Intuitive operation and pilot training when using marine azimuthing control devices

AZIPILOT

Report Title:

Deliverable 3.10 A&B:

Map out the landscape for future research & development within the field of Maritime Training

This document contains Parts A (p3-11) & B (p12-41) of Deliverable 3.10.

Deliverable 3.10A: Map out the landscape of future R&D

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Publishable Executive Summary

The objectives of AZIPILOT “Work Package 3, Maritime Training” are to:

- critically review existing knowledge and ongoing research in the field of Maritime Training related to the human physical and behavioural components when using azimuthing control devices.(ACD)
- summarise the compiled knowledge in a format that is readily accessible to the cross-disciplinary audience formed by other Work Packages.
- review and assimilate material compiled and presented by other Work Packages.
- identify critical short-comings and thus map out the landscape for future research.

This final task 3.10 report summarizes the knowledge collected during the project and carries out a gap-analysis comparing the present state of the art knowledge described in “Task 3.6: Summarise training capabilities and needs” with the training needs described in “Task 3.7: Assimilate cross-disciplinary knowledge from other WPs”

The results of the gap-analysis have been used to identify critical short comings and to list a range of recommendations for future research and development within the ACD maritime training.

The recommendations are to:

carry out further research into:

- stress influences when handling ACD
- young personnel’s perception of ACD
- the most efficient training and teaching methods
- energy efficient ACD manoeuvring strategies
- cost-benefit analysis in order to define the level of fidelity of the simulator models and environments needed to achieve the expected training outcome;

and develop and test:

- manoeuvring equipment with enhanced functions designed to assist the operator by giving tactile force-feed-back information. This could be critical differences between manoeuvring handle position and actual propulsion position
- standardised courses for ACD handling training (e.g. IMO model course)
- universally accepted terminology and definitions and operations best practice
- Bridge Resource Management training integrated into ACD courses.

1 Introduction

The aims of task 3.10 are:

1. to map out the landscape of future research and development within the field of Maritime Training, specifically with respect to the application of Azimuthing Control Devices (ACD's). A gap analysis will be performed, comparing the subject state-of-the-art and possible cross-disciplinary contribution from the industry as a whole. The results will be used to identify critical knowledge gaps that restrict progress and identify possible ways to address such short-comings.

   The main objectives will be to:
   - cross-reference the Summary and Assimilation exercises to identify knowledge gaps.
   - evaluate both knowledge and industry capacity to address such gaps in the short, medium and long term.
   - identify any theoretical, technical or practical barriers that may stand in the way of addressing such gaps.
   - formulate a best-strategy for addressing industry needs.
   - make recommendations for future research and development.

2. to implement the knowledge obtained within the study into the development plans for Maritime Training. The objective is to use the information obtained throughout the project to make recommendations for the improvement of the technology and the Maritime Training Industry as a whole specifically when dealing with ships equipped with azimuthing control devices.

This report deals with the first task as specified above.

2 Summary of the present training state-of-the-art

ACD training is carried out at many training facilities in the EU and world-wide using:

- Full Mission Bridge Simulators (**FMBS**) or
- Manned Model Simulation (**MMS**)

2.1 Full Mission Bridge Simulators (FMBS)

FMBS are mock-ups of ships' bridges with relevant bridge equipment installed. The bridge is encircled by a viewing screen (of projected images or monitors) on which a computer generated presentation of the simulated environment is projected. FMBS use simplified methods of mathematical model coding which is adequate to fulfil the purpose of training. In general FMBS are able to simulate proper manoeuvring and ship handling characteristics in open and shallow water and interaction effects based on simplified theory. FMBS training programmes are developed for different ACD vessel types such as:

- Large Cruise Vessels
- Harbour tugs

- Escort tugs
- Off Shore vessels/ Emergency Towing Vessels
- Ferries (4 thruster/2 thruster)
- Cargo Vessels of different sizes

The training programs are designed for different categories of mariners such as:

- Marine Pilots
- Tug Skippers
- Cruise vessel Senior Officers
- Ferry and cargo vessel deck officers

Bridge Resource Management (BRM) and Human Factor elements are often included in FMBS training programs. Different levels of realism/fidelity are needed depending on the type of training the FMBS is used for. Deep water navigation with large vessels does not need as much realism or fidelity as tug operations in shallow and enclosed waters. Human Factor and BRM training demands human interaction and communication and highly realistic bridge design, instrumentation and environment but the mathematical models level of fidelity are not paramount. Factors that affect the realism and fidelity of the FMBS are:

- Bridge design – a true copy of the real bridge or a generic standardised bridge
- ACD's – real handles and gauges or generic standard types
- The quality of sound effects - engine/thruster noise, wind, waves, rain, seagulls etc.
- Tactile input such as vibrations, collision or berthing bumps
- Moving platform or visual impression of movements
- Visual propeller wash, towing hawsers, exhaust etc.

It is technically possible to fulfil most of these factors; it is a matter of allocating the effort and financial investments to the task.

2.2 Manned Model Simulation (MMS)

MMS are large scaled models of vessels. Propulsion power and control devises are scaled in order to match the model. Special designed exercise areas (lakes) are constructed in order to represent generic ports and waterways. In MMS the hydrodynamic forces are authentic in relation to the fidelity of the models. MMS training programs are developed for Experienced Pilots, Masters and Chief Officers on large ACD vessels. Factors that affect the realism of the MMS are:

- Bridge design has to be generic
- ACD's: can be the real handles in question but the placement must be generic
- The exercise are not performed in real time but is accelerated to "Model Time" due to the scaling effects. Wind, waves and current are hard to control and are affected by the scaling effects.

3 Knowledge gaps

3.1 Training programs

The training curricula that have been presented and reviewed during this project are generally consistent in the aims and objectives. Presentations, hand-outs and other instructional materials used in the courses are to some extend copies of each other and thus indicate that they origin from the same books, publications or operational procedures. Observations of and interviews with masters using ACD's in their daily work reveals that there is no global uniform standard method of ACD handling.

A "best practice" in ACD training centres based on practical operational experience, manuals from ACD producers and research has been developed. Different types of azimuthing propulsion, different types of vessels and operational areas and environments (ice, rivers, harbours etc.) have however had operators developing different strategies for ACD handling. Information on such strategies is not likely to be passed on to the training centres unless the operators get the opportunity to share his knowledge with a training centre.

3.2 Operational restrictions

Experience with podded azimuthing propulsion has revealed unexpectedly large loads to occur on different parts of the propulsion systems when operating the ACDs at critical speeds and conditions. This has forced the manufactures to make consecutive changes and restrictions in their operational manoeuvring strategies procedures. Information on these restrictions and changes in operational procedures are not always available to the training centres.

3.3 Human factors

Task Report 3.3 describes the research into the human factors and intuitive ACD handling in training perspective carried out in the AZIPILOT project. One of the conclusions is that high fidelity/ realism of the FMBS are important to the trainee's perception of the training outcome. This research is based on interviews with participants. It would be beneficial to look into the connection between learning outcome and the level of fidelity in the FMBS in terms of:

- mathematical modelling
- sounds and vibration
- moving platform versus moving visual system
- authentic copy of actual bridge versus generic bridge design
- bridge wing simulators to train change of control procedures

Improvement of ACD design has been discussed during the progress of this project in order to enhance the intuitive handling of them such as:

- ACD handles with build-in VHF talk key
- Tactile handles with built-in resistance illustrating the difference between handle position and thruster position
- Tactile indication of difference between power settings on the two handles
- Synchronised handles on all manoeuvring stations

Further research into these points would be beneficial.

3.4 Energy efficient operation

IMO's Marine Environment Protection Committee (MPEC) is promoting energy efficient operation of ships hereunder also the implementation of a compulsory Ship Efficiency Management Plan (SEEMP). (IMO: MEPC.1/Circ.683, 17. August 2009)

Different manoeuvring strategies can be applied to azimuthing propulsion. Some strategies include manoeuvres where the propulsion unit forces are counteracting each other and if operated at high revolutions, large quantities of fuel will be consumed. The same manoeuvres carried out according to other strategies might result in less fuel consumption. It would be beneficial to study energy efficient ACD manoeuvring strategies.

4 Evaluation of knowledge and industry capacity to address gaps

4.1 Training programs

There is adequate capacity to develop training programs suitable to ensure the necessary transfer of ACD handling knowledge and skills.

4.2 Operational Restrictions

The restrictions set by manufacturers are not always based on practical operational needs but in order to avoid damage to the equipment. Experience gained over the time span that ACD's has been in operation generates new or revised restrictions to the use of the propulsion. Such restrictions are often seen as business secrets and classified information and is not readily handed over to the training centres. This will probably not change in the future.

4.3 Human Factors

Tools and knowledge needed to carry out the research mentioned in paragraph 3.3 are developed, tested and approved of today. The capability to design and implement the improvements of ACDs suggested in paragraph 3.3 are within the capacity and knowledge of the industry today.

4.4 Energy efficient operation

The available simulators, FMBS or MMs, are fully capable of carrying out research into manoeuvring strategies considering fuel consumption measurements and calculations.

5 Identification of barriers

The identified barriers are:

- Getting access to technical information related to ACD equipment, ship and propulsion design and test results are often difficult due to the companies' reluctance to give away their business secrets. Even manoeuvring strategy information is often confidential.
- Developing exact mathematical models as well as exact manned models are costly and often customers are not prepared to invest the necessary money in training

- Limited capability of modelling the vessels accurately enough, technically and financially. It is possible to calibrate and fine-tune a mathematical model to mirror full scale trials exactly, but it is very costly and time consuming.

6 Best strategy

During the AZIPILOT project several companies involved in the azimuthing propulsion industry were approached and invited to participate in work-shops, meetings or to send information to the project partners. Continuation of this approach to the industry aimed at convincing them that cooperation would be beneficial for both parties should be a viable strategy.

Knowledge of the AZIPILOT project has to some extend already spread out to the maritime industry and some project partners have been contacted by shipping and other relevant companies wishing to make use of the project results. In order to support and promote future increase in such contacts, knowledge of the project and its results should be spread to a wide range of the maritime industry.

The relevant maritime authorities and international maritime bodies such as IMO and IALA should be approached via the proper lines of communication and informed of the project results and relevant recommendations.

7 Recommendations for future R&D

The recommendations for future Research and Development are based on the work carried out and the results presented in AZIPILOT Work Package 3

7.1 Research

It is recommendable to research into:

- In what way and to what extend does stress influence intuitive handling of ACD?
- How do new and young deck officers perceive intuitive use of ACD?
- Should part of on-board-training in ACD handling be carried out before attending a training course in order to achieve the maximum training outcome?
- Which teaching methods, in transfer of knowledge and skills during ACD training, are most effective?
- Energy efficient ACD manoeuvring strategies

This project has established that in order to get the highest training outcome for FMBS's authentic bridge design, real equipment, accurate mathematical models and a high level of fidelity in replicating the environment is essential.

Further research is needed in order to establish the cost - benefit relations of:

- Which level of fidelity of the mathematic model is needed to achieve the expected training outcome related to the specific type of training in question?

- Which quality of instruments and equipment is required to comply with training needs? Could some instruments be generic and others real?
- Do we need special bridge wing simulators for "change of command" training
- What is the gap between the available level of FMBS and our needs? (if any)

7.2 Development

During the course of this project, ideas of improvements to existing equipment or design of new features have evolved and been discussed, between the partners and the participating maritime professionals, intending to support more intuitive and safe operation of ACDs. This is mainly focused on tug handling. The following recommendations for development are the essence of these discussions.

It is recommendable to develop and test:

- ACD handles with built-in VHF talk/listen key for tugs. With traditional systems the operator has to move one hand from the ACD to the VHF and thus focus shortly on the VHF instead of manoeuvring aspects.
- Tactile ACD handles with built-in resistance making it possible for the operator to sense the difference between ACD handle position and actual thruster position. A quick turn of an ACD followed by a force command might induce a thrust in a different direction than the ACD indicates. A kind of "Force Feed Back" would warn the operator of this risk.
- Tactile indication of difference between power settings on the two handles. When operating the thrusters in "Toe Out/Toe In "strategy it is necessary to apply exactly equal forces on both thrusters. A feat that can be difficult to accomplish without consulting the RPM gauges and thus take away focus from the manoeuvring conditions.
- Standardised courses outlining the minimum requirements of ACD handling training carried out in FMBS and MM. This could be IMO Model courses for ACD training addressing the different types of vessels and ACDs
- Universally accepted terminology, definitions and operational best practice in terms of rudder commands and manoeuvring orders.
- Bridge Resource Management training to be integrated into ACD courses addressing ordinary as well as emergency situations.

8 References

- All AZIPILOT task reports in work package 3
- AZIPILOT task reports 4.2 and 4.6
- IMO: Guidance for the development of a ship energy efficiency management plan (SEEMP), MEPC.1/Circ.683, 17. August 2009

Deliverable 3.10B: Map out the landscape of future R&D

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PUBLISHABLE EXECUTIVE SUMMARY

The aim of this task is to implement the knowledge obtained within the study into the development plans for Maritime Training. The objective is to use the information obtained through the project to make recommendations for the improvement of the technology and the Marine Training industry as a whole; specifically when dealing with ships equipped with azimuthing control devices. Training requests and training needs are reviewed with the conclusion that as the ASD system usage will become more widespread in the future, thus education and training is a necessity. Training could be accomplished on Full Mission Bridge Simulators and/or on Manned Model Simulators, supplemented by *in situ* training. Both types of simulators have certain advantages and disadvantages and both should be used for training supplementing each other.

There are few data related to technical qualities of the Full-Mission-Bridge-Simulators which are in operation. But it is thought that most existing simulator modules for podded propulsive drives do take into account propeller thrust, transverse propeller forces, and lift and drag forces on the pod body. They also model the interaction effects between different pod units, and shallow water effects on podded vessels although the methods used are not known and the effects are not always correct. There is therefore a need to promote development of appropriate mathematical algorithms taking the all interaction effects and hydrodynamic memory effects present in close proximity into account in simulation

When using large manned models for training, the bank, shallow water and interaction effects are automatically taken into account. There is, however, a need to improve manned models equipment including monitoring systems of motions of models and simulation of tug action and development of training areas for simulation of interaction effects. In both types of simulators accurate models of the particular vessel that is to be handled should be used. For the future more work has to be done to produce more harmonized and optimal designed ACD control systems fully fit for the use by ship handlers in various manoeuvring circumstances. Specific ACD control lay out is required for the different type of manoeuvres and positions on the navigation bridge. Those controls have to be reproduced in FMB simulators.

There is a clear need for optimal ergonomic lay-out and design of the bridge equipment Particular attention should be given to the layout of the ACD handling controls, display of ACD status information and take-over command features. Intuitive control, degree of automation and stress aspects play a role in the optimizing of the ACD control systems. The ergonomic requirements of the IMO guidelines on bridge layout affects the ACD systems. More research is needed regarding stress influence on intuitive control. More research is needed regarding perceptions of azimuthing control devices by new and young personnel. Standard azipod model training programmes for both types of simulators should be developed and assessed. They should include programmes of training in escorting operations where escort tugs are involved.

INTRODUCTION

The first aim of this task is to map out the landscape of future research and development within the field of Maritime Training and specifically with respect of the application of marine azimuthing control devices.

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

- The implementation of guidelines for the selection of appropriate methods for Marine Training when using ships equipped with azimuthing control devices.
- To identify best practice for system operations. To identify guidelines for bridge system operations.
- To recommend best practice for standardized procedures
- To promote understanding of current perception and actual use.

The task will culminate in a task report that will delineate the above aims and objectives and will constitute one deliverable. This report deals with the second task as specified above.

1. IMPLEMENTATION OF GUIDELINES FOR THE SELECTION OF APPROPRIATE METHODS FOR MARINE TRAINING WHEN USING SHIPS EQUIPPED WITH AZIMUTHING CONTROL DEVICES.

1.1. Training requests and training needs

During last decades attention of the maritime world has been focused on safety of shipping. Amongst other causes of accidents at sea, casualties related to manoeuvrability happen quite often and analysis of casualties shows that CRG casualties (Collisions-Ramming-Groundings) constitute about 53% of all serious accidents leading to ship loss (Reference 17). The data showed that in the year 1984 1 ship in 22 took part in CRG casualty this year (Reference 19).

CRG casualties occur more often with increasing speed and size of vessels and such casualties may cause more serious consequences. Collisions may also happen more often in restricted waterways and canals and in particular in areas where additional external factors, as e.g. current, make handling of ships more difficult.

Risk of CRG casualty depends on several factors, one of which is human factor, i.e. operator's skill. Published analyses associated with commercial shipping during recent years indicated that human errors that occurred during handling operations were responsible for approximately 62 per cent of the major claims figure (Reference 17). Other sources show, that about 80 % of all CRG casualties are results of human failure. Therefore attention is focused recently to the role of human factor in safety (Reference 22).

As about two thirds of all CRG casualties are caused by human error it is necessary to analyse factors which contribute to the efficiency of the operator (Reference 16). One of the most important factors contributing to this is training.

Important feature that might be seriously affected by training is way of handling critical situation. This was discussed *inter alia* by Bea (Reference 3), who did show that proper training may considerably reduce risk of mishap in case of emergency when action is planned and executed in time and then the system is returned to normal operating status, otherwise system fails. Once people were faced with critical situation during the training they will react quicker when such situation appears in reality. This is very important conclusion for programming of training.

1.2 Simulator ship handling training needs

Training needs for ship handling in general were discussed in the report on Task 3.1 (Reference 4). In this report reference was made to the requirements of the IMO STCW Convention (Reference 15).

Obviously the best way to train ship officers and pilots in shiphandling and manoeuvring is to perform training onboard real ships. Any use of simulators should be in addition to training onboard ships. However, gaining skill "on job" watching experienced practitioner working is a long and tedious process. Moreover certain handling situations including some critical ones may never occur during the training period onboard ships and no experience how to deal with such situations could be gained this way. When serving on ships engaged in regular service there is little or no possibility to learn about handling in critical situations because such situations must be avoided as far possible.

Simulator training is expensive; therefore the simulator courses must utilize time available in the most effective way. In order to achieve positive results simulators must be properly arranged and the programme of simulator exercised should be properly planned in order to achieve prescribed goals.

The effectiveness of a simulator in training mariners depends on the simulator capabilities to simulate the reality. Sorensen (Reference 20) stressed the point that simulators must be realistic and accurate in simulating the reality.

Specialised training in ship handling is required by the International Maritime Organisation. Seafarers' Training, Certification and Watchkeeping (STCW) Code, Part A, being attachment 2 to the Final Act of the STCW 1995 Conference includes mandatory standards regarding provisions of the Annex to the STCW Convention (Reference 15). Apart training onboard ships, approved simulator training or training on manned reduced scale ship models is mentioned there, as a method of demonstrating competence in ship manoeuvring and handling for officers in charge of navigational watch and ship masters.

There are also specific recommendations regarding need for simulator training (FMBS and MMS) In several places in the specifications of minimum standards of competence for ship officers as the method demonstrating competence use of simulators, either FMBS or MMS is mentioned There are also specified certain requirements as to the capabilities of simulators that must be satisfied. Those standards are repeated below:

"Section A-I/12 Standards governing the use of simulators

PART 1 – PERFORMANCE STANDARDS

General performance standards for simulators used in training

1. Each party shall ensure that any simulator used for mandatory simulator-based training shall:

.1 is suitable for the selected objectives and training tasks;

.2 be capable of simulating the operating capabilities of shipboard equipment concerned, to a level of physical realism appropriate to training objectives, and include the capabilities, limitations and possible errors of such equipment;

.3 has sufficient behavioural realism to allow a trainee to acquire the skills appropriate to the training objectives;

.4 provides a controlled operating environment, capable of producing a variety of conditions, which may include emergency, hazardous or unusual situations relevant to the training objectives;

.5 provide an interface through which a trainee can interact with the equipment, the simulated environment and, as appropriate, the instructor, and

.6 permits an instructor to control, monitor and record exercises for the effective debriefing of trainees.

General performance standards for simulators used in assessment of competence

2 Each party shall ensure that any simulator used for the assessment of competence required under the Convention or for any demonstration of continued proficiency so required, shall:

.1 be capable of satisfying the specified assessment objectives

.2 is capable of simulating the operating capabilities of shipboard equipment concerned, to a level of physical realism appropriate to the assessment objectives, and includes the capabilities, limitations and possible errors of such equipment

.3 has sufficient behavioural realism to allow a candidate to exhibit the skills appropriate to the assessment objectives;

.4 provides an interface through which a candidate can interact with the equipment, the simulated environment;

.5 provide a controlled operating environment, capable of producing a variety of conditions, which may include emergency, hazardous or unusual situations relevant to the assessment objectives, and

.6 permits an assessor to control, monitor and record exercises for the effective assessment of the performance of candidates."

In many countries sea pilots are required to attend special simulator courses either on FMBS or MMST every few (usually 5) years. Therefore there is certainly need for simulator training of ship masters and officers and also pilots in ship handling.

1.3. Simulator training needs for ships equipped with azimuthing propulsion units

Azimuthing propulsion is innovative solution revealing several advantages. Within past twenty years podded propulsors with a power up to 25MW per unit have been developed and put into service. Podded propulsors are characterized by two main qualities:

- Electric motor is located inside a hydrodynamically optimized submerged housing
- The total unit is rotated with the propeller(s) by 360 degree rotation

Fig.1 shows classical podded propulsor as defined above. However, there are known many variations of this type propulsors including many hybrid designs and also other types of azimuthing propulsors of different construction that do not include electric motor inside of the propulsor housing. Those are Voith-Schneider propellers, Schottel propellers, outboard motor principle and rotating nozzle propellers. These types propulsors are known and used for a long time, usually, however, in rather small ships and boats. Real innovation is development and application of high power podded drives as defined above.

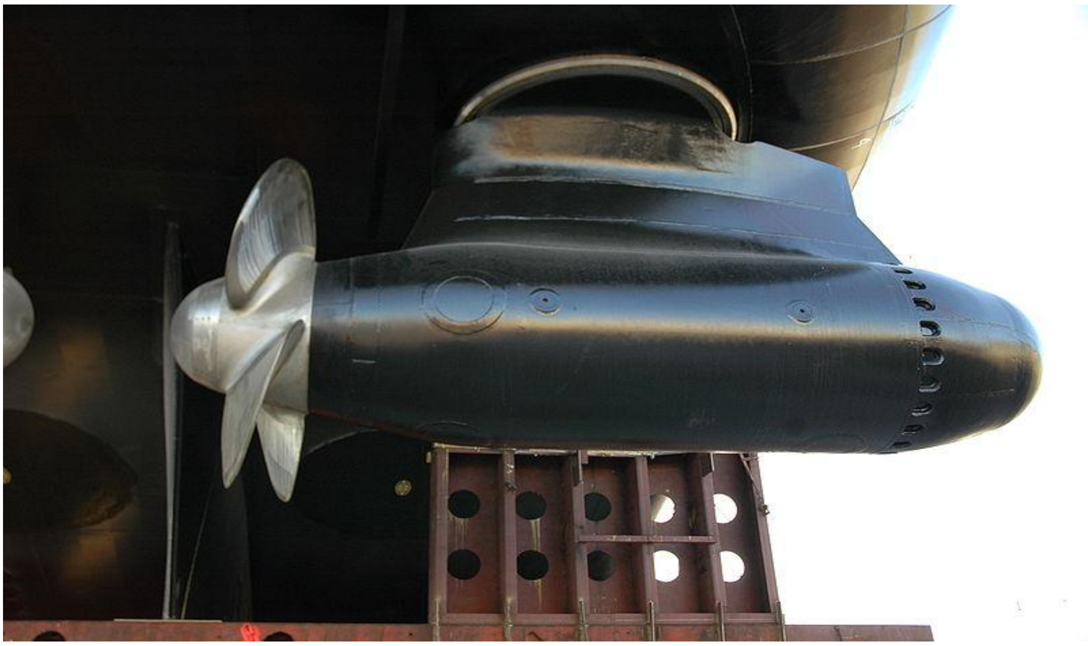

Fig.1. Classical AZIPOD arrangement

According to Rees (Reference 18) vessels fitted with azimuting propulsion constitute 6.9% of all vessels, the largest groups being tugs, off-shore vessels and cruise liners. Rees (Reference 18) reported that 8044 pilots were questioned on the matter of the need for training on azimuthing propelled ships, of which 2334 responded, and of these 96% use azipods. From this number 736 pilots (32%) received some kind of training on azipods and few others received some instruction from manufacturers.. The others did not receive any training on azipods at all.

About 40 pilots from Scandinavian countries coming to the SRTC training centre for ship handling training were also questioned *re* need for training on azipods. In great majority of cases they expressed willingness to receive training, because they have often ships with podded propulsion visiting their district. Therefore in SRTC in the general training course for pilots, training on the model fitted with azipods for one day was included.

Recently in many districts escorting of large vessels carrying dangerous goods - oil tankers, gas carriers and similar is required. Escort tugs are almost always fitted with azimuthing propellers and escorting operations in case of emergency require greater skill from the tug masters and ship masters. Training in escorting operations is another fast developing area where azipod propelled vessels is involved and where special training is required. It may be concluded that there is certainly the need for training on azipod driven ships and tugs for pilots and for prospective masters of azipod propelled ships. In particular there is certainly a need for training pilots and prospective ship masters of ships equipped with azimuthing propulsion devices (AZIPODS especially) in escorting operations because they require greater skill in handling.

2. IDENTIFICATION OF BEST PRACTICE FOR SYSTEM OPERATIONS. IDENTIFICATION OF GUIDELINES FOR BRIDGE SYSTEM OPERATIONS

2.1 Existing simulators used for training in handling of pod driven ships

In general, simulator may be either equipment or 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, however, 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.

Simulators used in training in ship handling and manoeuvring are basically of two types: Full Mission Bridge Simulators (FMBS) and Manned Models Simulators (MMS). FMBS computer controlled 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. There is at present a considerable number of such simulators of different types operating throughout the world, starting from desk simulators to sophisticated FMBS where the trainee is placed inside a bridge mock-up with actual bridge equipment, realistic visual scene of the environment, and sometimes rolling and pitching motions and engine noise. FMBS are working in the real time and are controlled by computers programmed to simulate ship motion controlled by rudder and engine (and thrusters or tugs) in different environmental conditions. MMS use large models for training purposes in specially arranged water areas, ponds or lakes. Models are sufficiently large in order to accommodate 2-4 people (students and instructors) and are constructed according to laws of similitude. Models are controlled by the helmsman and are manoeuvring in the areas where mock-up 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. Also in certain areas current is generated. As a rule, monitoring system allowing to monitor track of the model is available.

Important feature of manned model exercises is that all manoeuvres are performed not in real time, but in model time which is accelerated by the factor λ^{-1}. (λ – model scale). This may pose some difficulties for trainees at the beginning who must adjust to the accelerated time scale. Currently there is only few training centres using manned models in the world, however, according to the recent information, few others are planned or even in the development stage.

In FMBS, because there is a mathematical model of ship motion on which computer codes are based, it is important that this mathematical model represents properly behaviour of the real ship. In spite of great progress in the development of the theoretical basis of ship manoeuvrability, not only in unrestricted water areas (turning, course-keeping and stopping characteristics), but also in the proximity of other objects (bank, shallow water effects and the effect of other ships), the last effects are still investigated not sufficiently enough. Sophisticated computer programmes include calculations of hydrodynamic coefficients using advanced methods require powerful computers and extreme large memory. Simulating the close proximity effects cannot be used in FMBS because they must work "on line" therefore rather simplified methods must be developed for this purpose.

There are rather few available data on the capabilities and technical qualities of the FMBS. Data of some of them are included in the report on Task 3.2 (Reference 21). There was direct or indirect information available on training courses realised in the following training centres:

- MITAGS- Maritime Institute of Technology & Graduate Studied Maryland USA
- TRANSAS Inc. Cork Ireland (and USA)
- Hochschule Bremen, Bremen, Germany (NS 5000 simulator by Rheinmetall Defense Electronics)
- FORCE Technology, Lyngby, Denmark
- Australian Maritime College Launceston, Tasmania
- DST- Development Centre for Ship Technology and Transport Systems Duisburg , Germany
- STAR CENTER, Dania Beach, Florida USA
- ABB Marine Academy, Finland
- MARIN, Wageningen, The Netherlands
- TYNE -South Tyneside College
- CSMART- Centre of Simulation and Maritime Training (Owner: Carnival), the Netherlands

Special simulation programs of azipod driven tugs was available in the majority of the above centres. On top of that, according to the information provided by Ankudinov (Reference 1, 25), at following simulator centres such programs are also available

- MITAGS, Washington Di, USA: 2 Full-Bridge 360 degrees view Simulators and Tug simulator.
- Pacific Maritime Institute, PMI, Seattle, USA: 2 Full-Bridge Simulators and Tug Simulator
- Marine Engineering School, MEBA, Easton, Maryland, USA: 2 Full- Bridge Simulators and 2 Tug simulators
- STC B.V. Centre for Simulation, Maritime Research, STC Group Rotterdam, The Netherlands
- Georgian Great Lakes Maritime College, Canada, 4 Full-Scale Bridge Simulators in Network. Bridge layouts allow simulation of practically any ship types including tugs with all existing drives (FPP, CPP, Steering Nozzle, Pods, Voith – Schneider, etc), tows, and many others.
- FORCE Technology, Denmark (a full bridge tug mock-up, two auxiliary tug cubicles, a vector tug station, an instructor/operator station)

The scope of the available information on the programmes of the azipod courses realized in the above training centres using Full Mission Bridge Simulators (FMBS) is widely different, in the majority of cases is rather scarce.

Detailed Information about training courses and programmes are available from two training centres using Manned Models Simulators (Reference 21):

- PRS -Port Revel, France
- SRTC – Ilawa, Poland

2.2. Capabilities of existing simulators

Capabilities of existing simulators were reviewed under the Task 3.2 of the AZIPOOD project (Reference 21). The main conclusions of this review are included in this report. The effectiveness of a simulator in training mariners depends on the simulator capabilities to simulate the reality. Sorensen (Reference 20) stressed the point that simulators must be realistic and accurate in simulating the reality. Therefore simulators should, apart from simulating properly the main manoeuvring characteristics of a given ship, i.e.

- Turning characteristics
- Yaw control characteristics
- Course keeping characteristics and
- Stopping characteristics

Be capable to simulate different factors influencing ship behaviour, e.g.: at least:

- Shallow water effect
- Bank effect
- Effect of proximity of quay or pier
- Effect of limitation of dimensions of harbour basin
- Surface and submerged channel effect
- Ship-to-ship interaction
- Effect of current
- Effect of special rudder installations, including thrusters
- Effect of soft bottom and mud
- Ship-tug cooperation in harbour (low speed towing) and.
- Escorting operations using tugs
- Anchoring operations.

As far as it is known practically all modern FMBS are capable to simulate manoeuvring and ship handling characteristics in open water quite properly. Usually they are also capable to simulate the close proximity effects based on simplified theory. With regard to simulation accuracy 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 (Reference10). With respect to ships equipped with azimuthing propulsion devices most simulated results show the correct agreement with the theoretical considerations (Reference 5 and 21), but results of validation of the simulation against full scale ship trials are few. Those results that are available reveal good agreement with respect of turning circles and zig-zag tests (Reference 21). Gronarz (Reference 12) investigated capabilities of four advanced FMBS to simulate ship-ship interaction, shallow water and bank effect. The conclusions of this investigation are:

- 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 simulated 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.

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. However, as it is well known, the requirements of second law of similitude which is 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 the Reynolds number is sufficiently high to avoid the majority of such effects.

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). Wind force is proportional to the windage area and to the wind velocity squared. Windage area is reduced automatically by factor λ^2 but wind velocity apparently cannot be reduced. However, actually windage area in models is usually reduced more than by factor λ^2, and wind velocity due to sheltered training area and low position of the windage area in the model in comparison with the full-scale ship is considerably reduced. Still usually wind force is larger than it should be.

Capability of manned models to simulate shallow water, bank, submerged and surface canal effects, effect of current, close proximity of other stationary or moving objects is automatically assured and is practically unlimited, restricted only by local conditions in the training area. There is no information available whether soft-bottom and mud effect is simulated in any FMB simulator or in MM simulator. Simulation of those 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 (Reference 1) claims that some FMB simulator listed have 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.

However it is certain that matters related to proper simulation of tugs working near the stern of pod driven ships where there may be strong interference between the ship and tug require further research effort. The same applies to situations where pod driven ship is rapidly reversing pod revolutions from ahead motion to astern motion or performing crash stop pod way where memory effects in the water may be important.

2.3. Best practice for system operations

As stated the system of training in ship handling, in particular in handling ships equipped with azimuthing propulsion devices as used at present consists of training in FMB and/or MM simulators. Both types of simulators reveal some advantages and disadvantages and both types require future improvements of technology. 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 2.2 of this report.

With regard to FMB Simulators the general standard of visualization 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. Best practice for standardized layout 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

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 12), the magnitude of those effects is sometimes very different and the magnitude of the effects is sometimes very different. This should be the matter of further research and improvement. 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. However, the information on the method of how those effects are simulated generally is not available. 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. Other should do that in the future.

At present there are very few simulator facilities using manned models. The best practice for standardized 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 new centre at 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 waters there 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, not manned, but captive models are 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.

Gaps in present simulation technique were revealed in the following areas:

- Flow pattern around propulsor housing
- Interaction between propulsor main elements
- Scale effect in performance prediction
- Interaction between multiple azimuthing propulsion devices
- Simulation of pods at large angles

Lack of relevant experimental and full scale data was revealed on:

- Response under extreme steering
- Manoeuvring in ice
- Slamming effect
- Wake and thrust deduction factors
- Hydrodynamic effects on tugs operating near the stern of pod driven ships

2.4. Identification of guidelines for bridge system operations.

Recommendations and guidelines for azimuthing control devices user’s regarding the use of the given azimuthing control device are included in the report by Pinkster et al (reference 23), from which the most conclusions are taken. Along with this, current shortcomings of each ACD system were given and furthermore linked with possible ways forward.

There are quite a large number of different azimuthing propulsion devices and these often differ to great extend from each other and are used in different types of ships. Amongst those are azipods propulsion devices that may include two or more propulsion devices, sometimes combined with conventional propulsion (hybrid construction), Schottel devices with or without nozzle fitted, Voith-Schneider propellers, pump jets, water jet propulsion devices and others. The main interest of this task is in AZIPODS.

There are quite a large number (around 14 identified) of different ACD control devices and these often differ in great extend from each other and are rather representing the individual view of the manufacturer than based on a general philosophy regarding implementation of relevant ergonomic rules. Each observed system has, in one way or another, a less optimal element in the design or layout of the ACD control components. In general there are various bridge layouts for the different ship types equipped with azimuthing propulsion devices. The number of consoles range from 1 to 4 and the position thereof is changing from the centre of the wheelhouse, the bridge wings and the rear of the wheel house. Optimal bridge layout with

ACD propulsion system will vary and is dependent upon the task type. The types of tasks and manoeuvring situations are as follows:

- Open sea
- Confined waters
- Anchor areas
- Narrow channel, rivers, port basins
- Terminal approach
- Open sea off shore
- Short track ferry
- Tug assistance

The table below shows manoeuvring situations for different types of ships equipped with azimuthing propulsion devices (Reference 26). At present the following types of ships may be equipped with ACD systems:

- Passenger cruise liners
- Container vessels
- Small and mid-size tankers and gas carriers
- Heavy lift vessels
- Ice breakers
- Shuttle tankers
- Off-shore supply ships

	TYPE OF SHIP									
	Merchant marine	Navy	Harbour tugs	Inland ferry	Offshore supply vessels	Pipelayers	Heavylift vessels	Icebreakers	Ice going tankers	Drilling rigs
Open sea	x	x				x	x	x	x	
Open sea off shore					x					x
Confined waters	x	x								
Anchor areas	x	x			x	x	x	x	x	
Narrow channel / rivers	x	x	x	x	x	x	x	x	x	
Port basins	x	x	x	x	x	x	x	x	x	
Terminal approach	x	x	x	x	x	x	x	x	x	
Tug operation			x							
Short track ferry				x						

It should be considered that depending upon the manoeuvring situation the workload and requirement for active handling will vary. The guidelines related to the bridge layout are included in the IMO MSC/Circ.982 (December 2002) (Reference 27). Below, the recommendations related to field of view from the wheelhouse, controls and alarms as specified in the IMO guidelines are repeated. They were extracted from IMO Guidelines by Hutchins et al (Reference 26). For the choice of the bridge layout ergonomic aspects and requirements play important part.

In accordance with the IMO MSC/Circ.982 (Reference 27) the navigation bridge has a number of different work stations as shown below:

- Navigation, communication and manoeuvring
- Monitoring instruments and environment
- Manual steering
- Docking from bridge wing
- Planning and documentation
- Safety

In relation to ACD systems handling the navigation and manoeuvring, the monitoring, the manual steering and docking workstations should be taken into account. The IMO guidelines have, however, the status of recommendation and are not compulsory.

One problem to which often not enough attention is attached is minimum field of view from the wheelhouse.

The view of the sea surface from the navigating and manoeuvring workstation should not be obscured by more than two ship lengths or 500m, whichever is the less, forward of the bow to 10^0 on either side under all conditions of draught, trim and deck cargo.

There should be a field of vision around the vessel of 360^0 obtained by an observer moving within confines of the wheelhouse.

The horizontal field of vision from the navigating and manoeuvring workstation should extend over an arc of not less than 225^0, that is from right ahead to not less than 22.5^0, abaft the beam on either side of the ship.

If the view in the centre line is obscured by large masts, cranes, etc., two additional positions giving a clear view ahead should be provided, one on the port side and one on the

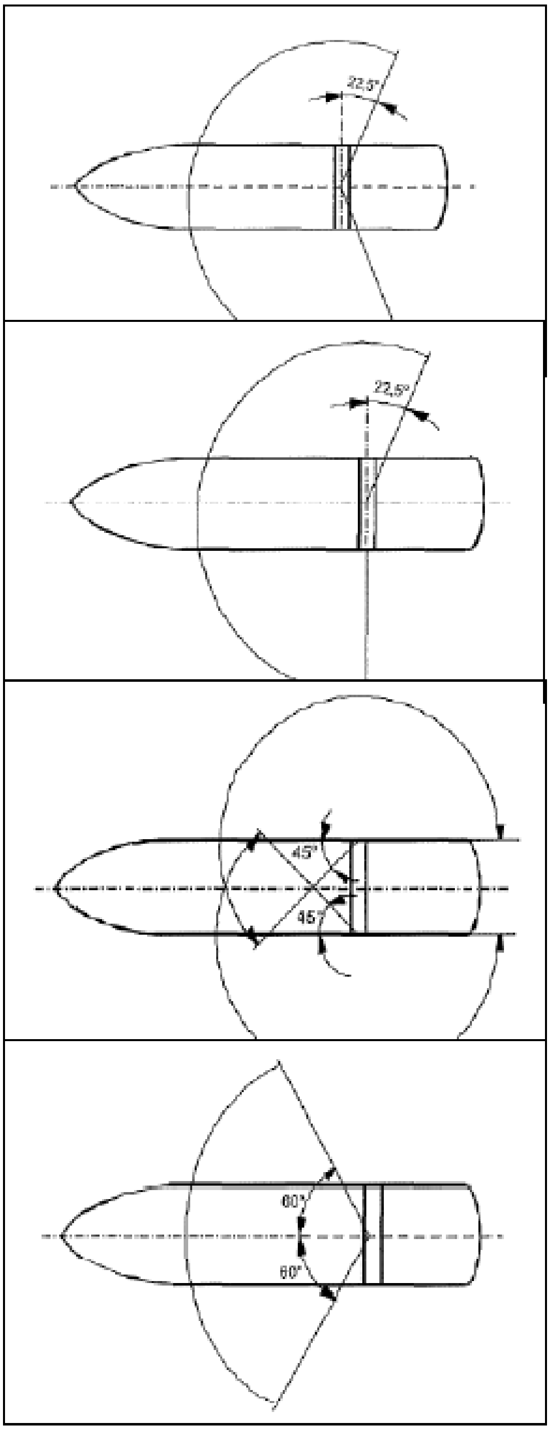

Fig.2.IMO recommendation related to visibility

starboard side of the centre line, no more than 5m apart.

From the monitoring workstation, the field of vision should extend at least over an arc from 90^0 on the port bow, through forward, to 22.5^0 abaft the beam on starboard. From each bridge wing the horizontal field of vision should extend over an arc at least 225^0 , that is at least 45^0 on the opposite bow through right ahead and then from right ahead to light astern through 180^0 on the same side of the ship.

The ship side should be visible from the bridge wing. Bridge wings should be provided out to the maximum beam of the ship. The view over the ship's side should not be obstructed. From the main steering position (workstation for manual steering) the horizontal field of vision should extend over an arc from right ahead to at least 60^0 on each side of the ship. The above recommendations are illustrated in Figs.2 and 3.

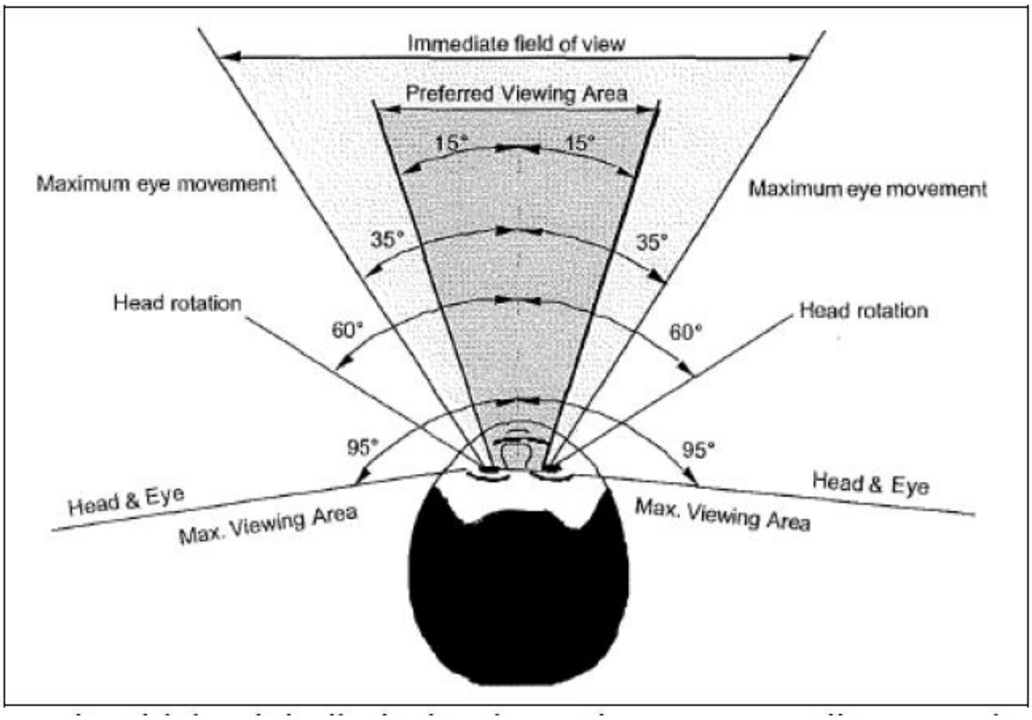

Fig.3.IMO recommendation related to visibility

The other recommendation refers to internal communication in the bridge. An internal communication system between the workstation for navigating and manoeuvring should be provided when the distance between the workstations is greater than 10m. An internal communication system should always be provided between the workstation for navigating and manoeuvring and open bridge wings. Where workstations are widely spread, an internal communication system should be provided so that unhampered communication can be achieved under all operating conditions. It is important that all order/action communication systems be two-way. In practice a portable phone will be used in these circumstances.

The distance between adjacent workstations should be sufficient to allow unobstructed passage to persons not working at the stations. The free passage in passageways between different workstations areas should be at least 700mm. The workstation operating area should be in front of the workstation not of the passageway. The distance of a passageway between the front bulkhead and any consoles should preferably be at least 1000mm, and not less than 800mm.

The workstations for navigating and manoeuvring, monitoring and for the bridge wings should be planned, designed and placed within an area spacious enough for not less than two operators, but close enough for the workstations to be operated by one person. Displays, controls and alarms within the bridge. Displays providing visual information to more than one person on duty should be located for easy viewing by all users concurrently, or if this is not possible, the displays should be duplicated.

Controls and their associated displays should be located in such a way, that the information on the displays can be easy read during the operation of the controls. Controls or combined controls/indicators should be visually and tactually distinguishable from elements which only indicate. Controls should be located so, that simultaneous operation of two controls will not necessitate a crossing or interchanging of hands. The most important and frequently used controls should have the most favourable. Position with respect to ease of reaching and grasping should have a prominent position. The most important and/or frequently used displays should be located within the operator' immediate field of views (with eye rotation only). Controls and displays should be labelled clearly and unequivocally according to their function, possibly by using standardised symbols.

Adjustable lighting (dimming control) should be provided for controls and visual displays, including display, control, and panel labels and critical markings, which must be read at night or under darkened conditions. The range of the dimming control should permit the displays to be legible under all ambient illumination conditions. Alarms should be provided to indicate sensor input failure or absence. Alarms or acknowledged alarm should only be capable of being cancelled if the alarm condition is rectified. This cancellation should only be possible at the individual equipment. The number of alarms should be minimized. Visual alarms should clearly differ from routine information on displays. Audible alarms should be used simultaneously with visual alarms.

Controls should be selected so that the direction of movement of the control will be consistent with the related movement of an equipment component, or vessel. The direction of motion of operating elements for manoeuvring equipment should correspond with the direction of the effect on the ship caused by the installation controlled. Controls should be easy to identify and operate. When precise reading of a graphic display is required, the display should be annotated with actual data values to supplement their graphic representation.

As the IMO Guidelines refer to all ships, there is a problem of how far those guidelines are applicable to vessels equipped with azimuthing control devices. It seems that almost all recommendations are applicable, but on the basis of opinions of two experienced masters of such ships there may be some additional remarks (Reference 26). According to their opinion closed bridge wings have the advantage over open bridge wings, because the instruments vulnerable by weather could be installed. The central bridge console in such ships is equipped with auto pilot, steering option, telegraphs for both thrusters and ACD handles. With closed bridge wings these elements are duplicated on each wing.

In the old discussion of flow versus force representation of the working of an ACD, the best solution is thought to be a force indicator which combines the thrust direction (forward or backwards) and the angle of the direction of the ACD (0° to 360°) in one instrument. As this is problematic for mechanical instruments, an electronic solution with a display may be the best variant of an intuitive instrument which hopefully then lacks the potential of misinterpretations.

Some advantage in this respect is provided by the thrust direction indicator (TDI) that is shown in fig. 4. This indicator works onboard a vessel equipped with ABB AZIPODS. Position of the pod and its thrust turned to port by 30^0 is shown, but the ship turns to starboard. The rear pointer shows helm angle that is in this case 30^0 to starboard to be in line with the normal operation of ships with conventional rudder – starboard rudder, ships turns to starboard. It is not known in this case whether the control lever is turned to port or to starboard by 30^0, but in some ships in this situation control lever may be turned to starboard, in direction in which ship turns. Such arrangement may be provided in order to make control of the pod intuitive.

The presentation of the ACD thrust direction should not confuse the operator. Azimuthing propulsion devices may be fitted with pulling or pushing propellers. This should be clearly shown as, for example, is shown in fig.5. Ideally, direction and force should be indicated which relates directly in magnitude and direction to the engine order.

Steering with ACD handles may create confusions. The navigator should consider the turning effect of a force on the stern on the starboard or port side. A force to port means a turn to starboard. Thus turn to starboard means a settling of the force of the ACD to port and *vice versa.* Compared with the wheel this action is opposite and may be considered incorrect. This may confuse the navigator not familiar with the system. A clear indication on the pods may improve the clarification. Possible layouts of the console are shown in fig.6.

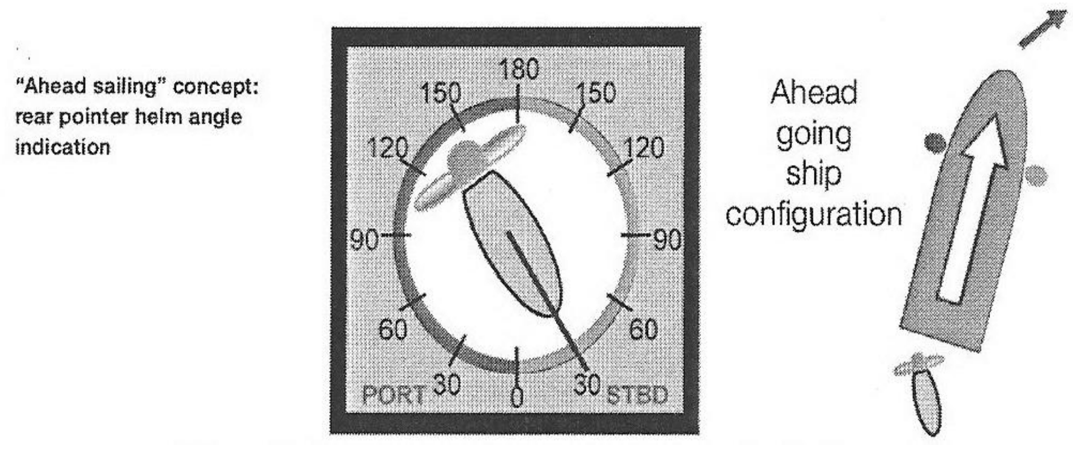

Fig. 4. Example of Thrust Direction Indicator

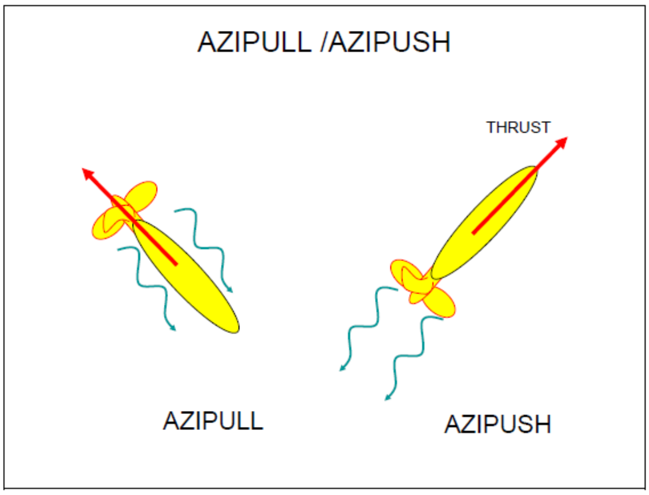

Fig. 5. Display of AZIPULL and AZIPUSH

Hutchins et al (Reference 26) pointed out that in most escort tugs equipped with azimuthing propulsion devices the mate or captain handling the tug is constantly operating the two controllers, one for each propulsion device. That means that he must constantly operate the control handles. This is his primary task, while for instance communication with pilot and captain of the assisted vessel, harbour authorities or his own crew, is secondary. This situation is defined as overload situation. The solution may be using some automation. Four categories of reasons for automation can be identified:

- Involving impossible or hazardous processes which poses a danger to the human operator
- Presence of difficult or unpleasant processes
- Extension of the human capability
- Automation installed “*because it is technically possible*”

However installation of automation poses certain problems and it has some advantages and disadvantages. These are thoroughly discussed by the authors (Reference 26).

With the great variety of ships equipped with azimuthing propulsion devices and the great variety of control layouts it is impossible in simulation facility to use many of them. It is necessary to provide a selection of handle types for the ships mostly used in that simulator. Each simulation facility has to choose those applications which are most common. Example of the inland navigation simulator SANDRA (Reference 23) where the chosen strategy was realisation of a system of modular handles for different ship types in one simulator shows that this may be the solution.

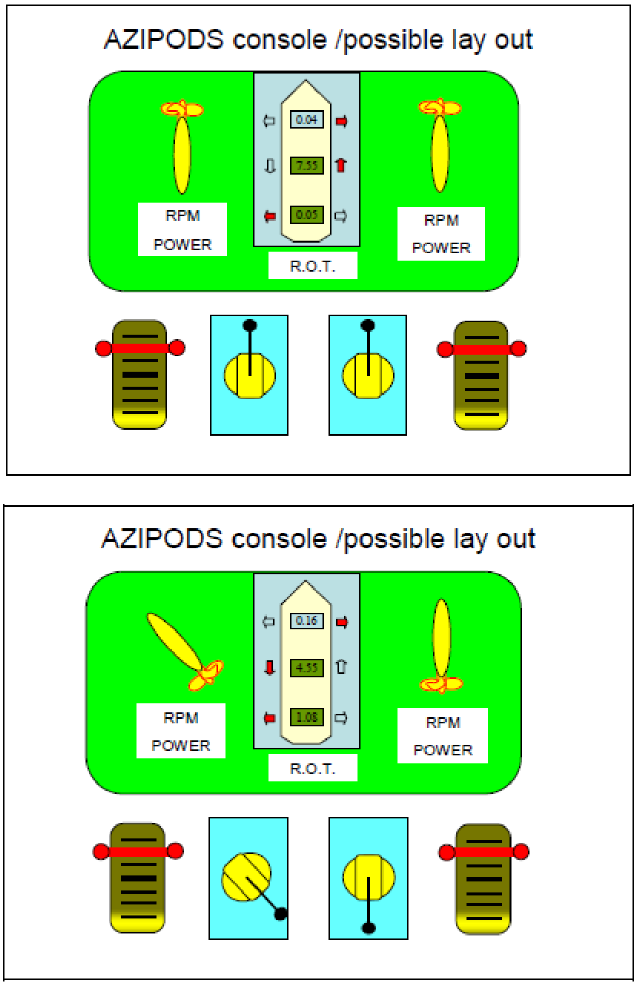

Fig.6. Possible recommended layouts of the console

When operating a control device that gives an angular command as it is the case for a conventional rudder or an ACD handle, the helmsman has always the problem that he has to know the actual angle of the device. This is important because when thinking that a certain force is needed for a certain action the helmsman must know, whether this commanded angle is already available or not. Giving full thrust before the shaft has reached the desired angle might result in a wrong reaction of the ship and may cause an accident. The worst case of all is that the device does not react to the instruction due to a failure with the steering gear machine. The common way to solve this problem is a feedback instrument (Fig.7), right instrument), which gives the information about the actual angle by visual inspection. In most situations this seems to be sufficient, but in some applications with a great demand on manoeuvrability a better response on the commanded angle is needed.

Fig.7. Triple instrument (rpm, pitch, angle)

The Options for control layout and use (Simulators) has led to the following conclusion: Simulation applications of ACD's differ mostly in the type of propulsion system and the additional control instruments as bow thrusters etc. The problem for the simulation facility is the fact, that the different propulsion systems such as conventional rudder – propeller arrangement, single or multiple propellers, ACD's of the various types, water jet propulsion, etc. use special handles for their proper operation. In principle, all control handles can be used in a simulator as long as the signals from each handle can be transformed and inter-phased with the propulsion system concerned.

			Open water	Open sea off shore	Confined waters	Anchor areas *Port*	Narrow channel / rivers	Port basins	Bridge locks	Terminal area	Terminal approach	Short track ferry	Tug operation
Nr. Of ACD pod's		1 or 2											
ACD Control by		Wheel	■		■								
		Auto pilot	■		■								
		Tiller					■						
		ACD Handles					■	■	■	■	■		
		Joystick + turning knob							■	■			
		DP system											
Primary info & commands	ACD status	Pod thrust				■	■	■	■	■	■		
		Pod azimuth				■	■	■	■	■	■		
	Ship position	Outside view	■		■	■	■	■	■	■			
		Radar/Arpa	■		■	■	■	■		■			
		ECDIS	■		■	■	■	■		■			
	Ship movement	Longitudinal speed	■		■	■	■	■	■	■	■		
		Lateral speed				■	■	■	■	■	■		
		ROT				■	■	■	■	■	■		
	Commands	ACD Take over					■	■	■	■			
		ACD shut down					■	■	■	■	■		
		ACD mode			■	■	■						
	Communication	VHF hands free											
Secondary info	Pod status	Pod rpm /pitch	■		■	■	■	■	■	■	■		
		Pod alarms	■		■	■	■	■	■	■	■		
		Pod shut down	■		■	■	■	■	■	■	■		
	Ship position	Radar/Arpa							■		■		
		ECDIS							■		■		
	Communication	VHF	■		■	■	■	■	■	■	■		
		Intercom	■		■	■	■	■	■	■	■		
	Environment	Wind indicator	■		■	■	■	■	■	■	■		
		Depth indicator	■		■	■	■	■	■	■			
ACD Console location		Navigation bridge centre	■		■	■	■		■				
		Navigation bridge wing						■	■	■	■		
		Navigation bridge rear											

Remarks: The main ACD controls and ship handling information sources are situated in the bridge centre location. However, the ship handling with high frequency to ACD settings take place in the bridge wing location and are carried out in all kind of weather conditions in day and night time. Therefore most of the ACD handles and information as well as the other ship handling information sources are also placed in this location. The intensity of ship handling for pipe/ cable layers and ice breakers will at open sea be more intensive than for other merchant marine vessels.

The possibilities regarding helm response variation depending on configuration of the selected ACD control systems has led to the following conclusions:

- A response signal in the form of a vibration signal seems to be the best for angular feedback on ACD for the helmsman.
- When multiple ACD control consoles are installed on a vessel, the non active console(s) are best fitted out with handles that move and follow the position of the handles of the active console (even though this means that overload sensors should be installed at these consoles to protect unwanted blockage of any of these handles due to any items placed on such consoles).

Based on overviews of required equipment, bridge systems and bridge layout related to the ACD control and systems information has been produced for the following ship types: Merchant marine, pipe/cable layers, ice breakers and sea going tugs (Reference 23). As an example the table on page 29 indicates the required equipment in the various ship handling situations.

3. RECOMMENDATIONS ON BEST PRACTICE FOR STANDARDISED PROCEDURES

Training in ship handling of ships equipped with azimuthing propulsion devices could be accomplished on board of full scale ships and on simulators. Simulators used for training are of two types: Full Mission Bridge Simulators (FMBS) and Manned Models Simulators (MMS). Although training onboard of ships is the best way to gain experience in ship handling, and it is a must for ship pilots and masters. However, as stated in paragraph 1.2 of this report, gaining skill "on job" watching experienced practitioner working is a long and tedious process. Moreover certain handling situations including some critical ones may never occur during the training period onboard ships and no experience how to deal with such situations could be gained this way. When serving on ships engaged in regular service there is little or no possibility to learn about handling in critical situations because such situations must be avoided as far possible.

Therefore training on simulators is considered to be the best practice for accomplishment of training. Both types of simulators offer, however, different possibilities to acquire skill in ship handling due to their different capabilities. The capabilities of both types of simulators are discussed in paragraph 2.2 of this report.

Advantages and disadvantages of both ways of training in shiphandling were discussed by several authors, the most comprehensive review was presented by Barber and Hunt (Reference 2).

Full Mission Bridge Simulators- Advantages

- In full mission bridge simulators those scenarios may be reproduced where full scale bridge with all its equipment and corresponding illusion of surrounding world is required.
- They are suitable for actual handling of ships using rudder, engine, thrusters, anchors, tugs and other equipment. In particular positioning and control of tugs, anchoring in crowded anchorages, steering according to leading marks or lights.
- Familiarisation with specific pilotage areas which could be simulated visually
- Bridge team management and master-pilot interaction. Full mission bridge simulators allow creating integrated team on the bridge including pilot. Exercises performed involve pilot working with the bridge team in different situations.
- Emergency procedures could be simulated, such as machinery breakdown, disabled vessel. various rudder problems, man overboard etc.
- Blind pilotage, use of radar navigation, and use of electronic charts

Full Mission Bridge Simulators - Limitations

- Lack of feel for the ship when manoeuvring. In reality pilot is watching subtle changes in ship behaviour and environment which give important clues how to handle the ship. Those are not present in simulators which are working according to prepared programme. It means that definite input provides definite response which is not always the case in reality
- Lack of feeling external environment. Simulator is placed inside the building and in spite of attempts to reproduce noise of the engine and sometimes rolling of the ship the trainee is out of touch with the real conditions onboard.
- As simulator is controlled by a computer programme, the accuracy of the mathematical model representing ship manoeuvre is important. Currently used models may be not sufficiently accurate and sometimes may show entirely different behaviour of the ship as in the reality
- Final phases of berthing and close proximity manoeuvres where engine is reversed many times and thrusters used are not realistic

Manned Models Simulators- Advantages

- Proper representation of hydrodynamic forces. There are physical phenomena governing model motions, not mathematical simulation which is always approximate and sometimes incorrect.
- Close proximity realism. There is complete realism when two models are meeting or overtaking in close proximity, when the model is in the final stage of berthing or when

negotiating very narrow passages. All physical phenomena in those situations are reproduced properly and the model is behaving naturally what cannot be done even in the best electronic simulators.

- Realism in emergency situations. Training on manned models assures psychological effects by better feeling of effects of groundings, rammings and collisions which, if they happen, are very realistic.
- Possibility to exercise anchoring and other special manoeuvres. Manned models are specifically advantageous for performing exercises with dredging anchor, anchoring in wind and tide and single point mooring.
- Possibility to perform manoeuvres in current and tide. Effects of wind and current are clearly visible and realistic. Current generators may create non-uniform current and river estuaries could be modelled. Such environment allows learning quickly influence of changing hydrodynamic forces on model behaviour and influence of momentum when manoeuvring in current.
- Effective use of time. As models are working in accelerated time scale, one week training on models corresponds approximately five weeks training on electronic real-time simulators.
- Understanding physical phenomena. When performing specific manoeuvres something goes wrong the trainee immediately see that the result is wrong and with the help of instructor he may easily understand physical phenomena playing part in this manoeuvre.

Manned Models Simulators- Limitations

- Accelerated time scale. Accelerated time apart from advantages has also the disadvantage because it poses some difficulties in adjusting by the trainee. It is necessary by the trainee to think and take decision much faster than in the reality.
- Small "funny boat" syndrome. Some trainees, especially these having some experience with sailing small pleasure motor boats try to handle models available for training in a similar way. The big difference lies in power available - for example 50hp for, say 8m boat and about 0.8hp for the model of the same size.
- In spite of attempts to locate the pilot or master in the position where the visibility is similar as from the full size bridge the full similarity is impossible to achieve. The trainees must adjust to judging the situation in the terms of model lengths rather than in the real distances.
- Wind effect is not properly scaled down and is usually to strong. For example, wind force 2 (Beaufort) in the lake may correspond to wind force 8 in reality.

From the above it may be concluded that the best practice would be performing training on both types of simulators supplemented with training *in situ*. In this way experience in ship handling satisfying all needs sufficient and complete could be gained by pilots and ship masters.

Use of ACD’s and standardized bridge layout should be supported by educating and training at the very least by simulator training and, if possible, supplemented by on-site training.

If a specific arrangement of thrusters is selected, this can present problems if the Conn is now changed to the bridge wing position. The joystick position on the bridge-wing (not yet connected) may not mimic the arrangement originally selected from the central conning position. This may result in confusion or even in accidents. When, and if, the Conn position is changed to the bridge wing the necessary information for manoeuvring must also be available. Tugs often change the Conn position from central looking forward to central looking aft. This is also an opportunity for confusion for the user.

4. PROMOTION OF UNDERSTANDING OF CURRENT PERCEPTION AND ACTUAL USE

There is obvious need for specialised training of pilots and ship masters, including tug masters for ships equipped with azimuthing propulsion devices. This could be accomplished either in Full Mission Bridge Simulators or Manned Models Simulators, with different training goals. In order to make training more effective a sample template for specialized training courses for ships fitted with azimuthing control devices have to be developed and accepted by International Maritime Organization, responsible authorities, pilotage organizations and ship owner companies.

Authorities responsible for the provision of Pilotage services and Ship owners/operators should ensure that personnel operating ACD units receive a thorough and comprehensive understanding of the theory behind the operation of such units and be trained in their efficient and effective use to ensure the safety and security of life and property. In these aspirations there is an urgent need of collaboration with ship owners.

It is necessary to increase the sensitivity of the pilotage organizations and also of the shipping companies with ships equipped with these propulsion systems, about the provision of training courses to their pilots (officers) in order to use azipods in the most effective way in all different kind of situations they could have to afford and to be sufficiently trained to avoid errors and incidents. The other important point is necessity of adoption of universally accepted terminology and definitions specific to ships equipped with azimuthing propulsion devices

Official standardisation for operating systems and bridge lay-outs and controls should be promoted and considered further as well as further consultation of experienced users is necessary in order to come to a standardized bridge layout for ACD’s. Use of ACD’s and standardized bridge layout should be supported by educating and training at the very least by simulator training and, if possible, supplemented by on site training. More specifically: **ISO 13407 Human Centred Design Process for Interactive Systems** should be referenced**.**

Review of the human physical and behavioural components shows that more research is needed regarding stress influence on intuitive control. More research is also needed regarding perceptions of azimuthing control devices by new and young personnel. With regard to operation of azimuthing propulsion devices the resultant thrust component is often difficult for the user to estimate and comprehend during operations. This problem was discussed in

Chapter 3 of this report. Continued development of the visual accessibility, sound quality and actual physical movement of/in the simulator should be considered when designing simulators for ASD tugs (the same goes for "ordinary" simulators). Certain pedagogical methods should be considered when designing the bridge layout.

CONCLUSIONS

1. The ASD system usage will become more widespread in the future, thus education and training is a necessity.
2. Training could be accomplished on Full Mission Bridge Simulators and/or on Manned Model Simulators, supplemented by *in situ* training. Both types of Simulator have certain advantages and disadvantages and they should supplement each others.
3. There are few data related to technical qualities of the Full-Mission-Bridge-Simulators which are in operation. But it is thought that most existing simulator modules for podded propulsive drives do take into account propeller thrust, transverse propeller forces, and lift and drag forces on the pod body. They also model the interaction effects between different pod units, and shallow water effects on podded vessels although the methods used are not known and the effects are not always correct.
4. There is a need to promote development of appropriate mathematical algorithms taking the all interaction effects and hydrodynamic memory effects present in close proximity into account in simulation. As there is lack of data on wake and form coefficients for ships with podded propulsors those data should be collected..
5. When using large manned models for training the bank, shallow water and interaction effects are automatically taken into account. There is a need to improve manned models equipment including monitoring systems and simulation of tug action and development of training areas for simulation of interaction effects.
6. In both types of simulators accurate models of the particular vessel that is to be handled should be used.
7. For the future more work has to be done to produce more harmonized and optimal designed ACD control systems fully fit for the use by ship handlers in various manoeuvring circumstances. Specific ACD control lay out is required for the different type of manoeuvres and positions on the navigation bridge.
8. There is a clear need for optimal ergonomic layout and design of the bridge equipment Particular attention should be given to the layout of the ACD handling controls, display of ACD status information and take-over command features. Intuitive control, degree of automation and stress aspects play a role in the optimizing of the ACD control systems. The ergonomic requirements of the IMO guidelines on bridge lay out affects the ACD systems.
9. Official standardization for operating systems should be consulted further as well as further consultation of experienced users in order to come to a standardized bridge layout for ACD's. Consultation with user experts is an absolute requirement even though standardized elements have been identified and documented**.** Aside from the more academic factor of the positioning of bridge equipment, field of viewing is sometimes overlooked and requires attention. Standard terminology related to ACD systems should be developed and introduced.

10. More research is needed regarding stress influence on intuitive control. More research is needed regarding perceptions of azimuthing control devices by new and young personnel.
11. Standard azipod model training programmes for both types of simulators should be developed and assessed. They should include programmes of training in escorting operations where escort tugs are involved.

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