



Latest Developments in the Use of Tug Simulation and Tug Simulation Technology

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SYNOPSIS

In 2007, the International Association of Lighthouse Authorities (IALA) produced a new guideline, *Use of Simulation as a Tool for Waterway Design and Aids to Navigation Planning*. This paper will present this guideline, and the role of tug simulation specifically mentioned within, as well as the rationale for including tug simulation. The paper will also present the latest developments in tug simulation technology, with an emphasis on the visual systems supporting simulation. In recent years, the visual systems used for simulation have increased the perceived reality, thus dramatically supporting use of this method. Projected images have also improved in terms of brightness, contrast and with the ability to produce night simulation.

New technology for projectors is now available and is beginning to be used in marine simulation. These systems, combined with the development of new visual aids, give an enhanced perception that is crucial, for example, identifying aids to navigation viewed at a realistic distance – something that has not, until now, been available for full-mission bridge simulation. The use of 3D stereoscopic views has been significantly improved and is now used to achieve enhanced reality and depth awareness for the benefit of tug simulation.

INTRODUCTION

Since 2004, Force Technology has been working with Svitzer on simulation training and port development. Combined with a general increase in the demand for more accurate and realistic tools to determine the best strategy, type, size, and number of tugs to be used for a given operation, this joint effort has driven development. Most of the developments described in this paper are based on our experience during enhancement of the DMI multi-simulator centre and the underlying mathematical models to fulfil the requirements for tug simulation.

Up until 2000, most studies were undertaken using so-called vector tugs, controlled by very simple mathematical models and a simulator operator. The advent of high-performance affordable PCs and networks made it possible to use real interactive tugs instead. Compared to the vector-tugs this dramatically improves the authenticity.

Tug simulation and hydrodynamics are strategic focus areas for Force Technology. All nine ship simulators, of which four are full-mission systems, can be coupled and used for tug simulation. The simulators' bridge layout can easily be transformed and used as tugs of various types, such as ASD, VSP, Tractor or more conventional types of vessels. Considerable development funding has been used specifically to create simulation systems, tank tests

and mathematical models supporting and improving simulation involving interactive tugs.

Today, Force Technology is experiencing an increasing demand for tug training for specific types of tugs and for advanced and accurate use of tug simulation as part of port studies. In international forums, such as the IALA, there is also an increased focus on simulation, including tug simulation. This may at first seem unusual, but as tugs are increasingly used for escorting larger and larger vessels in waterways, the design of waterways, their marking and the placement of aids to navigation will, indeed, benefit from taking tug operations into consideration.

The reason for discussing the new standard in this paper, where the subject is the latest developments within tug simulation, is to illustrate one of the important elements that shows there is an increased focus on advanced realistic simulation; and the guideline is expected to be a catalyst in demands for further developments.

STANDARDS, GUIDELINES AND RATIONALE

IALA's new guideline on use of simulation

In December 2007, IALA issued a new guideline (IALA Guideline 1058), *Use of Simulation as a Tool*

for *Waterway Design and Aids to Navigation Planning*. In general, the new guideline provides information on which simulation tools are available (fast-time, desktop, part-task, full-mission and traffic flow), how to select a specific simulation tool for a given task, and how to plan, analyse and report a simulation study.

The guideline also suggests important issues to consider regarding the capability of the simulation software and the advantages and limitations of each type of simulation tool. Finally, there is a discussion on important accuracy and versimilitude considerations. It is therefore important to understand that such studies require very accurate mathematical models for the vessels and accurate input data (bathymetry, current, waves etc) for the areas to be studied in order to be able to provide a sufficient basis for decision making.

An important part of the guideline focuses on the requirements for the personnel participating in, for example, a simulation study of a new or modified fairway where the width, layout and marking is to be evaluated and possibly changed. When going from investigations focussing on feasibility or providing overviews to actual validation of final layouts, there is an increasing need for realism and participation of experienced mariners. The guideline therefore suggests that, for final validation of a new or modified waterway or port where shipping may be required to be supported by escort tugs, a full-mission simulation system, including use of interactive tugs manned by tugmasters, should be used. (See an example of a full-mission simulation system with coupled tugs and assisted vessel in *Appendix 1*.)

The following is an important extract from the guideline addressing the interaction between simulators and experienced personnel:

“Verification of a final layout of a channel, port area or port adjustment should be studied by the use of a full-mission simulation system. Thus, compared to the smaller desktop-based simulation systems or part task simulators, the full-mission concept is preferred for validation. The full-mission simulations should have participation by local pilots, tugmasters, port authorities and other relevant subject matter experts who can contribute with expertise and practical experience in order to establish a viable foundation for decision making. The fundamental reason for emphasising the use of a full-mission system in combination with the above-mentioned participation of relevant experts is that this is the only way to ensure that technical ship handlings, as well as the important human factor elements, are sufficiently highlighted. Also, bearing in mind that the safety margins are constantly being reviewed to reduce, for example, the required channel width and under keel clearance for increasingly large ships calling at the ports. A desktop-based study using vector tugs provides a frequently over-optimistic picture of the situation in such cases.

“If a simulation service provider is involved, it is important that such providers are capable of managing the simulation studies. The simulation provider should be able to source experienced mariners and engineers. Their input should be based on professional experience while maintaining the neutrality of the simulation provider. In summary, the simulation provider should be able to provide an unbiased third party expert opinion on the subject matter.

“The full mission concept is characterised by a wide visual field for the simulators that play a vital role in the evaluation process. The use of real instrumentation and handles provide the mariners with as realistic cues as possible. In this way the conclusions and recommendations are based on a thorough review of technical aspects, as well as the important human factors (such as response times and communication).”

The essence of the above extract is that a simulator-based study should be carried out by experienced engineers and mariners, including tugmasters, with recent operational and simulator experience. The focus should be not only on the technical aspects when determining the operational limits, but also on the human factor, and that the facilities used should have a certain quality and standard.

Henk Hensen's book *Tug Use in Port* describes in more detail how to handle tugs and also includes descriptions of how simulators are used for training and port studies.

Rational requirements

During the past five years, we have seen a worldwide increase in requests for detailed studies of waterways and ports with the need for simulation of individual specific types of tugs. In addition, we note that there is an increased need for training, especially ASD tug training. In an article in *Lloyds List* on 30th November 2005, it was mentioned that, over a period of four months in 2005, the Marine Accident Investigation Branch (MAIB) had noted several incidents involving tugs. MAIB concluded that lack of training and familiarisation by the tugmaster was the reason for these incidents. MAIB therefore issued a safety bulletin highlighting the need for tugmasters to be fully trained and an assessment made to ensure that tugs and crews were suitable for each task.

The studies where we have seen a need for involving advanced tug simulation include:

- Escort operations for large VLCCs into terminals on deep channels;
- Tow-out of large new-builds from shipyards;
- Assistance with LNG carriers to and from terminals positioned offshore;
- Tug assistance in new or modified ports that will be operating larger vessels in the future, such as large LNG carriers, container vessels, cruise ships or tankers.

Obviously, if the objective is to be able to assess if the best solution for a given operation is based on ASD or VSP tugs of a given size and number, it is important that the mathematical models used are very precise and accurate. Experienced tugmasters should be involved in the validation of the models, but such checks should also be supplemented by comparing objective data from real operations and tank data with the behaviour of the simulator models.

TECHNICAL DEVELOPMENTS

Developments in the mathematical models

The mathematical models of the tugs are already very sophisticated, and further development within complex ship-ship interaction between the assisted ship and the tug has been undertaken. Likewise, the tug's performance in waves (lee effects) and when interacting with fenders in three dimensions is addressed in development programmes, as well as features linked to loss of power when operating in waves.

Improved ship-ship interaction, lee effects, fenders and 3D collision models

When the tug model approaches the hull of the assisted ship, the tug model must be affected by the pressure field generated by the assisted ship. This pressure field is very complex and varies significantly along the hull and sterns of the assisted ship according to the assisted ship's and the tug's speed and position relative to the assisted ship.

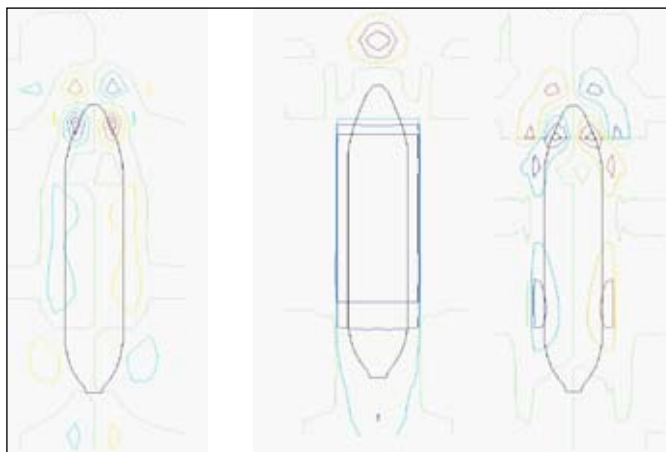


Figure 1: Example of detailed modelling of ship-ship interaction forces and moments between an assisted ship and a tug (Y-Force, X-Force, N-moment).

The resulting forces (expressed in transversal and longitudinal forces and moments) experienced by a specific tug with a given speed, hull form and displacement in a relative position to an assisted specific ship with a given speed, hull form and displacement are shown in Figure 8. It can therefore be illustrated that it is possible to simulate the complex pressure conditions affecting a given tug when approaching another ship. This, of course, has a significant effect on the verisimilitude of the simulations.

A range of tug simulator development activities are performed in the EU FP6 integrated project EFFORTS (Effective Operations in Ports). These include the development of a real-time CFD solution of the ship-ship interaction, the implementation of movable wind, wave and current lee zones around the assisted ship, a full 3D collision detection and fender module, and the incorporation of wave effects on the propeller efficiency and, thus, bollard pull. The test and implementation of stereo view facilities were also performed under the EFFORTS project.

Some of the effects developed are particularly important for offshore applications, eg for studies of shiphandling at offshore LNG terminals. In these situations, wave action is an important factor influencing the tug operation.

Traditional fender action between the tug and the assisted ship has only taken account of the push force and longitudinal friction force. In waves 2m to 3m high, which are not unusual at these terminals, the vertical fender force becomes important for the tug motion and possible fender damage. The newly developed fender module calculates these forces and takes into consideration the various means to reduce fender damage, eg water lubrication of the fender to reduce the vertical forces. Another feature of the new module is that it detects contact between the tug and assisted ship even when this is not on the fender, say if the bridge house of the tug hits the overhanging bow or stern of the assisted ship.

A large assisted ship influences the wind, wave and current field around the ship hull, and when a relatively small tug is sheltered from the environmental effects from the assisted ship, it is important for the reality of the exercise that this effect is captured by the simulation. It is implemented in the simulator as overlaid lee zones for the different effects modifying the ambient environmental conditions as function of assisted ship size, water depth, relative directions of wind, current and waves, and taking account of the wave diffraction around the assisted ship's hull. Wind and current lee is determined by numerous wind tunnel tests.

Force Technology has performed a large number of towing tank tests of tugs, many of which include the bollard pull performance in waves. All the data gathered from these tests, as well as data from the available literature, has been implemented in a simulator module which calculates the effect of wave height, period and relative direction on the effective bollard pull. In the present module, this is expressed as a "macro" effect, ie a gross overall reduction or increase of the bollard pull due to the wave effect. A more advanced method, taking into consideration the "micro" effects, ie the water particle velocity and direction of the propellers, is being considered.

Finally, an additional activity of the EFFORTS project is the development of a realistic simulator model of the rotor tug, including the interaction between the three azimuth thrusters. It is not considered possible to develop a realistic model of this particular tug type if this interaction

effect is not adequately incorporated. Modelling this tug is a good example of the versatility and applicability of ship modelling, based on first principle physics: the physics of all the effects modelled has to be understood in order to be adequately modelled and authentically tuned.

Visual out-of-the-window system

For smaller ships such as tugs, visual perception is a particularly important part of handling the vessel, just as in real life. Distances, bearings, speed, turn rate, tow force, propeller thrusts are all parameters that for a small vessel are picked up using visual perception. Improved visual realism and the use of new technology for enhancing the visual are therefore important, in particular for tug simulation.

Innovations in this field have been developed and tested at FORCE Technology as follows:

Stereoscopic display systems

The human visual perception of depth is better close to than at longer distances. When a small tug is near to the vessel that needs assistance, visual depth perception is useful and possible. In order to replicate this in a simulator, a stereoscopic display system can be used.

Over the last two years, two technologically different systems have been tested and initiated: the head-mounted display (HMD) and the projector based.

HMDs are available within a wide price range, say from US\$1,500 to US\$150,000. The Visette45, developed by CyberMind, NL, has an affordable price tag of about US\$15,000. It has a resolution of 2 x 1,280 x 1,024 pixels with a field of view of 45 degrees. The helmet purchase included a 3DOF tracking device, InertiaCube by InterSense. This provides a full 360 degree field of view, even from a small tug cubicle with one stereo-enabled visual channel (see *Figure 2*). The helmet is the transparent version where both the CGI, the real manoeuvring controls, winch controls and other navigation displays, such as radar screens and ECDIS, can be viewed at the same time. It weighs approximately 800g, including the tracking device, which is possibly close to the limit for acceptable wear during longer periods of simulation. At FT two additional Visettes will be operational in spring 2009 for use in real engineering waterway design. Visette HMDs, with wider fields of view of around 70 degrees, will soon become available. The increased field of view is expected to dramatically improve realism and fidelity as the 45 degree field of view is a little too small.



Figure 2: The Visette45 3D lightweight HMD with transparent stereoscopic projector system.

During the investigation of which stereoscopic projector system to acquire, two passive systems were tested: a polarised and a frequency filter-based system. Both these types introduce some distortion in colour. With a polarised system, ghosting also occurs if the head is tilted and special non-depolarising screens must be used.

A one-channel system was tried in depth, using actual tug captains. The system is based on the INFITEC system built into two F30 projectors by projection design. Having two separate projectors, alignment and identical optics are of paramount importance. Recently, projection design released an interesting single projector-based active system, using the F20 model as basis, and which eliminates the alignment, separate colour adjustment and optics problems.



Figure 3: 3D INFITEC glasses.

Comparison

There are pros and cons for both systems. The helmet requires some adaptation, but the picture is very sharp and clear, and with the efficient tracker system it is possible to see instantly in any direction with 45 degrees field of view. In the near future, the field of view will be expanded to 70 degrees. When increasing the field of view the challenge will be to keep the weight down. The existing systems could benefit from mounting a support strap across the head of the user.

The system where the operator uses glasses has the advantage of the relatively light weight of the glasses compared to the helmet, but the quality of the picture is lower, the field of view is restricted to the amount of screens, and it requires an effort in fine-tuning and aligning adjacent projected images. It is possible to wear spectacles when using both systems. It is our view that a Visette45 HMD with tracking is superior to a fixed one-channel stereoscopic projection system with 45 degree field of view.

Projectors for visual systems display

Over the years, there has been continual developments in affordable projection systems aimed at providing bright pictures with high contrast for day, as well as night projection. Digital light processing (DLP) technology was developed by Texas

Instruments Technology and has been in use for many years now. It is a technique whereby the light produced by a bulb is transferred to a number of micro mirrors embedded in a chip. Each mirror represents a pixel and can tilt slightly, which has an impact on the contrast performance.

A single-chip projector alternates between colours and produces separate red, green, and blue images. In a projector with a single DLP chip, colours are produced either by placing a colour wheel between the lamp and the DLP chip or by using individual light sources to produce the primary colours. Compared to the previous system it provides a much better level of contrast. A three-chip DLP projector uses a prism to split light from the lamp, and each primary colour of light is routed to its own DLP chip, then recombined and routed out through the lens. Three-chip systems are found in higher-end projectors. According to DLP.com, the three-chip projectors used in cinemas can produce 35 trillion colours, which many suggest is more than the human eye can detect. The human eye is believed to be able to detect around 16 million colours, which is theoretically possible with the single-chip solution.

For both single and three-chip systems the resolution has been increasing and has reached WUXGA, ie 1,920 x 1,200 pixels. The rationale for selecting three-chip projectors for the simulators at Force Technology was primarily that we experienced a better contrast during night simulation making navigational lights more visible and at greater and more realistic distances.

With the new projection systems, it is possible to identify aids to navigation, such as buoys, navigational lights on buoys and lighthouses, and leading lights, from further away. With an eye height of, say, 4m or more, and in clear weather and a calm sea, it is usually (depending on the background) possible to identify a normal 3m red or green buoy without binoculars at a distance of 3nm. With the old three-tube projectors, it was possible to see such buoys within 0.5nm. With the single-chip DLP projectors, this distance was increased to up to 1.5nm with new lamps. With the three-chip systems, we are now coming closer to the 3nm.

For the one-chip projectors of type F30 that are also used on some bridges and where the contrast ratio is not as good as for three-chip models, the motor-driven iris can significantly improve the contrast required for night vision. The iris is controlled through the network interface and interfaced to the SimFlex Navigator system.

With time changes during simulation, the iris is opened and closed accordingly. This is obviously a very important issue, especially for pilots, but also for tugs involved in channel simulations, as they are dependent on the awareness of the pilot as to location and need to be able to support the pilot with accurate navigational information based on visual observations made from the tugboat.

Visual system software – BridgeView

As an additional feature to increase accuracy, Force Technology has launched a new visual system – BridgeView (see Figure 4).

Directional spread wave driven by wind and swell, mooring lines, anchors, propeller wash and details on the ships will support the tugmaster's perception of the situation, including distances and depth. It is important to note that the same representation of the ocean waves, using up to 4,225 spectral components, is used for the motion calculation in the mathematical model – DEN-Mark I.



Figure 4: Example of the new visual system.

The following images illustrate some of the features of the visual system:



Buoys: Standard IALA or specific modelled navigation buoys are moving realistically in the seaway.



Reflections: The amount of reflection in the ocean is a function of sea state and roughness.



Animations: Radar antennas, bow visors, winches are animated when operated either by the instructor or the trainees.



Navigation lights: Flashing or fixed lights on ships and buoys are rendered with a glare. Lights have correct visibility according to COLREG.



Visibility: Reduced visibility owing to fog and rain is easily introduced by the instructor.



Lines: Moorings lines to shore and to other ships, such as with assisting tugs, are shown. The line is textured and indicates if tight or slack.



Propeller wash: The direction and thrusting state of propellers, thrusters, etc are important cues for tug operations.



Binocular and crosshair: A magnified view is available, including a crosshair for taking bearings.



Search and deck lights: At night the scene is lit by search and deck lights. Lights can be turned on and off and direction controlled as for searchlights.



Sun glare and trace: When looking in the direction of the sun, a trace is rendered in the ocean. Also, sporadic spots of glare are modelled.



Rain, snow etc: Isolated precipitation is consistent with that on the radar.



Ship's wake: The ship's wake is seen in the ocean. Close to, this provides information about ship speed and turning.



Flags and signals: Flags are animated according to relative wind speed and direction.



Ocean waves: Realistic 3D ocean waves are modelled identically in the mathematical mode DEN-Mark 1 and in BridgeView.



Sky and clouds: The overall weather condition is set by the instructor.

Warping and blending

As described above, affordable projectors providing increased quality are now available. However, cutting cost is always of interest, and the warping and blending (or W&B) forms a significant part of the total visual projection system. W&B is required in order to produce a seamless image projected on to a non-planar screen from any position.

The W&B can be made at three different places in the image processing pipeline:

- In the projector;
- In a separate box placed between the projector and the IG;
- In the GPU placed in the IG.

These three options are shown in Figure 5 below.

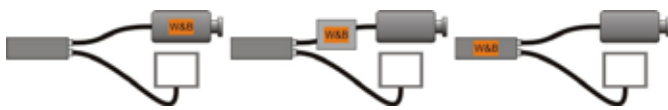


Figure 5: Warping and blending processing in the pipeline.

Force Technology decided to develop a GPU-based solution in SimFlex Navigator, when upgrading the four main bridges with new projectors. Significant costs were saved as the W&B image processing is performed in the same GPU that generates the image, and is already available.

The SimFlex Navigator W&B solution include two elements:

- Aneeditortodesign,configureandmanipulatetheW&B;
- The real W&B image processing module in the Visual System software

The W&B editor is used to:

- Configure a projection theatre;
- Generate and manipulate warping;
- Generate and manipulate blending geometry and decay function using a Chroma Meter;
- Colour match projectors using a Chroma Meter.

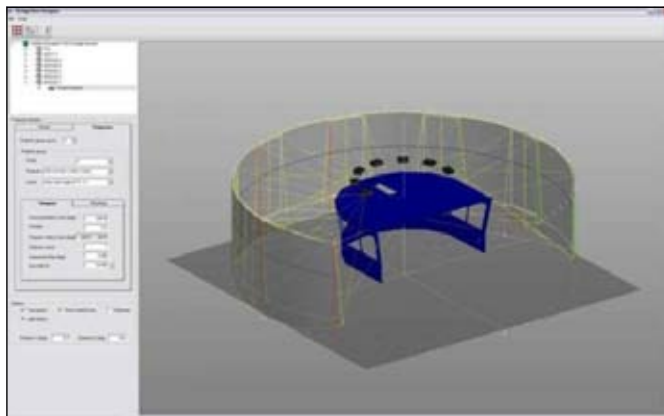


Figure 6: BridgeView setup – the main interface for projection system configuration.

In the BridgeView runtime software the W&B image processing is made as a post-rendering effect in a pixel-shader.

A new compact tug simulator using flat-screen technology

Figure 9 shows a new compact tug simulator where 27 52in flat screens with full HD resolution arranged in a 360 degree cylindrical array have been used to provide a very large field of view, including the full horizon. Modern PCs and GPUs (graphic cards) are so powerful that one PC and GPU can drive two monitors. This means that 15 PCs can drive the visual system at this bridge. However, this required a modification in the visual software. In the PC, the image for the two monitors is one coherent image of 1,920 x 2,160 pixel resolution. Before sending the image to the two monitors, corrections for the blind area occupied by the monitor frame at the top and bottom must be made. This Bezel correction is a special case of the general warping methodology built into the new visual software – BridgeView.

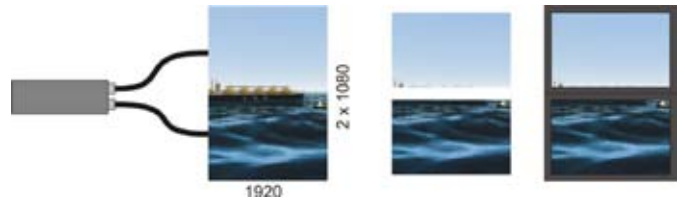


Figure 7: Bezel correction using warping technology.

When the vertical field of view is not symmetrical around the horizontal it needs to be able to tilt the image plane in the visual software (see Figure 8).

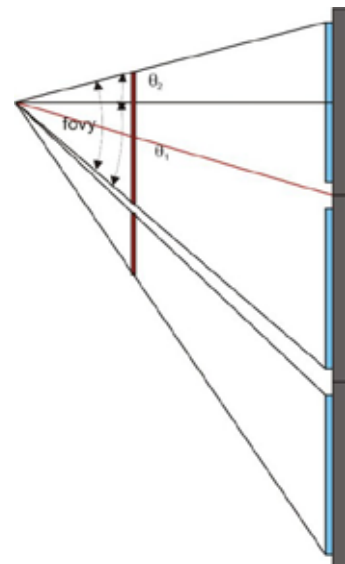


Figure 8: Tilted image plane for unsymmetrical vertical FOV.

The simulator is configured for operation of both ASD and VSP tugs and includes a vast selection of handles, winch and engine controls and instruments, including overhead panels.



Instrument console when looking forward.



Looking aft

Looking forward

Figure 9: Photos from the 360 degree FOV compact tug simulator using flat-screen HD technology.

The two pictures in Figure 9 illustrate how well the large horizontal and vertical fields of view support the tugmaster by providing a real sense of the position and alignment of the tug when, for example, operating close to the assisted vessel. This feature, as well as the very clear and realistic visual system, has been extremely well received by the mariners.

CASE STUDY

Waterway design

The two figures below show real photos, screen shots and track plots taken during the tow out of a large container vessel. Up to six tugs were used for the operation. The objective of the study was to investigate the required increase in channel width and placement of aids to navigation.



Figure 10: The real and simulated tow out operation.



Figure 11: Track plots from study (also shown in Figure 1).

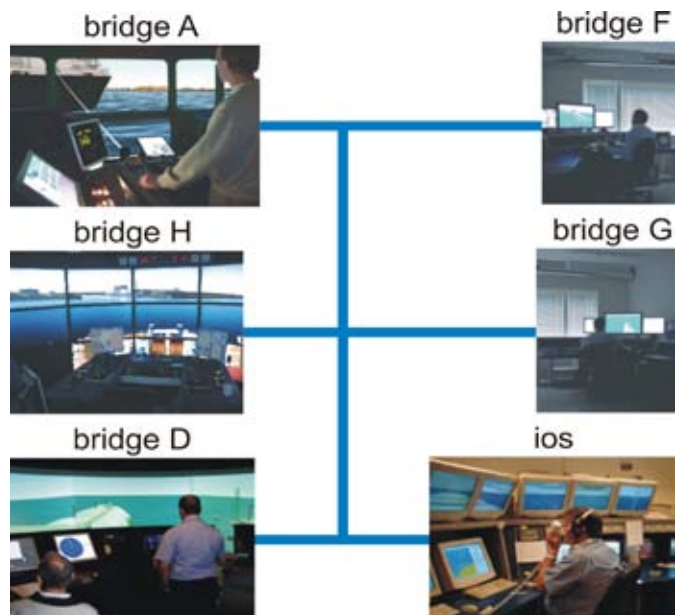
CONCLUSION

There is increased focus on the use of tug simulation for training and engineering projects from all sides of the industry, including international forums such as IALA. In line with this increase in interest, the tug simulation systems and tug modelling features are continuously being enhanced. This includes the visual systems and projection systems that are aimed at increasing realism by providing systems that support an increase in depth perception.

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APPENDIX 1



Conceptual display of full-mission tug simulator set-up.