use vector tugs instead of interactive tugs. Tug captains from other ports could be used for certain projects, but they don't have the local experience required for correct simulation.

Therefore, when using full mission bridge simulators for research or training it depends on a number of factors which kind of simulation is most suitable. In many cases it may result in the use of one or more vector tugs.

When the angle of out-of-window view is a limitation in using an interactive tug and the simulator institute has a bridge simulator with a 360° angle of view, consideration could be given to using this simulator for a tug while the assisted ship could be simulated on a bridge simulator with a 225° angle of view.

When the costs of bridge manoeuvring simulators are found to be too high, for certain projects manoeuvring simulation programs on desktop computers can be used.

8.6 Simulator training

8.6.1 Enhanced training possibilities

In this chapter, various training objectives have been discussed, including the requirements for proper tug simulation. A full mission simulator with vector tugs and the input of experienced tug captains is a suitable tool for training in shiphandling with tugs. Together with the pilots, tug captains can learn, for instance, strategies and procedures for entering a port and for berthing and unberthing, the influence of wind and current, the tug effort required and ship's response to it. As mentioned, another aspect of participating in training with pilots, and also in research projects, is the positive effect on pilot/tug captain co-operation. In discussing different manoeuvres, they learn from each other.

It is clear that tug captain training has been improved by the use of interactive tugs. They open up much better training possibilities and tug captains can, in co-operation with pilots, actively participate by operating their own tug. Although there are some limitations, interactive tug simulation opens up the following possibilities for active training of tug captains in:

- Improved strategies and procedures for entering or leaving a port, manoeuvring in port areas, berthing/unberthing with vessels calling at the port or specific vessels expected to call at the port.
- A new port or new port area.
- A new type of tug, such as an ASD or reverse-tractor tug. They can be trained in handling of the thruster controls and in learning new capabilities of the tug with regard to ship handling.
- Escorting.

New tug captains can be trained in:

- Subjects such as communications, operational procedures, co-operating with pilots and other tug captains, basic manoeuvres and avoiding dangerous situations.

8.6.2 Steps to be taken for a simulator training set up

To start simulator training for pilots and/or tug captains with interactive tugs the following is an indication of the steps to be taken as far as is relevant in close co-operation with a simulator institute:

- An accurate definition of training needs and training objectives.
- A definition of training requirements.
  Subjects to be considered include: the situations and circumstances for which training is required, number and experience of tug captains, number and experience of pilots, co-operation required between pilots and tug captains, type and number of tugs, type of ship, environmental conditions, communications and operational procedures.
- An assessment of whether the simulator institute can meet the training requirements with regard to:
  - simulator facilities such as the type and number of interactive simulators, suitability of the interactive tug simulator for the type of tug and method of tug assistance;
  - ship and tug models;
  - simulation of particulars of the given area, such as the outside view, aids to naviagtion, wind, current, waves, water depths, shipping traffic and moored ships;
  - communication facilities including, if relevant, VTS communication;
  - instructors
- A validation phase.
  After reaching agreement with a simulator institute and preparing the simulator the following should be tested, amongst other items, during the validation phase:
  - tug models: free sailing, and whilst interacting with the assisted ship while towing/pushing manoeuvres are carried out at different angles and speeds; it should be tested whether manoeuvres can be carried out in a realistic and an acceptable manner;
  - applied towing and pushing forces;
  - ship models: manoeuvring performance and the effect of applied tug forces on the ship;
  - environmental conditions, including water depths, and their influences on ship and tug;
  - wheelhouse layout, including tug engine, rudder and/or thruster controls, display of towline forces, bridge instruments;
  - simulated wind and engine sound;
  - out-of-window view, including the view of the assisted ship and tugs as projected on the screen and the view of the towline;
  - communication facilities and procedures.
- A definition of training programs.
  Training programs should preferably include simulation parts as well as theoretical parts. For the former the various scenarios to be simulated, required tug assistance and related communication procedures should be carefully specified.

Of great importance in training is the capability of the instructor. An instructor should have extensive practical experience regarding the training subjects, a sound theoretical background knowledge and be able to pass on his experience in a professional way to trainees.

The steps indicated above are, as far as is relevant, also applicable to simulator training where tug assistance is simulated in another way than with interactive tugs. Also, for research projects, when tug assistance is an essential part of the study, similar steps should be taken.

8.7 Areas of tug simulation that need further attention

Simulated tugs should perform realistically with regard to type capabilities, achievable towing forces, response times and limitations. Tug simulation should be such that no tug manoeuvres can be executed that are not possible or are too dangerous in real world operations. The shortcomings of vector tugs can partly be compensated for by the participation of tug captains. For interactive tugs, which represent much more sophisticated simulation, it has been indicated what is essential from a practical point of view regarding realistic simulation. However, for further improvement of tug simulation in general, and interactive tugs in particular, the following areas need attention. Some have been mentioned previously when discussing interactions and tug safety. It depends on the simulated situation to what extent the following aspects are important. The reader is also referred to the book 'Ship Bridge Simulators. A project handbook', which addresses ship and tug simulations in detail (see References).

Tug model tests

Model testing is the only feasible method available to obtain correct hydrodynamic data for a tug hull moving through the water. It can also give a good insight into tug performance. These data are important for simulator models, particularly for escort tugs, which operate at high speeds. Some of the following can be included in the model tests.

Effect of angle of heel and trim on forces on a tug's hull and appendages

Usually the hull force data are obtained with the tug (model) constrained in the horizontal plane, i.e. no effect of heel angle and trim is present. In some dedicated tug simulator models, however, the effect of heel is taken into account through extensive model testing, or in an approximate manner. The effect of heel angle will be prominent in more extreme situations and conditions.

Photo: Marin, The Netherlands

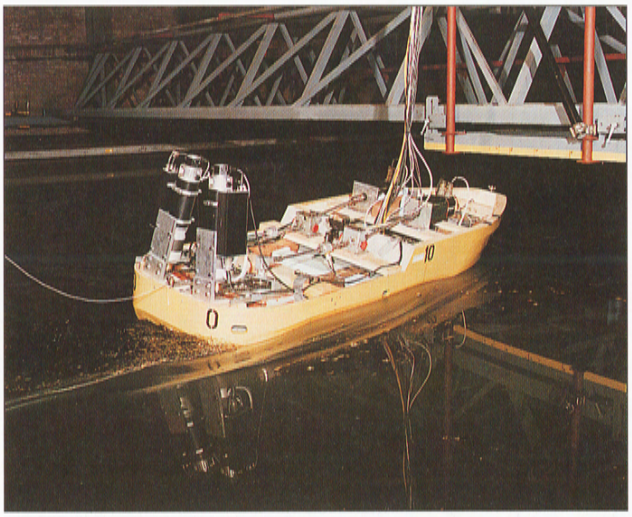


Photo: Marin, The Netherlands

Figures 8.10 and 8.11 Model and model tank test for escort tugs to obtain hydrodynamic data, optimise tug design and evaluate performance. Study by Wijsmuller Engineering / Marin

Influence of waves on tug performance

In several ports harbour tugs have to operate outside breakwaters in the open sea, as do escort tugs. Waves limit tug performance due to the high dynamic loads generated in the towline. Under such conditions tug captains often reduce power to avoid parting the towline. It is also possible to more or less control towline forces by a load reducing system. Tug motions and dynamic forces in the towline due to waves affect tug performance, which also depends on towline characteristics such as stiffness and on towline length.

Influence of flow around ship and of water depth and confinement

Water flow around a ship influences the performance of tugs pushing at a ship's side of a ship having way on, and tugs operating in a ship's wake. These effects are not included in simulator models. The effect of water depth on the hydrodynamics of a ship is included, but not the effect shallow water has on the flow around a ship and subsequently on the performance of a tug in that flow field. Furthermore, the highly complicating factor of confinement is not included in any model. Neither is the effect included of the following water flow in a channel as mentioned in section 6.2.2. Finally, the influence of the ship's propeller slipstream and wash on a tug operating near and behind a ship's stern should be considered.

Influence of a tug's propeller wash on a ship's hull

Some models incorporate an approximate method to allow for this. However, it is only valid for conditions where the propeller wash hits the hull directly. Not included are the effects of towline length and shallow water. The negative effect of tug propeller wash impinging on a ship's hull can be minimised by lengthening the towline. However, in narrow harbour basins this is rarely possible and under more extreme conditions the negative effect of propeller wash can be rather high. The very specific 'Coanda effect' (see section 5.2.5) canot be reproduced by any of the present simulator models

Towing and pushing forces

Towing and pushing forces should be as realistic for vector tugs as for interactive tugs. Full scale trials can be used to verify simulated tug forces. The better towing and pushing forces can be simulated for vector tugs, the better use can be made of these vector tugs for simulation of tug assistance.

Thruster – tug hull interaction and thruster – thruster interaction

With regard to thruster-hull interaction, some simulator models include an approximation for this, others ignore it entirely. As far as is known, thruster-thruster interactions are generally not included for tugs with nozzle propulsion.

Out-of-the window view for interactive tugs

In general, as most close quarter manoeuvres are carried out predominantly using visual cues, the importance of an all round view cannot be overemphasised. Depending on how detailed the projection on the screen is, distances off are often difficult to assess. A proper assessment of distances is essential for close quarter manoeuvring.

Visualization of towline behaviour

A tug captain reacts to a large extent to his towline, such as direction and tension. On modern simulators the towline is made visible in the out-of-window view. Towline forces are displayed on a monitor. In real life, when towing or pulling forces are required while the towline is slack, a tug captain will gently manoeuvre his tug till the line is tight and only then increase power.

Although complicated, if it were possible to visualise in the out-of-window simulator view whether the towline is slack or tight, it would be another step forward.

8.8 Conclusion

In world ports there exist an almost unlimited number of different tugs. Further, each port has its own method of providing tug assistance. This requires a very high degree of flexibility to simulate all forms of tug assistance in a realistic way. Towing on a line increases the demands on the mathematical modelling of tug behaviour, due to the combination of hydrodynamic behaviour, tug limitations, line and winch characteristics. For a correct and realistic application of tug simulations co-operation with local nautical experts is essential. By utilising the combined expertise of hydrodynamicists, pilots, tug captains and scientists, sophisticated simulations studies and training, including tug operations, can be performed.

Finally, various training methods have been discussed. Seeing the accidents that happen, the importance of a proper professional training can not be emphasized enough. Training of tug captains and also of pilots should focus not only on tug assistance and the capabilities and limitations of tugs, but also on the risks involved when tugs operate in the close vicinity of ships and when rendering assistance, while learning from the accidents that happened.

Chapter NINE

ESCORT TUGS

9.1 The background to escorting

ESCORTING BY TUGS IS NOTHING NEW. This chapter should therefore not be seen apart from the foregoing. In the past, as well as today, this kind of service has been available in many ports around the world, particularly where ports are situated along rivers and canals or behind locks. When large ships started to enter these ports they were, initially, often escorted by a number of tugs from the river entrance, or from a location where the river becomes more confined, up to the berth. Escorting is often practised in situations involving large tows like offshore rigs or ships with limited manoeuvrability due to engine or rudder trouble. It is also practised in adverse weather conditions or when a river or canal configuration or a specific situation is such that tug assistance may be required during the passage for certain categories of ships. In general, however, these escort services are limited to port areas and adjacent rivers and canals, while the type of escorting discussed in this chapter concerns mainly escorting of tankers in port approaches.

Specific attention to the escorting of tankers started in the USA around 1975. Towing company Foss Maritime, USA, began escorting tankers when it was mandated to do so by the State of Washington that year. The purpose of the legislation was to minimise the likelihood of oil spills in Puget Sound on the west coast of the USA. Tankers over 40,000 dwt had to be escorted by tugs. Tug escort of laden tankers has also been a feature of tanker operations in Prince William Sound, Alaska, since 1977.

On 24th March 1989 the *Exxon Valdez* ran aground during her outgoing passage of the Valdez Arm, Alaska, resulting in a huge oil spill. As a consequence, renewed attention was paid to escorting loaded tankers in the United States. Shortly after the *Exxon Valdez* disaster the Oil Pollution Act became law (1990) in the United States. It had taken some 15 years to formulate this act which, amongst other things, empowered the US Coast Guard to set up new regulations for tanker escort, specifically in the waters of Prince William Sound and Puget Sound.

Escorting of tankers, oil tankers and sometimes also gas tankers, is applied in many other countries, particularly in Europe, where escorting of tankers is practised in several ports with large oil and/or gas terminals. Most of such European countries will be mentioned below, and for some countries or ports also the cause that led to the introduction of escorting. In the UK the decision for escorting tankers is taken on a port-by-port basis and first escorting of tankers started on the Solent in 1991.

In Norway tanker escort became mandatory in the Grenland area in 1979 after the accident with the gas tanker *Humboldt* in the narrow approach channel to Porsgrunn on Norway's east coast in March 1979. Escorting with a special-purpose built tractor tug tethered to the ship started in 1981.

Following the sinking of the bulk carrier *Mercantile Marcia* in 1989, with a major spill of heavy bunker oil, escorting of tankers in excess of 30,000 dwt was introduced at Mongstad and Sture on Norway's west coast. In Norway escorting of tankers is now mandated by the government for port approaches of all major tanker ports. In Sweden escorting of tankers was introduced, amongst others, in the Port of Gothenburg in 1990. In Finland escorting of tankers started in the early nineties. The tragic accident of the tanker *Aegean Sea* off the Spanish coast in 1992 led to escorting of tankers in the port approach to La Coruña (Spain).

A US Coast Guard study in 1990 reported that 20% of oil entering the marine environment is caused by tanker accidents. There is a variety of other entry sources such as tanker operational losses and municipal and industrial wastes. In general, a small number of tanker accidents is responsible for most of the spillage, while the majority of tanker accidents result in negligible oil pollution.

The largest oil spill in the world was that of the *Atlantic Empress* (West Indies, 1979) with 270,000 tons of oil lost, followed by the *ABT Summer* (off Angola, 1991) with 260,000 tons, the *Castillo De Bellver* (South Africa, 1983) with 250,000 tons and the *Amoco Cadiz* (Lands End, Great

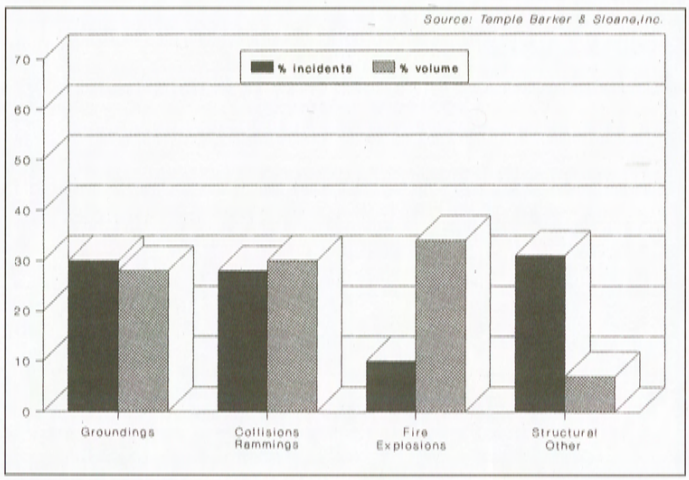


Figure 9.1 Major oil spills from tankers and their causes: No. of incidents & volume, World, 1976-89