Intuitive operation and pilot training when using marine azimuthing control devices

AZIPILOT

Report Title:

Deliverable 2.8:

Implement obtained knowledge in development plan

Contents

Publishable Executive Summary

The aim of this task is to implement the knowledge obtained within the study into the development plans of Marine Simulation. The objective is to use the information obtained throughout the project to make recommendations for the improvement of the technology and the Marine Simulation industry as a whole; specifically when dealing with ships equipped with azimuthing control devices. The main areas are:

- Implementation of guidelines for the selection of appropriate models for the marine simulation of ships equipped with azimuthing control devices.
- Recommendations of best practices for standardised layout.
- Recommendations of best practices for augmentation of systems for standardised response
- Identification of guidelines for bridge systems selection.
- Identifications of best practice for system operations.

The report identifies best practice for standardised lay-out and possible improvement of improvement of simulators for two types of simulators:

- Full Mission Bridge Simulators, (FMBS); and
- Manned Models Simulators (MMS).

Introduction

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- Identification of guidelines for bridge systems selection.
- Identifications of best practice for system operations.

1. Implementation of guidelines for the selection of appropriate models for the marine simulation of ships equipped with azimuthing control devices

1.1. General

In general, simulators may refer to either the equipment or the situation. A simulator is defined as any system used as a representation of real working conditions to enable trainees to acquire and practice skills, knowledge and attitudes. A simulator is thus characterised by the following:

- Imitation of a real situation and/or equipment which may permit, for training purposes, the deliberate omission of some aspects of the equipment in operation being simulated; and
- User capability to control aspects of the operation being simulated.

Simulation of ship manoeuvring performance, specifically handling of ships equipped with azimuthing control devices could be accomplished using two types of simulators:

- Full Mission Bridge Simulators, (FMBS); and
- Manned Models Simulators (MMS).

The recommendations regarding ship handling simulators of both types, in particular regarding handling ships equipped with azimuthing control devices include:

- Visual data base of simulation scenario with relevant current, wind, wave and channel effects;
- Visual data base of the ship itself.

Hydrodynamic and simulation modelling of ship manoeuvres including realistic and accurate simulation of characteristics of podded propulsors, especially:

- The interaction between two or more propulsion units and interaction between propulsion units and ship hull and appendages.
- The interaction between manoeuvring ship and different environmental conditions, external forces and factors affecting ship manoeuvrability and including interaction effects between ships, ships and other objects and tugs action.
- The capabilities of existing simulators to simulate the above effects were discussed in detail, in the AZIPILOT PROJECT reports on task 2.2, 2.3 and 2.6 (references 1 to 8) showing how these recommendations were implemented.

Realistic simulation requires adequate modelling capability verified with full scale data and pilot handling validation. There are three alternatives to evaluate hydrodynamic forces on vessels equipped with azimuthing devices:

- Directly from model tests;
- Indirectly from various semi-empirical approaches as synthesis of experimental, statistical and analytical methods;
- Indirectly from full-scale trials by applying system identification techniques. System identification could serve as validation base for model tests and computer predictions because it provides proper modelling of viscous damping forces.

The following report summarises the hydrodynamic of simulation modelling aspects, assuming that problem of visualisation is a matter of development of computer technology that is outside of the scope of this study.

1.2. Characteristics of FMBS and MMS

1.2.1. Full Mission Bridge Simulators

Full Mission Bridge Simulators (FMBS) are controlled by computers and computer codes used are based on mathematical models of ship manoeuvring motion. FMB simulators are working in the real time and consist of a mock-up of the ship bridge with all equipment and normally with the simulated view of the environment. There are many different models of this type of simulator operating throughout the world, starting from simple desk simulators up to very advanced and sophisticated models. The most advanced simulators of this type are provided with several control desks, with full 360 degree view of the environment and with ship vibrations, ship rolling and pitching motions and engine noise produced. There are hundreds of FMBS of different models in operation throughout the world.

FMB simulators are widely used for training of ship officers, pilots and students of marine schools and also for studying various manoeuvring problems, first of all problems associated with the design of ports and harbours. The trainee is placed inside a bridge mock-up with actual bridge equipment, realistic visual scene, and sometimes rolling and pitching motions and engine noise. The capability of these simulators depends on the quality of the mathematical model used and of the computer code based on this model.

As stated, in FMBS, because there is a mathematical model of ship motions on which computer codes are based it is important that the mathematical model used represents properly behaviour of the real ship. The theory of ship manoeuvrability is, however, at present far from perfect.

The most useful mathematical model of ship manoeuvrability is the so called modular model, which takes account action of various hydrodynamic forces acting on hull, rudder, propeller and thruster separately. These forces are expressed by hydrodynamic coefficients included in the equations of motions. External effects, such as wind, restricted water, proximity of banks etc. could also be included. Hydrodynamic coefficients in curvilinear motion could be estimated directly based on model experiments in a towing tank equipped with planar motion mechanism - PMM or indirectly by system identification procedure that consists of measurements of input and output data of free-running models or full scale ships. Both methods are expensive and time consuming and, moreover, indirect identification is rather difficult because of great accuracy of measurements required. Hydrodynamic coefficients could also be calculated by different methods such as theory of slender body, lifting line theory, panel method or most advanced method of finite volumetric elements and Navier-Stokes equations (e.g. reference 20).

Unfortunately, because of extremely complicated flow phenomena around the manoeuvring ship, application of theoretical methods available cannot provide accurate results. With a ship in ahead motion and not to large deviations from the original course the numerical methods provide results which in many cases are within an acceptable 20% error in estimation of tactical diameter or overshoot angles in comparison with results of model tests or ship trials. However, when the ship is manoeuvring using often ahead and astern engine and rudder, and perhaps also thrusters at the same time and if manoeuvres are performed in the vicinity of piers or quays, in docks or in proximity of other manoeuvring ships, these methods are not accurate enough. In order to achieve accurate prediction of such manoeuvres it would be necessary to know propeller and rudder characteristics in four quadrants and those could be estimated only on the basis of elaborate model tests which are exceptionally difficult and rarely performed. Moreover, the proper mathematical simulation of rapidly changing flow patterns around the ship hull, propeller and rudder, taking into account external restrictions such as shallow water and bank effects where hydrodynamic memory effects must also be included, is not possible.

As FMBS are working "online" there is no possibility to use very sophisticated computer programmes which include calculations of hydrodynamic coefficients using advanced methods where computer time is quite long, the mathematical models used must be comparatively simple, and this is the primary reason behind the gap between reality and simulated situation. This happens mostly when harbour manoeuvres, manoeuvres in shallow water or in the canal or in proximity of other ships or objects are performed. This was shown by Gronarz (Reference 2). But sometimes even simple manoeuvres such as turning circle manoeuvre or zig-zag manoeuvre are often simulated inaccurately. Gofman (References 6, 7) showed several cases where results of simulation on FMB simulator differed considerably from results obtained during tests of full-scale ships.

1.2.2. Manned Models Simulators (MMS)

In MMS manned self-propelled scale models are used for training purposes in open water areas. Models are sufficiently large in order to accommodate 2-4 people (students and instructors) and are constructed according to laws of similitude. This means that not only geometry of the ship hull is properly reproduced according to chosen scale, but also dynamic characteristics of the ship such as speed, centre of mass and mass moments of inertia are correctly reproduced in the model. Also characteristics of the propeller (thrust, revolutions) rudder engine (time from hard over to hard over) and main engine (power, time of reversing etc.) are reproduced to scale. Models are fitted with anchors, thrusters and tug simulators where appropriate. Models are controlled by the helmsman and manoeuvred in scale mock-ups of ports and harbours, locks, canals, bridges piers and quays. Shallow water areas and other facilities are constructed and where also routes marked by leading marks or lights (for night exercises) are laid out all in the same reduced scale as the models. Current may also be generated.

In the case of manned models the governing law of similitude is Froude's law and all quantities for models are calculated according to the requirements of this law. This means also that all hydrodynamic forces acting on the ship are properly reproduced in the model scale. This applies to:

- hydrodynamic forces acting on the underwater part of the ship hull
- propulsion forces (propeller thrust and torque)
- controlling forces (rudder force, azimuthing propeller thrust)
- external pulling or pushing forces exerted by tugs
- inertia forces
- forces exerted by current

However, as it is well known that the requirements of second law of similitude relevant to ship motion, Reynolds law, cannot be met. This means that the flow around the ship hull and appendages and in particular separation phenomena might be not reproduced correctly in the model scale. Fortunately those effects are important when the models are small. With models 8 to 15 m long, as they are usually used in MMS, the Reynolds number is sufficiently high for substantially reducing or even avoiding such effects.

An important feature of manned model exercises is that all manoeuvres are performed not in real time, but in model time which is, according to Froude's law of similitude, accelerated by the factor λ^{-1}. This may pose some difficulties for trainees at the beginning who must adjust to the accelerated time scale. However the accelerated time scale has no impact on the simulation of manoeuvres themselves.

1.3 Simulation of interaction effects between multiple azimuthing propulsion devices

1.3.1. General

Important considerations in simulation of manoeuvrability of ships equipped with azimuthing propulsion devices are the interaction effects between multiple pod propellers and the interaction between pods and ship hull (this problem was discussed in references 1, 2, 7 and 8).

The survey of available sources shows that interaction between two or more podded propulsors is important and it may affect manoeuvring characteristics in certain modes of control and in certain situations considerably. Strong interaction may be expected when one pod is working in the propeller slipstream of the other one and this is affecting considerably the thrust and torque of the pod.

When working in the cruise mode strong effects may be present when pods are deflected to angles between about 60 to 120 degrees both sides. Similarly when pods are working in manoeuvring modes one may expect strong interactions if one pod get into propeller slipstream of the other. This is the case with pods fitted with pulling propellers as well as fitted with pushing propellers. The form of the stern part of the hull affects the interaction; in particular interaction effect may be different if at the stern of the ship one long skeg or fin is fitted that may distort propeller slipstream (reference 7).

1.3.2. FMB Simulators

In mathematical models used as a basis for computer codes governing FMBS the effects of interaction between multiple azimuthing propulsion devices and between azimuthing devices and ship hull should be taken into account. This could be done utilising experimental data from model tests in towing tanks, theoretical considerations, or approximate methods.

Search for theoretical methods and experimental data related to the interaction effects between multiple pods brought little results. There are very few publications providing experimental data, and few publications investigating these effects from the theoretical point of view. Generally there is lack of theoretical studied and experimental data regarding interaction effects between azimuthing propulsion devices, some experimental data are available on interaction between pods and ship hull, in particular with regard to the effect of fins and skegs.

Some indication how one pod is affecting the other one may be seen from tests performed by Grygorowicz and Szantyr (reference 12).

Tests were performed using large manned model of a gas carrier fitted with two podded propulsors having tractor type arrangement (pulling propellers) Measurements were taken when pods were working in the cruise mode. Forces and moments were measured on the pod axis. Measurements were taken on one POD during circle test manoeuvre with different angles of rudder to both sides. Measurements were taken on first the inside, then the outside, pod during circle tests. It was shown that with large angles of rudder the outside pod is strongly affecting the inside one.

More data is available on the interaction between pods and the ship hull, in particular on the effect of skegs and fins. It appears that skegs and fins affect manoeuvrability considerably, first of all their effect is most visible on dynamic stability. There is general tendency that ships equipped with one pod are dynamically unstable, the same happens with ships equipped with two pods, but without skegs or fins, or with small fins installed. Installation of skegs and fins improves dynamic stability, however making turning ability characteristics slightly worse. How this effect is taken into account in mathematical models is not certain, but some data from experiments with ship model tested without skegs or fins or with skegs or fins of different size installed are available and may be used (see: reference 11)

Data on wake and form coefficients for ships with podded propulsors cannot be found in publications, but certainly such data are available as a result of model tests performed in towing tanks when testing ship models for shipyards. Some information on how to assess wake coefficients for podded propulsion is given in the report by ITTC (Reference 10).Whether the method recommended by ITTC is used in computer codes controlling simulator is, however, not certain. Many FMBS claim that the effect of interaction between multiple pods or pods and ship hull are taken into account in the computer codes used in simulation of manoeuvrability of ships equipped with azimuthing control devices. This was pointed out by Ankudinov et al Reference 2). For example, simplified methods of taking account of this effect was used in simulation program ANS 5000 (de Mello Petey Reference 9) used in Warnemuende FMBS. The simulation module ANS 5000 developed by Rheimetall Defence Electronics GmbH, Bremen, simulating manoeuvring capabilities of pod driven ships takes into account the following:

- Propeller thrust
- Transverse propeller force
- Lift and drag forces of the pod body
- Interaction effects between different pod units
- Interaction effects between pod and hull, and
- Shallow water effects

The method of taking account of interaction effects between two pod units and between pod and the ship hull is described by de Mello Petey (reference 9). The method of taking account of shallow water used in the simulation module referred to above is not known. The results of simulation were validated by sea trials of the German pollution control ship ARKONA that took place in Baltic Sea in November 2005. The results of several tests performed with this ship were compared with simulated manoeuvres revealing satisfactory agreement (references 2, 3 and 9). The other example is the method used to simulate azimuthing propulsion devices in PC Rembrandt (Reference 1 and 2). The model used has been designed to be generic in both mathematical and programming sense to allow its application to a wide range of ship and stern configurations. The methods have been programmed to allow them to be applied to propellers, rudders and azimuthing propellers where applicable. The modelling may be split roughly into three sections:

- Estimating the influence of other pod wake on the inflow velocity and angle of attack
- Estimating the pod inflow velocities and angle of attack
- Estimating pod forces on the ship

Reference 1 described principles of simplified semi-empirical method that takes into account the interaction effects applied in FMBS run by Transas Ltd. and by some other FMBSs. In the simulation program local surge and sway velocities are obtained by adding the velocity of the propeller race to the local forward and lateral velocities due to ship motion. The velocity of propeller race is modelled in the simplified manner as a jet flow the direction of which is opposite to the thrust generated by pod.

These are examples of the current best practice in simulating manoeuvring of ships equipped with azimuthing propulsion devices there is no information available on whether other FBMS use similar methods, but it is supposed that at least some of them take into account the effect of interaction of multiple pod drives, however it is not known how.

There is no information available whether FMBS take into account interaction effects between pod drives and ship hull when simulating manoeuvrability of ships equipped with azimuthing control devices. This effect is, however, included in all standard procedures with interaction coefficients (wake, thrust deduction) taken from self-propulsion model tests in towing tanks, it may be assumed that all advanced FBMS include this effect in their procedures for ships with azimuthing propellers as well.

1.3.3. MM Simulators

In MM simulators, because large manned self-propelled models are used, interaction effects between multiple pod drives and between pod drives and the ship hull are automatically taken into account. There is however, the problem of Reynolds Number that is as a rule smaller than for the real ship. The possible scale effect that may be present with self –propelled ship models is little investigated. With propellers of small diameter there is possibility that in propeller blades laminar flow may occur if Reynolds number is in the sub-critical region. According to the recommendation by ITTC (International Towing Tank Conference) the propeller diameter should be not smaller than 20cm. This, however, applies to the tests performed with free-running propellers (without ship hull) in towing tanks or cavitation tunnels. With self-propelled models the propeller works in the flow distorted by the ship hull that is highly turbulent. In manoeuvrability tests the flow is even more turbulent in particular when tests are performed in open waters. In consequence in such tests even with smaller propellers the flow around propeller blades would be turbulent.

One important difficulty with manned models is impossibility to reproduce wind effect. Wind is a natural phenomenon and according to laws of similitude wind force should be reduced by factor λ^3 (λ - model scale). Taking into account that windage area of the model is, because of geometrical similitude, reduced proportional to λ^2, the wind force is too large proportionally to λ. There are attempts to reduce wind force in model scale by reducing windage area in comparison with full-scale ship and also by choosing sheltered area for exercises therefore reducing the wind velocity at the model, but even so, the wind force is usually too large.

When manned models are used they as a rule must be quite large in order to accommodate two or more people. Model scale λ=24 or λ=25 is used as a rule. With such models 5m diameter real propeller would have 20cm diameter, but in larger ships the propeller diameter is larger. Also models are manoeuvring in open waters with high natural level of turbulence, therefore there is no danger of laminar flow occurring on propeller blades.

In some cases models of very large ships (large container vessel or VLCC tankers) could be built using smaller relative scale (e.g. λ=40) and still be able to accommodate people. This may, however, cause the propeller diameter to be too small, and therefore this arrangement is not recommended.

1.4. Simulation of the effect of environment and external forces and factors

1.4.1. General

Effectiveness of simulators depends also on the correct simulation of environmental conditions and external forces and factors affecting ship manoeuvrability.

The different environmental conditions and external forces and factors affecting ship manoeuvrability that are recommended to be simulated are:

- shallow water effect
- bank effects
- surface and submerged channel effects
- soft-bottom and mud
- steering with azimuthing control devices when towing
- steering with azimuthing control devices when under tow
- issues associated with assisted braking including the indirect mode
- issues related to tugs operating near the stern of pod driven ship
- issues related to ship-to-ship interaction.

The above factors and their effect on ship manoeuvrability are discussed by Ankudinov et al and by Kobylinski (References 2 and 7). The main conclusions are as follows.

1.4.2. FMB Simulators

As FMBs are controlled by computer codes based on mathematical models, the most important problem is development of appropriate mathematical models of the impact of the above effects on ship behaviour under different conditions.

With regard to the shallow water, bank and channel effects and the effect of ship to ship interaction the survey shows that there is a number of experimental data on these effects available (e.g. references 7, 14 and 17), but almost all of them are applicable to ships with conventional propulsion devices However, it is considered that the main physical reason that those effects are present is deformation of the pressure field around the ship hull by the proximity of the bank or bottom or by the limitation of the cross-section of the canal, this effect must be not very different for ships equipped with conventional or azimuthing propulsion devices unless those devices are not deflected to large angles. Therefore as the first approximation data for conventional ships may be used also for ships equipped with azimuthing propulsion devices. Data on the effect of shallow water on manoeuvring characteristics of pod driven ships based on model tests or on tests of full-scale ships were not found, but there are available some data based on simulation. Ankudinov (reference 1 and 3) shows comparison of basic manoeuvring parameters for four pod driven cruise liners in deep and shallow water simulated by TRANSAS (Queen Mary 2, Radiance of the Seas, Lirica and Voyager of the Seas).

Comparison of the results achieved by simulation for deep and shallow water reveals that in all cases except for one case of Queen Mary 2 ship, the turning circle characteristics for 35 deg rudder (advance, transfer and tactical diameter) in shallow water is actually larger than in deep water which is in agreement with the theoretical considerations. In the case of Queen Mary 2 the simulation shows that they are smaller. This is in contradiction to the general rule that turning characteristics in shallow water are worse than in deep water. The reason for this discrepancy is not clear and impossible to explain, because only simulation data are available and they cannot be compared with results of full scale or model tests.

The large discrepancy in results of simulated zig-zag tests for the ship Lirica by TRANSAS and MIT was also discovered. In general, however, the overshoot angles in zig-zag simulation tests in shallow water are larger than in deep water which is in accordance with the general rule that course keeping ability in shallow water is worse than in deep water. This rule may be then equally applicable with regard to ships with conventional propulsion as well as to pod driven ships.

In simulation of manoeuvring characteristics of a ship in shallow water the effect of UKC is mostly taken into account by adding suitable coefficients to the set of hydrodynamic derivatives valid for deep water.

Gronarz (reference 5, see also reference 6) provided data on simulation of the effect of shallow water in four advanced FMB simulators. The conclusions drawn from comparison of the results of simulation are as follows:

- All special hydrodynamic effects are covered from the simulators investigated.
- The magnitude of the effects is sometimes very different.
- The expectations from theory are satisfied mostly.
- The development of the shallow water effect with decreasing water depth is not always modelled correctly.
- The magnitude of the bank effect is very different on the two simulators investigated.
- The ship-ship-interaction effect shows reasonable development with the passing distance but some doubtful results during the time of the manoeuvre.

There is currently no information whether simulation of steering with azimuthing control devices when towing and steering with azimuthing control devices when under tow is possible. Several FMB simulator facilities claim that they are capable of simulating escorting operations with azimuthing propelled tugs. Issues associated with assisted braking including the indirect mode and issues related to tugs operating near the stern of pod driven ship are considered in the simulation process (references 3 and 4).

Several FMB simulators made attempt to simulate effect of ship-to-ship situation (References 3 and 6). There are also available results of computer simulation of this effect and some experimental data (e.g. reference 18). The accuracy of prediction and simulation of the interaction of two ships meeting or overtaking each other at close distance especially ships equipped with azimuthing control devices and in shallow water areas or in canals is not certain. As far as it is known effect of muddy bottom on manoeuvrability is not taken into account in any simulator, although there available few studied of this effect (e.g. references 13 and 19).

1.4.3. MM simulators

In the training centres using manned models (MMS), models perform manoeuvres in open water areas (ponds, lakes) where situations simulating influencing different factors that affect ships discussed in the Part 1 of this report are physically created. They include shallow water areas, banks, fairways, canals of restricted and different cross sections, docks, locks, harbour basins, river estuaries with current created and other artificially prepared situations. Interaction effects between two or more ships, escorting operations, towing operation and tug work in general could also be easily simulated.

When using manned models there is no need to develop mathematical algorithms representing effect of environmental factors or hydrodynamic force components representing interaction effect. Those are simulated automatically because they depend mainly on pressure distribution around the ship body that, in turn, is simulated properly if Froude's law of similitude is used, which is the case in model work. The proper simulation depends therefore on the exact scaling down external limitations, i.e. harbour basins, canals, shallow water, banks etc.

Both Port Revel and Ilawa training centres claim that they are capable of simulating the majority of such situations using models of conventional ships and models of pod driven ships that are available in both centres. Basic data on models of pod driven ships in both centres are also available (references 1 and 8).

In order to simulate shallow water, bank and canal effect as there are arranged areas where water depth is small, canals are dredged and bank effect routes are arranged. With manned models available there is no difficulty to arrange meeting or overtaking situations with two or more ships, also to arrange ship-to-ship and towing manoeuvres. As shown in the report on Task 2.1, at least in Ilawa training centre it is possible to arrange escort operations using one or two ASD or tractor tugs with azimuthing propulsors. Also Port Revel training centre claims that they are capable to simulate escorting operations (reference 6)

The capabilities of training centres using manned models with respect to ability to simulate the typical environmental factors discussed in this report are shown by the example of training areas and arrangements of Ilawa training centre (references 6, 7 and 8). However muddy bottom effect is not simulated.

2. The recommended best-practice for standardised lay-out

2.1. FMB Simulators

The review of requirements regarding appropriate models for the marine simulation of ships equipped with azimuthing propulsion devices and the review of how they are implemented currently shows that some well advanced FMB simulators made attempt to simulate the majority of factors affecting manoeuvrability of ships equipped with azimuthing propulsion devices including interaction effects between multiple azimuthing propulsion devices and interaction between azimuthing propulsion devices and ship hull with fins and skegs provided. There are also attempts to simulate external environmental factors such as bank and shallow water effects and to some extent also other effects listed in paragraph 1.4-General.

With regard to FMB Simulators the general standard of visualisation of simulation scenario with relevant current, wind, wave and channel effects is rather high and so it is with regard to visualisation of the ship itself. Inclusion of engine noise and ship motions (rolling and pitching) is also recommended. Therefore as the best practice for standardised lay-out those simulators may be recommended that satisfy the above requirements.

With regard to simulation capabilities of standard manoeuvres of ships equipped with azimuthing propulsion devices the data available from different FMB simulators show that those manoeuvres with respect to conventional ships are generally simulated accurately, although there are some cases where the accuracy of simulation is questionable (reference16). With respect to ships equipped with azimuthing propulsion devices most simulated results show the correct agreement with the theoretical considerations (reference 3 and 4), but results of validation of the simulation against full scale ship trials are few, and those which are available reveal good agreement (reference 2 and 9).

Best practice for standardised lay-out may be based on the experience of those FMB simulators that provide realistic and accurate simulation of characteristics of podded propulsors, especially

- the interaction between two or more propulsion units, and interaction between propulsion units and ship hull and appendages.;
- the interaction between manoeuvring ship and different environmental conditions, external forces and factors affecting ship manoeuvrability including interaction effects between ship and other objects and tugs action in harbour and escorting operations.

It appears that several FMB simulators have the capability to simulate those effects although in approximate way on the basis of theoretical considerations partially supported by few experimental data from model tests. Currently the best practice would be to use these data as far as possible and validate the results of simulations using results of model tests or results of full scale ships by employing system identification procedures. Apparently some facilities made such attempts and those facilities may be recommended as using best practice. With regard to different environmental conditions and external forces and factors affecting ship manoeuvrability that are recommended to be simulated some FMB simulators did show that they are capable to simulate at least some of them.

Shallow water, bank, surface and submerged channel effects need to be simulated if the FBM simulator may be assessed as using best practice. Several FBM simulators claim that they are capable to simulate those effects, but, as shown by Gronarz (reference 5), the magnitude of those effects is sometimes very different.

There is no information available whether soft-bottom and mud effect is simulated in any FMB simulator. Simulation of these effects is, however, not of prime importance. The same conclusion applies to simulation of steering with azimuthing control devices when towing and steering with azimuthing control devices when under tow.

Especially important issues are issues associated with assisted braking including the indirect mode and issues related to tugs operating near the stern of pod driven ship. Ankudinov claims that some FMB simulator listed (reference 1 and 3) possess good capability to simulate these issues. It is possible some others have this possibility as well, although they did not provide the relevant information. The best practice, however, requires that these possibilities should be available.

2.2. MM Simulators

At present there are very few simulator facilities using manned models. The best practice for standardised lay-out for MMS may be recommended taking example of two existing advanced manned model centres – Ilawa and Port Revel and to some extent also the new centre at Southhampton -Timbury. This applies to both models and manoeuvring areas.

With regard to models that are suitable for simulation the following requirements should be met:

- Models should be large enough, suitable model scale should be not smaller than λ=25. With smaller models (larger model scale) effect of Reynolds number may be important with regard to propeller and rudder forces;
- Models should correctly represent the form of underwater part of the hull including all appendages;
- Models should correctly reproduce all quantities dependent on time according to Froude's law of similitude (accelerated time scale), i.e. time to reverse engine, time to deflect the rudder, time of tug reaction etc., and also correctly reproduce characteristics of the main engine, either diesel, turbine or electric propulsion;
- Models should be capable of using tugs, either in a way of simulating tug forces or tug models. Tractor tugs or reverse tractor tugs may be necessary to simulate escorting operations;
- Model movements on the manoeuvring areas should be monitored on line making possible assessment of all manoeuvres performed.

With regard to manoeuvring areas the following requirements should be met:

- Manoeuvring area (pond, lake) should be chosen as to be large enough to perform different manoeuvres including manoeuvres requiring large areas, such as escorting operations, ship-to-ship operations and similar;
- Manoeuvring areas should be sheltered from strong winds. They should be free from other traffic – fishing boats, yachts, motor boats etc. that may disrupt manoeuvring with manned models;
- In manoeuvring areas there should be the possibility to install different required arrangements such as mock-up of port facilities, docks, locks, shallow water areas, submerged and surface canals, banks, piers and jetties of different configuration, river estuaries, etc.;
- In certain areas current should be created and also waves may be created where necessary.

In MM simulators, as they are working in open water it is rather difficult to maintain strictly controllable conditions of performing manoeuvres in situations where interaction forces have to be measured, such as measurements of the bank and canal effect, shallow water effect and similar. Such measurements should be undertaken in hydraulic laboratories where smaller, unmanned captive models can be tested and forces measured in strictly controlled conditions. The data acquired may be used later on for preparation of computer codes used in FMB simulators. This subject is not, however, considered within the scope of the project.

3. Recommended best-practice for augmentation of systems for standardised response

In spite that both FMB and MM simulators exist for more than thirty years they are still developing technology, in particular with regard to simulating azimuthing propulsion devices. With regard to FMB simulators and simulation of azimuthing control devices the main areas of augmentation and improvement of simulation are:

- Development of more accurate mathematical models for hydrodynamic interaction between multiple azimuthing propulsion devices and interaction between azimuthing devices and ship hull.
- There are few theoretical investigations of these effects published. However there are published papers on the effect of propeller race of one propeller on the work of the other one. The results of this work may possibly be used for estimation of the interaction effect between multiple pods working in the position when they may affect each other. These tools are based on calculation of velocity field behind propeller assuming that the other propeller is working in the velocity field of the propeller in front. In this respect reference is made to the series of papers by Koronowicz et al (reference 15). The authors developed a computer code using lifting line and lifting surface models and used computation fluid mechanics methods. The method was successfully used for calculations of tandem and contra-rotating propellers, but it could be used also for calculation of podded propulsor characteristics working totally or partially in the slipstream of the other propeller. However this method was not yet applied to investigating this effect and it is not certain whether it will be applied in foreseeable future.
- Including propeller cavitation in the computer codes used for simulation of propulsive characteristics of azimuthing propulsion devices. There are a number of papers dealing with this particular subject and some experimental data from towing tanks are also available. The most comprehensive review of propulsive characteristics of pod driven ships including cavitation characteristics is contained in the (reference 21).
- Performing model test of ships equipped with azimuthing propulsion devices. At present in order to obtain reliable data on the interaction effects between multiple azimuthing devices the best way is to perform model experiments in towing tanks where measurements of forces and moments of pods were undertaken.
- In simulation of manoeuvring characteristics of ships fitted with podded propulsors it may be important to estimate propulsive characteristics and these in turn require knowledge of wake and thrust coefficients for the particular ship. At present, the only way to get accurate information regarding the value of these coefficients is to perform model tests in a towing tank.

Accumulated experimental data could be then used for improvement of simplified methods taking into account the interaction effects in simulation programmes:

- Improving mathematical models for manoeuvring characteristics of ships equipped with azimuthing propulsion devices especially with regard to manoeuvrability in close proximity situations, such as bank effect, shallow water and canal effect etc. Experimental data on these effects should be collected, evaluated and used in simulation computer codes.
- Muddy bottom effects should be included in the simulation codes. Experimental and theoretical investigations of this effect should be encouraged. Studies of the mud effect such as in (reference 13) should be utilised in development of appropriate computer codes.

- Azimuthing devices for tugs and simulation of cooperation of azimuthing propelled tug and ship in escorting operations should be improved (reference 2).
- There is a need for validation of computer codes used for simulation of manoeuvrability of ships equipped with azimuthing propulsion devices. Model tests, analytical methods and system identification methods could be used for that purpose.

With regard to MM simulators augmentation of the system may consist of:

- Developing more installations in the manoeuvring areas that may include mock-ups of different fairways, shallow water areas of different depths, submerged and surface canals with different slopes of the sides, docks and locks of different configuration, harbour basins, areas with created current and waves, and areas where muddy bottom may be present. They may be required to simulate manoeuvrability of azimuthing propelled vessels in different environmental conditions.
- Constructing more manned models representing different types of ships equipped with azimuthing propulsion devices. The equipment of the model should include the most accurate tracking system that should allow monitoring of the model trajectory on line. The equipment of manned models should also take into account the possibility to use tugs in harbour operations.
- Improving of the system of cooperation between azimuthing propelled tugs and the ship in simulation of escorting operations and the method of the most realistic simulation of these operations.
- Development of the methodology of simulation of some off-shore operations, in particular operations where shuttle tankers equipped with multiple azimuthing control devices are employed.

As the simulation either using FMB simulators as well as MM simulators is developing technology the above recommendations may be supplemented with others in the future with technological progress in marine industry develops.

References

AZIPILOT Project reports:

1. Ankudinov W.: Review of ability to simulate azimuthing device interactions. Azipilot Task 2.3.May 2010. Report

2. Ankudinov V.: Kobylinski L., Landamore M., Carnaby B.: Survey of industries ability to simulate azimuthing device interactions. Azipilot Task 2.3. 22 February 2011. Report

3. Ankudinov V. :Summary of simulation capabilities. Azipilot Task 2.6. Report

4. Ankudinov V. :Review of simulator capabilities. Azipilot Task 2.2. Report

5. Gronarz A. :Shallow water, bank effects. and ship to ship interactions. Azipilot Task 2.2a 29 July 2010. Report

6. Kobyliński L. : Review of existing ship simulator capabilities Azipilot Task 2.2. July 2010. Report

7. Kobyliński L. : Review of ability to simulate azimuting device interactions. Azipilot Task 2.3. June 2010. Report

8. Kobyliński L. :Review of ability to simulate azimuthing devices. Azipilot, Task 2.1. November 2010. Report

Other publications:

9. de Mello Petey F. (2008): Advanced podded drive simulation for marine training and research. International Marine Safety Forum Meeting, Warnemuende

10. ITTC (2008): The specialists committee on azimuting podded propulsion. Report and recommendations to the 25th ITTC

11. Kobylinski L. & Nowicki J. (2005): Manoeuvring characteristics of full-bodied ships with POD propulsion. Proc IMAEM

12. Grygorowicz M., Szantyr J. (2004): Design and experimental evaluation of POD propulsor models for a large self propelled ship model. Marine Technology Transactions 14

13. Delafortrie G. (2007): Manoeuvring behavior of container vessels in muddy navigation areas. Doctor thesis. Ghent University, Faculty of Engineering

14. Duffy J.T., Renilson M.R.,Thomas G.A. (2009): Simulation of ship manoeuvring in laterally restricted water. International Conference on Ship Manoeuvring in Shallow and Confined Water. Bank Effects. Antwerp, Belgium

15. Koronowicz T. Krzemianowski Z. Tuszkowska T. Szantyr J.A. (2009): A complete design of tandem co-rotating propellers using the new computer system. Polish Maritime Research, No4. Vol.16.

16. Gofman A.D., Manin V.M.: Shiphandling simulator validity. Validation and correction of mathematical models. International Conference on Marine Simulation and Ship Manoeuvring, MARSIM 2000, Orlando 2000

17. Lataire,E., Vantorre M., Laforce E., Eloot K., Delafortrie G.(2007): Navigation in confined waters: Influence of bank characteristics on ship-bank interaction. International Conference on Marine Research and Transportation, ICMRT, Naples

18. Spencer J., McBride M., Shennan D. (2008): Simulating moored and passing ship interaction for harbor and navigation channel design. Proc. International Conference on Coastal Engineering, Hamburg
19. Sellmeijer R., van Oortmerssen G. (1983) The effect of mud on tanker manoeuvres. RINA, Spring Meeting
20. Kijima K., Nakri Y., Tsutsui Y., Matsunaga M. (1990):Prediction method of ship manoeuvrability in deep and shallo waters. Proceedings MARSIM&ICSM 90, Tokyo
21. Pustoshny A.V., Kaprantsev S.V. (2001): AZIPOD propeller blade cavitation observations during ship manoeuvring. CAV 2001 session B.9