Executive Summary

The AZIPILOT Project aimed to provide a platform for cross-disciplinary communication between specialists in hydrodynamic modelling, marine simulation, maritime training, and operational practice, to facilitate an understanding of the needs and limits of each other's subject.

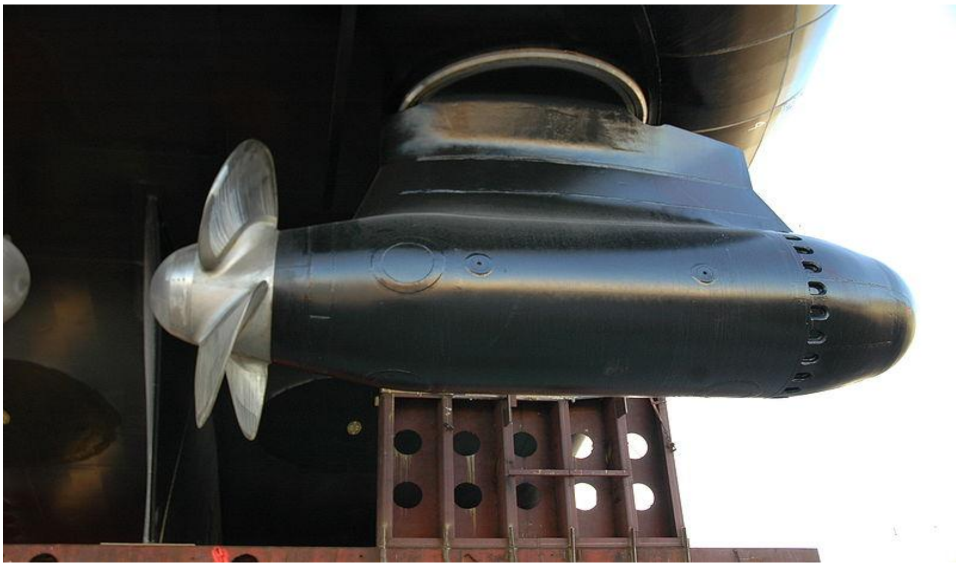

Figure 1: Classical AZIPOD arrangement

From the thrusters on smaller, but numerous, harbour support vessels through to the pod-drives on cruise ships and ocean going liners, azimuthing control has rapidly established itself in the maritime industry; but while the industry has risen to meet the demand, this rapid evolution has not allowed sufficient time for the propagation of knowledge throughout the different disciplines. Though the various sectors of the industry each have their own expertise, a lack of communication is both restricting progress and compromising safety and security – in addition, much work is being repeated unnecessarily.

Azimuthing control devices provide an innovative solution for ship propulsion and steering that offers significant economical and operational advantages, including safety due to redundancy, when manoeuvring in close quarters. However, for the ships pilots that have to use these devices, manoeuvring control can become very complicated and quite counterintuitive. The project's objectives can be summarised as four phases of work, to:

- Critically REVIEW and collate existing knowledge and ongoing research;
- SUMMARISE and compile knowledge in a format that is more readily accessible to the cross-disciplinary audience;
- ASSIMILATE material compiled by complementary disciplines;
- Identify IMPACT and critical short-comings and thus map out the landscape for future research, training, higher education and policy making.

In meeting these objectives, AZIPILOT has created a forum for cross-disciplinary discussion throughout the sector, and produced a wealth of open-access documentation and analysis to aid not only those working in the sector today, and interested in further research; it will also guide policy makers in the development of future Research and Development programmes, and the creation of improved policy and regulation of the sector, regarding intuitive operation and pilot training when using marine azimuthing control devices.

Intuitive operation
and pilot training
when using marine
azimuthing
control devices

AZIPILOT

Figure 2: Project Logo

Project Context & Main Objectives

The AZIPILOT Project aimed to provide a platform for cross-disciplinary communication between specialists in hydrodynamic modelling, marine simulation, maritime training, and operational practice, to facilitate an understanding of the needs and limits of each other's subject.

From the thrusters on smaller, but numerous, harbour support vessels through to the pod-drives on cruise ships and ocean going liners, azimuthing control has rapidly established itself in the maritime industry; but while the industry has risen to meet the demand, this rapid evolution has not allowed sufficient time for the propagation of knowledge throughout the different disciplines. Though the various sectors of the industry each have their own expertise, a lack of communication is both restricting progress and compromising safety and security – in addition, much work is being repeated unnecessarily.

Azimuthing control devices provide an innovative solution for ship propulsion and steering that offers significant economical and operational advantages, including safety due to redundancy, when manoeuvring in close quarters. However, for the ships pilots' that have to use these devices, manoeuvring control can become very complicated and quite counterintuitive.

Ships, by definition, carry people; pretty much without exception as crew and in many cases as passengers. Ships are in themselves valuable property, as is the cargo that they carry. Also, cargos carried by a ship and substances carried to operate the ship (e.g. fuel) can, in the event of an accident, present a substantial risk to the environment – and often in geographical areas that are most ecologically sensitive to such pollution. In addition, the operator of azimuthing control devices can direct the full-power from one thruster perpendicular to the ship's side and directly towards sensitive banks or quay-structures. In doing so, this can cause considerable damage to (or weaken) natural or man-made structures.

In order to enhance safety, large conventional equipped ships with limited manoeuvrability use tugs to assist them during the berthing/un-berthing phase of the voyage. Ships equipped with azimuthing control devices tend not to use tugs when manoeuvring within the close confines of a port. This in itself presents problems should an azimuthing control device fail or should wind speeds experienced during the manoeuvre be in excess of that predicted; when tugs are not in attendance. The art of ship-handling is one of using the forces at your disposal (engine; rudder; thrust; tugs) to overcome the forces over which you have no control (wind and tide) to achieve the desired effect (safe berthing/un-berthing). If a pilot loses one of those forces at his disposal, safety may be compromised. Clearly, for the ability to manoeuvre a ship with adequate 'safety' it is necessary to design the ship with adequate performance, to provide adequate and appropriate training for the pilot and to provide a reliable environment in which the pilot can exercise this training. To achieve this, we must provide a platform for cross-disciplinary communication between the described parties – to facilitate an understanding of the needs and limits of each other subject.

It is also conceivable that the existing ship systems and the man-machine interface are vulnerable to abuse or misuse – whether this be malicious in intention, or more likely, accidental. In context, just because it is possible to perform an action with the controls of a ship this does not mean that you should – or that it is safe to do so. The infinite number of control options on offer to the pilot of a ship equipped with azimuthing control devices introduces much technical uncertainty. This project therefore strives to address the issues associated with 'security' by investigating the vulnerability of ships systems and the man-machine interface to abuse or misuse, and aims to propose appropriate approaches for risk analyses and hazard identification.

In order to address these objectives, the project brought together experts from across the key industry sectors to participate in cross-disciplinary discussion and cooperation. Specifically, these were: specialists in HYDRODYNAMIC MODELLING and testing, both theoretical and experimental, expert in the understanding of azimuthing control devices; designers and manufacturers of MARINE SIMULATION software, hardware and physical models that are used for the training of marine pilots, including, designers, human factors specialists and manufacturers of automation and control systems, joystick systems and graphical user interfaces; MARITIME TRAINING facilities using both numerical and physical simulation tools, specialist in the theory and practice of human factors (physical and behavioural components) and the training of bridge-crews and pilots; and practitioners in OPERATIONAL PRACTICE, including maritime pilots, ship operators/managers, pilot associations/end-users, Maritime Authorities and Regulators specifically interested in policy and regulation. The body of the work was carried out over four phases, as shown in Figure 2.

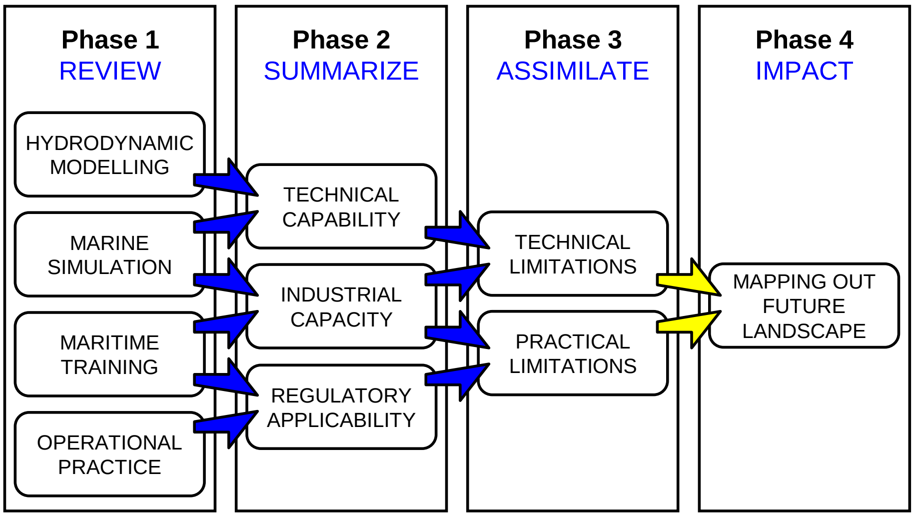

Figure 3: Project Phase Plan

Results

The AZIPILOT project aimed to identify the need for, and roots to, new technologies and to propose innovative solutions for the improvement of safety and security of ships that use azimuthing control devices. It is intended that this should ultimately lead to the protection of vulnerable people, materials and the environment. And within this context, the activities for safety will address multidisciplinary approaches for technologies, for both ships and the training of pilots, to ensure safer operation based on design for safety. The project encompasses the entire infrastructure of numerical modelling, simulator design, simulation training, human factors, human physical and behavioural response, system design and education for improved and intrinsic security, ship operations, the regulatory environment and ultimately policy. Figure 3 is a schematic which identifies how information flowed in and out of the AZIPILOT project.

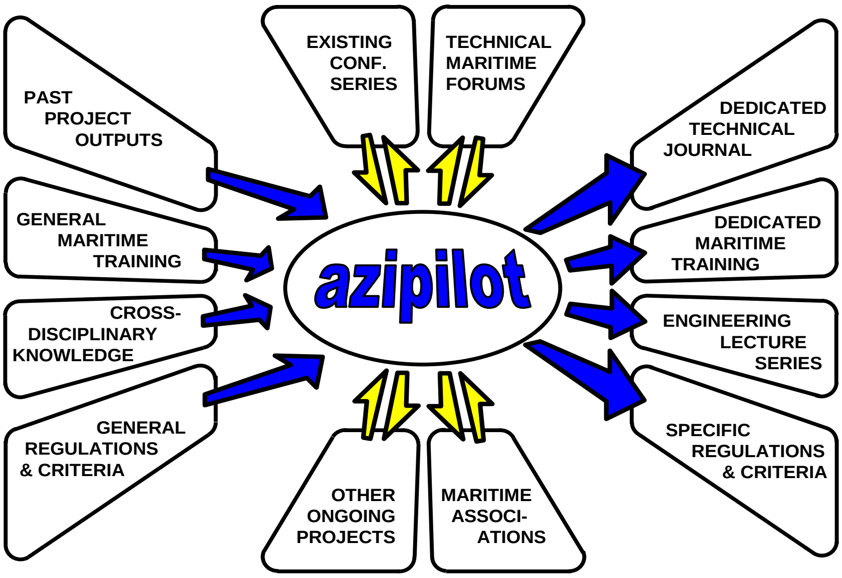

Figure 4: How area will benefit from network & coordination

Work Package 1 dealt with hydrodynamic modelling of azimuthing control devices (ACDs). Implementation of ACDs primarily affects the resistance, propulsion and manoeuvring aspects of ship operations, garnering both benefits and disadvantages, which must be properly researched to ensure that the full impact upon these characteristics is understood and hence properly modelled. The review of available literature and other data sources confirmed many initial expectations upon which the sometimes empirical science has been based, but also identified other areas where new phenomena have been observed, and further R&D is likely to be required.

In mapping out the landscape of future research and development within the field of hydrodynamic modelling, with special attention to marine azimuthing control devices, a gap analysis within gathered knowledge was carried out in respect to state-of-the-art, supplemented by respective contribution from the industry. The cross-reference of performed summary made it possible to identify critical knowledge gaps. Afterwards, these results were analysed from the point of view of its influence on due ship performances and possible ways of gaps compensation were taken into account. It resulted not only in nearly full recognition of theoretical and technical barriers which may stand in the way of addressing such gaps, but in elaboration of the general strategy to meet industry needs, and detailed recommendations for future research.

Figure 5: A twin pod arrangement

Work Package 2 was aimed at collating, reviewing and auditing available material that is relevant to the subject of Marine Simulation, specifically for ships equipped with azimuthing control devices (ACD). This audit identified areas in which future research and development would be beneficial in the area of Marine Simulation. Many aspects of the Marine Simulation domain for ships operating with ACD were examined and it was clear that there are still a number of further activities that can be undertaken in order to improve the quality of simulation (both full mission bridges and manned model simulations), addressing all stakeholders and especially ship owners/operators and pilots.

The objectives of Work Package 3 (Maritime Training) were 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; and identify critical short-comings and thus map out the landscape for future research. Knowledge related to maritime training was collated and summarised, and a gap-analysis undertaken, comparing the present state of the art knowledge with the training needs. The results of the gap-analysis have been used to identify critical shortcomings, and the information obtained through the project has guided 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 needs are reviewed with the conclusion that as ACD system usage becomes more widespread in the future, improved education and training is necessary. Training could be accomplished on Full Mission Bridge Simulators and/or on Manned Model Simulators, supplemented by *in situ* training. Ideally both types of simulators would be used as they have complementary characteristics.

There is a paucity of data available regarding the technical qualities of Full Mission Bridge Simulators, 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, and particular attention should be given to the layout of ACD handling controls, display of ACD status information and take-over command features. Intuitive control, degree of automation and stress aspects all play a role in the optimising of the ACD control systems, as do the ergonomic requirements of the IMO guidelines on bridge layout. More research is needed regarding stress influence on intuitive control, and perceptions of azimuthing control devices by new and young personnel. Standard ACD model training programmes for both types of simulators should be developed and assessed, and should include training for escorting operations, where escort tugs are likely to be involved.

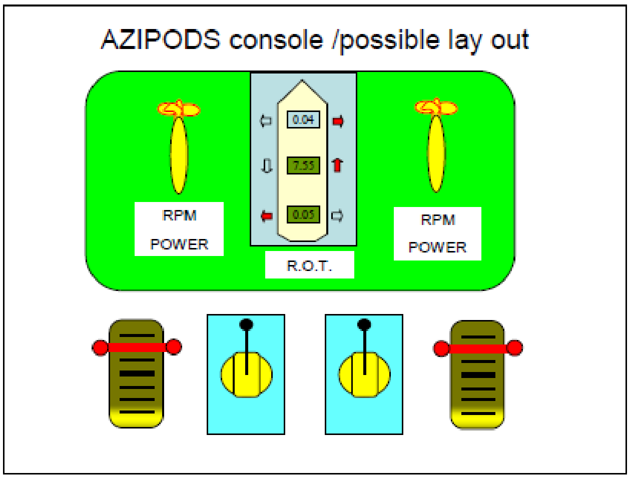

Figure 6: Possible recommended console layout

Work Package 4, Operational Practice, was aimed at collating, reviewing and auditing available material that is relative to the operation of azimuthing control devices when manoeuvring ships in Pilotage waters. This review allowed the identification of areas in which future research and development would be beneficial to Ships Officers and Marine Pilots of vessels fitted with azimuthing control devices.

A concrete recommendation from this study is that manufacturers of bridge equipment, both hardware and software, should be encouraged to standardise both control handles and modes of operation to avoid confusion among ships officers and Pilots. All controllers should be fully synchronised to assist and simplify the transfer of control between consoles during the manoeuvring phase of the voyage. It is recommended that the training courses currently on offer should be further developed to include more technical theory on the operation of ACDs. From this improved technical theory students will have a more comprehensive understanding and better insight into how the ACDs should be operated to obtain maximum efficiency, minimise mechanical failures and thereby prolong the working life of the units.

The current IMO STCW regulations were examined in detail and comprehensive recommendations for improving the current position made, ultimately leading to the development of an IMO Model Course for Basic shiphandling and advanced ACD ship handling. A need for further research in certain areas was identified, for example the emergency stop procedure. Such research should be aimed at obtaining accurate data, both from manned models and mathematical models, from which further development of best practice can take place. There are numerous different types of ACD units available which demonstrate a broad range of efficiency and operational practice. This would suggest that there is room for further testing on scale models to help understanding and development of future systems.

The four work packages identified and examined parallel streams of knowledge: hydrodynamic modelling, marine simulation, maritime training and operational practice; in order to elucidate not only the lessons available from the best practice in that arena, but also where synergies existed, and cross-disciplinary cooperation might therefore improve the impact of research and development outcomes.

Hydrodynamic Modelling

Work package 1 dealt with hydrodynamic modelling of azimuthing control devices (ACDs). Implementation of ACDs primarily affects the resistance, propulsion and manoeuvring aspects of ship operations, garnering both benefits and disadvantages, which must be properly researched to ensure that the full impact upon these characteristics is understood and hence properly modelled. The review of available literature and other data sources confirmed many initial expectations upon which the sometimes empirical science has been based, but also identified other areas where new phenomena have been observed, and further R&D is likely to be required.

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Podded propulsors are characterised by two main qualities: *an electric motor is located inside a hydrodynamically optimized submerged housing; the total unit is rotated with the propeller(s) by 360 degree rotation.* There are 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, for example Voith-Schneider propellers, Schottel propellers, outboard motor principle and rotating nozzle propellers. Real innovation is generally within the development and application of high power podded drives as defined above.

Figure 7: A Voith-Schneider propulsor

The ultimate aim of work package 1 was to identify and make recommendations for future research and development within the field of hydrodynamic modelling and testing of marine azimuthing control devices, both theoretical and experimental. The whole group of such devices includes pump jets, rudder - propellers, Voith-Schneider and azimuthing pod drives. Since, pod propulsors have been commonly applied for some years on different ship types, they were chosen as a representative type of ship propulsion system for subsequent analyses. The first step towards this aim was to review all available Azimuthing Control Device (ACD) knowledge. Primary sources for this included past and ongoing projects, conference series, technical maritime forums, and maritime associations. The review was structured around 'basic groups of interest', and included:

Ship Type	Simulator Manufacturers	Simulator Facilities
Test Facilities	Shipping Companies	Pilot Organisations

Table 1

The conducted reviews concerned modelling and test methods with special attention paid to ACDs and existing modelling validation methods. The gathered knowledge was encapsulated through up to date mathematical models and formulae. Reviews of modelling and testing methods made possible to recognise detailed physics aspects and hydrodynamic interactions accompanying exploitation of ACDs. All respective characteristics were analysed in the scope from the concept of test elaborations through its execution up to prediction elaborations on basis of received results. Thanks to available test procedures and critical investigation reports, it was possible to follow full paths of such investigation. The possessed basic hydrodynamic knowledge made possible to integrate the gathered knowledge in order to recognise introduced simplifications and corresponding gaps. It resulted in recognition of testing methods capabilities in respect to applied techniques and expectations. Having in mind respective remarks, comments and recommendations, necessary conclusions were possible and the best practice for manoeuvring model test procedures could be identified.

Since, dedicated training was planned within the project, in scope of azimuthing control devices application and operations, it was necessary to prepare a series of dedicated lectures in these fields in order to understand ACDs. Their main topics concerned new qualities introduced to pod designs and resulting new possibilities in range of open-water, resistance and propulsive characteristics followed by manoeuvring properties. Everything was assessed throughout their innovative qualities.

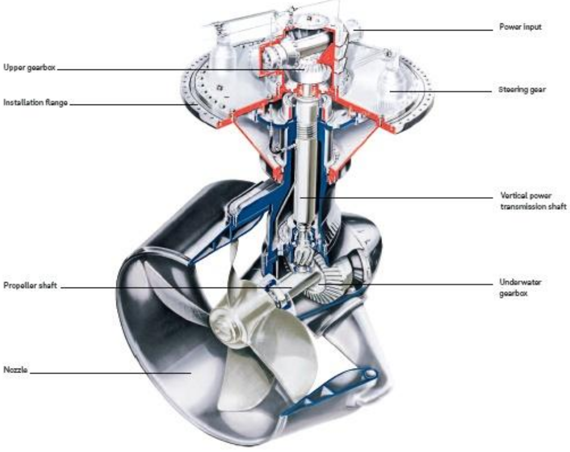

Figure 8: Schottel Rudder-propeller

Azimuthing Control Devices are simultaneously an innovative ship propulsor and a steering device. Although the concept has existed for some time, advances in technology and growing awareness of environmental concerns has accelerated their visibility to the market. The advantages associated with these new propulsion systems are predominantly higher operational efficiencies, good course stability and better environmental performance, although they also have their drawbacks. At first, these new propulsors demanded special dedicated approaches in fields of applied hydrodynamics. Moreover, these new systems required not only dedicated control systems which could guarantee proper and safe use of such systems but the qualified personnel as well. Pod units, the most commonly used ACDs, demonstrate:

- Improved speed-power efficiency via:
    - Better hull shape;

    - Bigger pay-load space;
    - Better alignment of propeller;
    - Less resistance from appendages;
- Improved manoeuvring performance;
- Better internal hull subdivision.

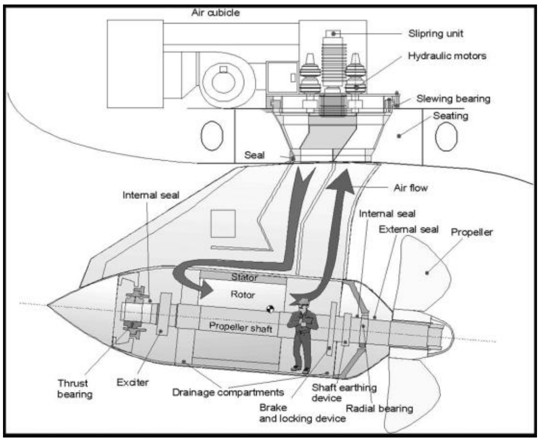

Figure : Inside of a pod unit

Basic hydrodynamic matters addressed
Speed-power prediction
Local interactions
Manoeuvring prediction
Prediction of structural loads
Hydrodynamic ship integrity

Table 2

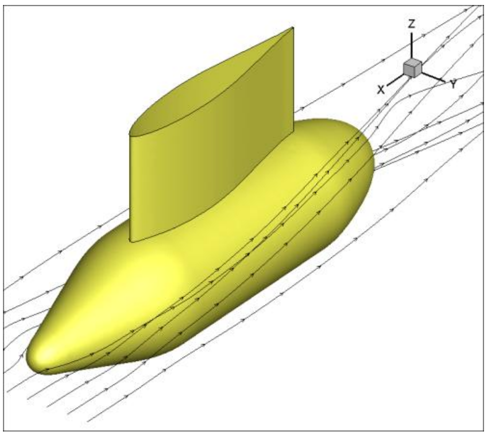

Figure 9: An example of flow streamlines along a pod housing

Example of "gap effect" between pod housing and propeller hub

The so-called "gap effect" results from the local geometry changes of the pod housing in range from podded propeller cap up to its cylindrical body. The abrupt cross section changes influence the local flow velocities generating additional axial forces between the cylindrical pod part and the podded propeller hub. This additional axial force changes podded propeller work point. This "gap effect" does not have any influence on propulsive characteristics but creates additional force that should be taken into account during podded propellers design.

Local pressure changes due to pod housing shape

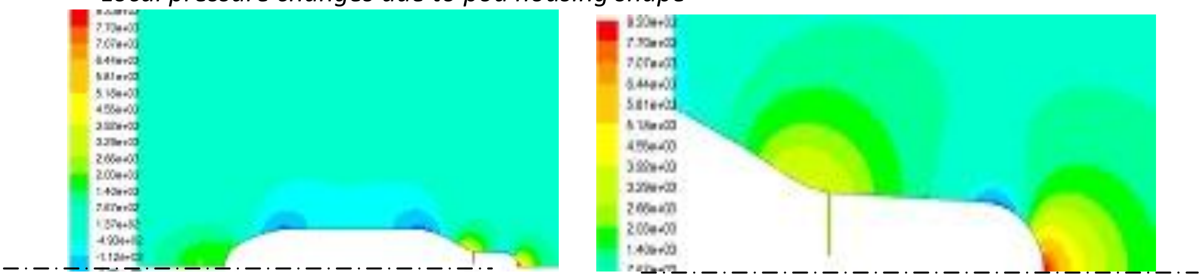

Figure 10: Results of CFD analyses

Example of interaction between ship hull and pod housing:

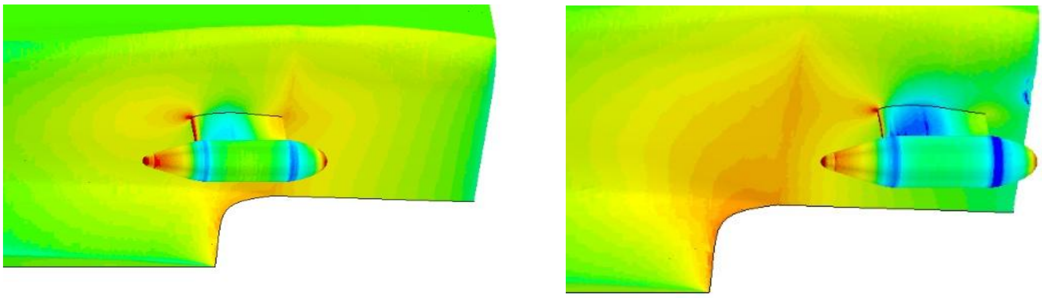

Figure 11: Changes of the afterbody pressure distribution due to pod location changes

Knowledge gaps in Azimuthing Control Device aspects

Podded ship hull resistance characteristics

There is lack of respective procedures concerning predictions of resistance characteristics of podded full scale vessels. The podded hulls can be investigated in two ways as bare hulls or as hulls with dummy pod housings as appendages in the design positions. Each of these approaches can have individual benefits and drawbacks.

Open water pod characteristics

The pod units introduce some new qualities in respect to classical screw propulsors. It results from presence of relatively big struts which working at different Reynolds numbers than a model hull and full scale ship, increase drag forces on its housing. Also separated pod unit creates its own wake that has big influence on podded propeller work point. Pulling pod units experience other effects influencing their work. It is a gap effect resulting from highly developed nacelle and propeller hub contours introducing pressure changes in the gap between the propeller hub and pod housing generating additional axial thrust that shifts the propeller work point.

Propulsive characteristics of podded vessels

Self propulsion tests are carried out to determine propulsive characteristics of full scale podded vessels in assumed service conditions and they are expected to deliver necessary data for podded propellers design. The main problem disturbing direct forecasting is included in the fact that model and full scale pod propulsors work at different Reynolds number. It results in higher podded propeller loads than full scale ones. Such a state forces to apply necessary corrections. The assumed service conditions are simulated by adding a friction correction force during a self propulsion test that should account for scale effect correction.

Manoeuvring characteristics of podded vessels

Manoeuvring characteristics of podded vessel are investigated in both experimental and analytical ways. Experiments are performed by means of free running models or as captive model tests. More advanced tests, which require specialised model basins and dedicated numerical tools, have also been recently developed, such as:

- Manoeuvring and course keeping tests in waves;
- Manoeuvring tests in confined waters, focused on:
  - Force predictions in shallow waters;
  - Bank effects;
  - Ship-ship interactions
  - Squat phenomenon.

Free running manoeuvring model tests

Are carried out on a lake or in dedicated model basins. Model trajectories are precisely controlled by GPS systems. The main drawbacks of such tests result from presence of scale effect what forces to conduct tests in the model self propulsion points. It is impossible to apply on a lake friction correction forces.

Captive manoeuvring tests

These tests are carried out in dedicated model basins with use of Planar Motion Mechanisms (PMM), Rotating Arms (RA), Circular Motion Tests (CMT), or Computerised Planar Motions Carriage (CPMC). In most of applications, these tests are used to measure forces acting on the model which are used to create mathematical models to simulate manoeuvres These tests free from scale effect and weather influences, but their accuracy depends on the mathematical model.

Scale effects

For manoeuvring, there is no established standard tests and correction methods to overcome scale effect yet. Before establishing a correct test and correction method for scale effect, it is essential to understand hydrodynamic phenomena during model tests and full-scale tests. It has been noticed that turning circles at full scale are larger than at model scale. Five potential sources of the inaccuracy are taken into account:

- Reynolds scale effects on the boundary layer thickness on the rudder surface;
- Differences in propeller loading between full scale and model propellers;
- Cavitation on full - scale rudders;
- Dynamic stall on rudders;
- Dissimilarity due to the power controller in full scale versus constant RPM on model scale.

Recently conducted tests have shown that no significant scale effects on the hull have been found. Nevertheless, scale effects may be expected on side forces and turning moments as function of Reynolds number.

Effects of propulsion point

The question whether manoeuvring tests should be carried out at model self propulsion point (MSPP) or at ship self propulsion point (SSPP) is still controversial. This is related with a problem how to make an inflow to a rudder dynamically similar between model and full scale ship. With SSPP, a propeller slipstream can be dynamically similar between model and full scale ship whereas decreased inflow to the propeller due to thicker boundary layer in the model cannot be considered. Traditionally, free model tests have been carried out at MSPP. Supporters of MSPP believe that higher propeller loading by MSPP can be cancelled out or balanced with higher model wake. However, this may apply only to single screw ships.

New quality in stopping manoeuvres

Azimuthing Control Devices have introduced new possibilities of stopping manoeuvres in respect to classical ships. They give chances to apply effective combinations of propeller revolutions and slewing angles so as to shorten a track reach. As a consequence temporary over-loadings of propulsion motors can be noticed. Some analyses or experiments are suggested to elaborate a kind of compromise taking also into account ship safety.

Knowledge capacity to eliminate identified gaps

The shipbuilding industry and ship operators have always been capable of implementing the newest innovations from applied sciences; a number of dedicated specialists were always capable to solve any technical problems Recently, even human factors have become an important factor of academic studies, as such there is available right away not only the complex technical potential but specialists from social domains as well.

Industry capacity to address noticed gaps in reasonable terms

Looking at ships equipped with ACDs, it is clear that their new qualities are connected with application of new, innovative propulsors and dedicated control systems. In majority of cases, traditional energy sources based on diesel engines have been replaced by powerful electric power plants. The suggested solutions to the identified gaps depend mainly on both the necessary costs and the importance of a given problem. The net technical problems of typical nature can be solved right away. In order to be up to date, research institutions should execute programs of permanent scientific developments suitable to challenges of the present time.

Recommendation for Future Research and Development

The performed reviews and analyses have shown out that there are some gaps and barriers in design, testing and operation of Azimuthing Control Devices which limit full realisation of their benefits, leading to the recommended future research and development strategies:

General

- Intensification of dynamic investigation as the most recommended for ACDs;
- Wider use of hybrid investigations joining experiments with advanced CFD tools;
- Development and application of artificial intelligence tools;
- Upgrade of respective model test procedures;
- Progress in experimental techniques;
- Wider applications of measurement uncertainty techniques;
- Intensify versatile validation works;
- New direction of research works accounting for the present technical development.

Speed power predictions

- Intensification of the scale effect compensation in resistance and self propulsion tests;
- Promotion of investigation of ACD single unit interaction with respective ship afterbody shape;
- Further analyses of multiple pod units interactions;
- New research works aiming to apply pod based hybrid propulsors and high temperature super-conducting motors;
- Precision improvement in speed - power prediction;
- New procedures for testing basic hydrodynamic interactions and gap effects;
- Harmonisation to ITTC test procedures.

Manoeuvring issues

- Further studies on course stability:

- How should IMO criteria apply to ACD ships?
- What changes can be introduced to classification societies' requirements?

- New research of scale effect in manoeuvring:
  - Collect and investigate model-ship correlation data in manoeuvring;
  - Stimulate the research on effect of the propulsion point depending on ship type and scale;
  - Develop a method to identify in advance whether model test results will suffer from scale effect or not;
  - Identify hydrodynamic coefficients which have large scale effects and develop their full scale correction method;
  - Investigate a ship-model correlation of coefficients by CFD;
  - Promote research to measure full scale flow into the propeller and rudder during manoeuvres;
  - Develop simulation techniques;
- Development in simulation techniques and new dedicated mathematical models up to 4-6 DOF;
- Elaboration of feasible stopping mode procedures;
- Modelling of effects in confined water, low speeds and large heel angle;

Structural loads

- Development of a method to identify the most vulnerable structure elements due to azimuthing control devices (ACD) work;
- Measurements of spike loads during manoeuvres;
- Analyses of gyroscopic effects as source of as additional propeller axis loads;
- Analyses of multiple ACDs work impacts on ship structure elements;
- New regulations in scope of the podded afterbody construction integrity (pod foundation, slewing bearings, anti-slamming precautions).

Marine Simulation

The capabilities of existing Marine Simulator facilities to accurately model azimuthing device interactions, including their application, validation and limitations was summarised. The key findings were that: in the range of small and moderate steering angles, modern simulators capture pod and other ACD interactions with very realistically; azimuthing control device (ACD) modelling and simulations for large steering angles requires comprehensive CFD computation combined with specialised model and full-scale trial testing; and hydrodynamic interaction of multiple devices also requires additional research efforts (including CFD) and validation test data. More specifically, this can be broken down into the following stages:

Review of ability to simulate azimuthing devices

This review included the capabilities of all simulators from PC-based simulators up to full-mission-bridge-simulators and manned model centres. The task collected data on full-mission-bridge-simulators and manned models simulators, and concluded that there is a lack of data relating to technical details of the Full-Mission-Bridge-Simulator in operation around the world. Often, these are simply unknown to an outsider, and other key data such as the types of ships being simulated, or the inclusion of shallow water effect, is not available.

Review of existing ship simulator capabilities

Existing simulator capabilities were also reviewed with respect to the ability to simulate the most common influencing factors that affect ships when operating in close quarters, including environmental effects such as: effect of proximity of the shoreline, bank effect, effect of proximity of other ships and other effects experienced by ships equipped with azimuthing control devices when manoeuvring in their most typical and critical situations. The hydrodynamic interactions experienced by a ship manoeuvring in shallow water or a canal, and their effect on manoeuvring characteristics of ships, either with conventional propulsion or ACD, as well as the hydrodynamic reactions between two ships meeting or overtaking each other at close quarters were all considered; as were escorting operations performed with ACD tugs, for example when a tug assists in braking or steering an escorted ship. It was found that the majority of simulator centres have the ability to simulate shallow water effect, but the progressive development of this effect with decreasing water depth is not always modelled correctly, and therefore further investigation is needed. There is also a general lack of information/data on tugs operating near the stern of pod driven ships.

Survey of industries' ability to simulate azimuthing device interactions

AZIPILOT reviewed the ability to simulate the interaction between azimuthing control devices of existing simulators. The capability and validity of the modelling used for the most common situations has been reviewed, namely the effects of hull-form on azimuthing control device performance, non-linear effect in azimuthing control device performance and operational models and effects on interactions. This task concluded 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 adequately model the interaction effects between different pod units, and shallow water effects on podded vessels. Interaction between two or more podded propulsors is important and it may affect the manoeuvring characteristics of a vessel in certain modes of control. When using large manned models for training this effect is automatically taken into account. The installation of skegs and fins improves dynamic stability, however at the same time making the turning ability characteristics slightly worse. How this effect is taken into account in mathematical models is uncertain, but some data from experiments with ship model tested without skegs or fins, and models tested with skegs or fins of different sizes installed are available and may be used. There is a lack of data on wake and form coefficients for ships with podded propulsors.

Review of ability to model bridge systems and human interface

When exploring the use of existing bridge systems, and reviewing their relevance when operating ships equipped with azimuthing control devices, the focus was on reviewing the capability and validity of the most common bridge systems. The methodology employed involved interviewing masters experienced in use of ACD propulsion, and manoeuvring experts visiting some ACD vessels and examining actual ACD operations on the spot. The recommendations were:

ISO 13407 Human Centred Design Process for Interactive Systems should be referenced. Consultation with user experts is required in addition to documented standardised elements. ACD use will become more widespread in the future, thus education and training is necessary.
It is easy for the master while manoeuvring to find him/herself in a cognitive overload situation due to the fact that two levers must be used simultaneously and possibly in very different configurations. Education and training, both simulator-based and in situ, are desirable.
Optimal bridge layout for ACD propulsion varies widely between similar and different types of vessels and the type of ACD arrangement, i.e. Azi-push or Azi-pull. Optimal bridge arrangement may be dictated by not only the vessel type, but also the type of work performed, e.g. Open sea, Confined waters, Anchor areas, Short track ferry or Tug assistance.
When transferring control of thrusters from e.g. the central console to the bridge wing, confusion can ensue if the joystick position does not mimic the arrangement on the central console. This may result in confusion or even in accidents, and further investigation is needed.
There is a clear need for optimal ergonomic lay-out and design of the bridge equipment, and particular attention should be given to the layout of ACD handling controls, display of ACD status information and take-over command features.

Table 3

Encapsulate knowledge using 'task analysis' feedback

The knowledge gained by these reviews was then encapsulated through a task analysis, to enable widespread dissemination and use. Guidelines for the selection and use of appropriate controls for different types of azimuthing devices were produced. A relatively large number of different Azimuthing propulsion units were identified as being in use, and because these often differ greatly from one another, there can be little consistency in design philosophy; the same can be said for ACD control units, it is clear that if any consideration is being given to the human element or ergonomics, then the manufacturers are not in agreement over what constitutes the best solution. Additionally, at least 9 different types of manoeuvres have been identified which may be frequently carried out on board. Further R&D effort is required to produce more harmonised and optimised ACD control systems fully fit for use by the ship handlers in various manoeuvring circumstances. Official standardisation of operating systems should be considered, as well as further consultation of experienced users to develop a standardised bridge layout for ACDs. The use of ACDs and standardised bridge layouts should be supported by educating and training in a simulator, ideally supplemented by on-site training.

Implement obtained knowledge in development plan

A number of recommendations for the improvement of the technology and the marine simulation industry as a whole and specifically when dealing with ships equipped with azimuthing control devices have been elaborated.

Full Mission Bridge (FMB) Simulators generally demonstrate good visualisation of simulation scenarios, with relevant current, wind, wave and channel effects; therefore improvements should focus on visualisation of the ship itself, and the inclusion of engine noise and ship motions (rolling and pitching). Best practice for standardised lay-out would meet these targets. The proposed best practice to simulate interaction effects would be to use experimental data from models where possible and validate the results of simulations using model test or full scale ship results by employing system identification procedures.

For **Manned Model Simulators (MMS)**, several recommendations for best practice are made:

Models that are suitable for simulation 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;
- correctly represent the form of underwater part of the hull including all appendages;
- 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;
- 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;
- and model movements on the manoeuvring areas should be monitored on line making possible assessment of all manoeuvres performed.

Figure 12: Four pod ship model during manoeuvrability tests

Manoeuvring areas (e.g. 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;
- 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;
- include 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.;
- be capable of providing areas where current and/or waves can be created where necessary.

Publication of Dedicated Project Journal

The AZIPILOT consortium wished to implement project dissemination through the creation and publication of a dedicated project *"Journal of Marine Simulation"*. As such, it was necessary to critically review the target market to see if a suitable niche could be identified. When considering whether to enter the competitive market of academic publishing, it is imperative that as well thought out business case be presented for scrutiny, to ensure that the most appropriate method of exploitation of the available scientific data is chosen, and that the decision to publish at all has been made on sound financial grounds. Publication of any peer-reviewed literature is time consuming, and can be prohibitively expensive, but if approached correctly is an unparalleled outlet for quality research to reach its intended audience.

The consortium looked at the market in which any publication would operate, and considered the most appropriate use of personnel time and effort, money, and the most valuable resource of all: research outputs. Implicit within the decision of how to publish, and where, are several questions hinging on the ability of different methods of distribution and publication to reach the broadest possible sphere of interested consumer, and the varied attributes of these available channels to deliver the optimum result for the Project, and the wider community interested in the hydrodynamic modelling, testing, simulation, training and practice associated with ship propulsion in general, and that of ships with the added complication of azimuthing drives in particular.

This report also briefly considered the background to the AZIPILOT Project, and what this brings to the debate regarding a suitable outlet for the dissemination of outputs; analyses the market in which a publication would be required to compete for market share. This all generated a publication format aims, scope, and rationale which were designed to best meet the needs of the identified market gap. It concluded that the publication of research findings, summarising the work undertaken within the four AZIPILOT work packages, would best meet the needs of project partners, the European Commission, and the European research community as a whole if this were undertaken within the existing sphere of specialised Journals in the four areas of interest which already have a large circulation, visibility and proven impact and track record.

Future Research and Development

This analysis of the current status of marine simulation research as applied to ACDs strongly suggests that there is further work to be done through research and development to improve the quality of marine simulation for vessels equipped with ACD. Several deficiencies have been identified in the available data sets which could improve the quality of numerical simulations, such as a lack of data:

on tugs operating near the stern of pod driven ships	*from (and proper use of) experiments with ship model tested without skegs or fins, and models tested with skegs or fins of different sizes installed*	*on wake and form coefficients for ships with podded propulsors*

Table 4

Human interface

This work has underlined the essential need of proper education and training of crews and operators in normal and abnormal situation, including overload situation, not only by simulation but also on-site. This issue of ergonomics of control systems is also particularly important, especially due to the fact that existing products 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. Therefore, further work has to be done to get more harmonized and optimal designed ACD control systems fully fit for the use by the ship handler in various manoeuvring circumstances.

Modelling

Simulations of manoeuvring with small pod angles have proven their efficiency. However, further work should be done to improve modelling and simulations for large pods angles, including the associated comprehensive CFD computations combined with the specialized model and full-scale trial testing. Further work (CFD and validation test data) should be done for improving the simulation of hydrodynamic interaction of the multiple pods.

Improved layout

In order to increase the lay-out and replicability of simulations, full mission bridges simulators should improve the visualisation of the ship itself and the inclusion of engine noise and ship motions (rolling and pitching). For manned model simulators, minimum model scale is important, and they should properly represent the underwater form, be capable of using tugs, and evolving in large manoeuvring areas, sheltered from strong winds, capable to reproduce different types of configurations in terms of port facilities, docks, water depth, canals, currents.

AZIPILOT examined many aspects of the Marine Simulation domain for ships operating with ACD. This analysis has shown that there are still a number of further activities that can be undertaken in order to improve the quality of simulation (both full mission bridges and manned model simulations), addressing all stakeholders and especially ship owners/operators and pilots.

Maritime Training

This section of the project’s effort aimed 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 was performed, comparing the subject state-of-the-art and possible cross-disciplinary contribution from the industry as a whole. The results identify critical knowledge gaps that restrict progress, and possible ways to address such short-comings. The main objectives were 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.

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.

The recommendations can be summarised as:

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

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).

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.

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.

Knowledge gaps

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 ACDs 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.

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.

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 to the sector as a whole.

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.

Training Needs

Recent 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; 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. Important feature that might be seriously affected by training is way of handling critical situation. This was discussed *inter alia* by Bea, who did show that proper training may considerably reduce risk of mishap in case of emergency when action is planned and executed in time. Once people were faced with critical situation during the training they will react quicker when such situation appears in reality.

Simulator

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. Simulator training is expensive; therefore the simulator courses must utilize time available in the most effective way. The effectiveness of a simulator in training mariners depends on the simulator capabilities to simulate 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.

Simulation of azimuthing propulsion units

Vessels fitted with azimuthing propulsion constitute 6.9% of all vessels WP4 questioned 8044 pilots questioned on the matter of the need for training on azimuthing propelled ships, of which 2334 responded, and of these 96% use azipods. 736 of these pilots (32%) received some kind of training on azipods. About 40 pilots coming to the SRTC training centre for ship handling training were also questioned regarding the 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. 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.

Evaluation of knowledge and industry capacity to address gaps

There is adequate capacity to develop training programs suitable to ensure the necessary transfer of ACD handling knowledge and skills. The operational 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. Human factors tools and knowledge needed to carry out the research required have been developed, tested and approved already. The capability to design and implement the improvements of ACDs within the capacity and knowledge of the industry today. The available simulators, FMBS or MMS, are fully capable of carrying out research into manoeuvring strategies to assess energy efficiency.

Existing simulators used for training in handling of pod driven ships

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. 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. These range from desktop 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 tracking of the model is available. Important feature of manned model exercises is that all manoeuvres are performed not in real time, but in accelerated model time. This may pose some difficulties for trainees at the beginning who must adjust to the accelerated time scale.

There was direct or indirect information available on training courses realised in the following training centres:

- MITAGS- Maritime Institute of Technology & Graduate Studies 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 for Simulation and Maritime Training (Owner: Carnival), the Netherlands

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:

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

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. WP2 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, the flow around the ship hull and appendages and in particular separation phenomena might be not reproduced correctly in the model scale. Fortunately, with models 8 to 15 m long the Reynolds number is sufficiently high to avoid the majority of such effects. One remaining difficulty with manned models is impossibility to reproduce wind effect. At present there are very few simulator facilities using manned models. 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 $\lambda=25$. 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.

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

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.

Identification of barriers
The barriers to improvement in maritime training worldwide are identified as:
- 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.

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.

	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						

Table 5: ACD usage scenarios

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).

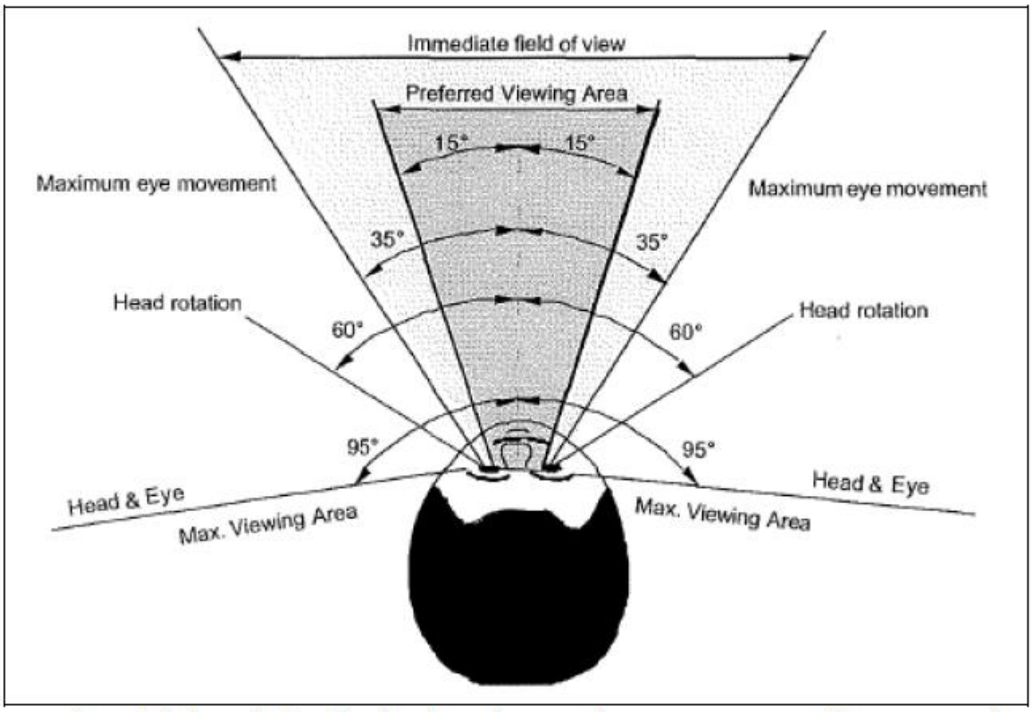

Figure 13: IMO recommendation related to visibility

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. It is important that all order/action communication systems be two-way. The distance between adjacent workstations should be sufficient to allow unobstructed passage to persons not working at the stations. 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 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. The most important and/or frequently used displays should be located within the operator’s immediate field of view and clearly labelled. Adjustable lighting should be provided for controls and visual displays, alarms should be provided to indicate sensor input failure or absence and should only be capable of being cancelled if the alarm condition is rectified. 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 ACDs produce additional comments. Some form of the thrust direction indicator (TDI, figure 14) is important.

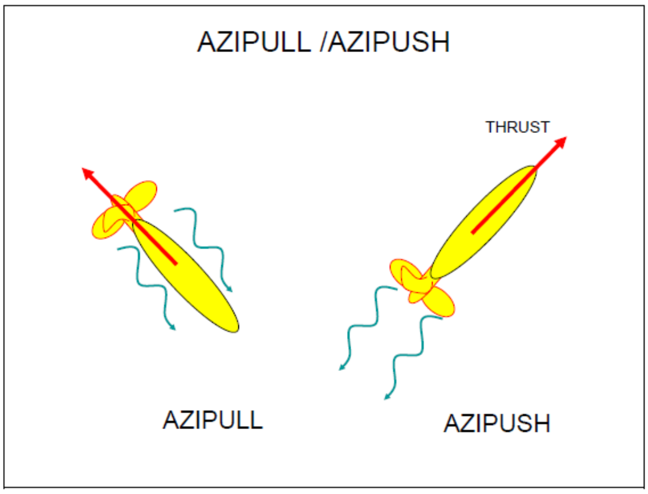

Figure 14: Display of AZIPULL and AZIPUSH

Hutchins et al 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, but this is considered an ‘overload’ situation. The solution may be using some automation.

Figure 15: Triple instrument (rpm, pitch, angle)

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 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.

			Open water	Open sea off shore	Confined waters	Anchor areas Port	Narrow channel /	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											

Table 6: ACD Control options and requirements

Recommendations on Best Practice for Standardised Procedures

Training in 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, it is a long and tedious process. Some critical situations may also never occur during the training period. Therefore training on simulators is considered to be best practice. Both types of simulator offer different possibilities to acquire skill in ship handling. 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.

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;
- Familiarisation with specific pilotage areas which could be simulated visually;
- Bridge team management and master-pilot interaction;
- Emergency procedures could be simulated;
- Blind pilotage, use of radar navigation, and use of electronic charts.

Full Mission Bridge Simulators - Limitations

- Lack of feel for the ship when manoeuvring;
- Lack of feeling external environment;
- The mathematical model representing ship manoeuvre is important and may be not sufficiently accurate;
- Final phases of berthing and close proximity manoeuvres are not realistic.

Manned Models Simulators- Advantages

- Proper representation of hydrodynamic forces;
- Close proximity realism;
- Realism in emergency situations;
- Possibility to exercise anchoring and other special manoeuvres;
- Possibility to perform manoeuvres in current and tide;
- Effective use of time;
- Understanding physical phenomena.

Manned Models Simulators- Limitations

- Accelerated time scale: the trainee must think and act more;
- Some trainees, especially those having some experience with sailing small pleasure motor boats try to handle models available for training in a similar way;
- Although visibility is as similar as possible as that from the full size bridge, full similarity is impossible to achieve;
- Wind effect is not properly scaled down and is usually to strong.

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.

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 (Maritime Training).

Research

It is recommended that further research is carried out looking at:

- 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)?

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 recommended that future efforts 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.

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 should be developed. 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. 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 ACDs. ISO 13407 Human Centred Design Process for Interactive Systems should be referenced**.** 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. Certain pedagogical methods should be considered when designing the bridge layout. 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. Official standardisation for operating systems should be consulted further as well as further consultation of experienced users in order to come to a standardised bridge layout for ACDs. 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.

Operational Practice

This task will look at the conclusions and recommendations made in the previous tasks within Work Package 4 and from the results obtained and observations made will identify areas in which future research and development could be undertaken that would be beneficial to Ships Officers and Maritime Pilots of vessels fitted with azimuthing control devices.

Review of Existing Operational Practice

Deliverable 4.2 set out to establish the extent and content of existing operational practice and guidance issued by ship owners, equipment manufacturers, Pilotage Organisations to Ships Officers and Maritime Pilots. This was achieved through interviews with Ships Officers working onboard Azimuthing Control Devices (ACD's) equipped vessels and through a worldwide survey of Pilot Organisations and Pilotage Authorities responsible for providing pilotage services. There is a need to increase the understanding of both the ship owners/operators and Pilot Organisations/ Authorities towards providing suitable training to Ships Officers and Maritime Pilots operating onboard ACD equipped vessels.

Review of Accident and Incident Reports

Deliverable 4.3 undertook a review of accident and incident reports that involved ACD propelled vessels.

The above summary shows that while no one fault exists in all the incidents there is some commonalty in that manoeuvring error and transfer of control issues are relevant in 60% of the incidents. In the incidents highlighting manoeuvring error as a factor the reports recommend further training and familiarization as being necessary despite the individuals having considerable experience at sea this has not always been onboard the vessels involved in the incident. In the incidents highlighting transfer of control issues the reports recommend improved onboard procedures and an improvement in equipment knowledge for the ships officers. The number of incidents investigated is minor when compared to the total number of Very Serious and Serious Incidents available for inspection. It was expected that more incidents would have occurred due to an expected lack of appreciation by personnel of the special characteristics of azimuthing propulsion and inadequate onboard procedures. Further training and familiarisation is necessary and there should be an improvement in onboard procedures and an improvement in equipment knowledge for ships officers.

Review of bridge operational practice and the human interface

Deliverable 4.4 focuses on a review of bridge operational practice and human interface, in particular it addressed ships using ACD's. The main objectives were to promote understanding of the needs of the bridge crews and ensure that this information is passed back to the bridge and systems design engineers, with the scope of enhancing usability and efficiency of these systems. It concluded that hardware (control handles) should be configured so that they can only be turned at the same rate as the pods can be moved. This is an approach that perhaps would be problematic for the operator who is use to having a delay between giving an order and that order taking effect and such configuration would be of no value to the operator. Bridge consoles could be equipped with an alarm system (visual or acoustic) so that the operator could be supported during manoeuvres, being continuously aware of the situation and warned in time if something is going wrong. There should be an agreement among all manufacturers of ACDs with a view to standardise their equipment in terms of tools available, labels, wording used, etc. In that way, operators could be familiar to the systems whatever ship they sail and risks of errors connected to misunderstanding could drastically be reduced.

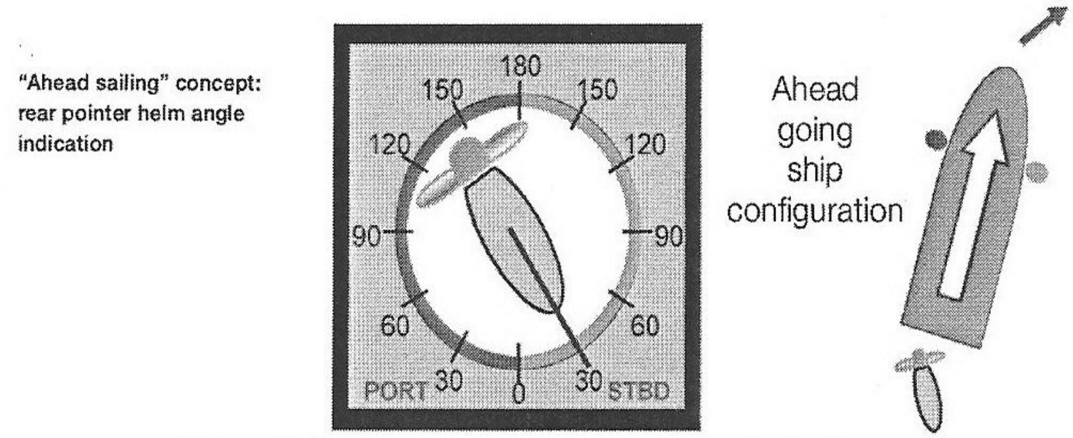

Figure 16: Example of Thrust Direction Indicator

Deliverable 4.5 summarises knowledge gathered in other tasks into an accessible form and in doing so proposes practical solutions for handling ACD propelled vessels. Typical manoeuvres were undertaken both in normal and emergency scenarios with a podded manned model. For turning circles the effect of twin pods on the turning diameter is similar to that of a rudder with twice the angle. In the situation of experiencing a pod failure the turning diameter is less affected when the inboard pod is still functional.

With regard to crash stops there are several suggested methods of quickly bringing the vessel to a stop. The manufacturer ABB suggest in their Operating Instructions that the most effective way to perform a crash stop is 'The Pod Way': turning the pods 180º outboard thereby maintaining positive thrust throughout. The Operating Guidelines suggest the pods be turned outboard but state it is not forbidden to turn the pods inboard. During interviews with ships staff experienced in ACD operations this is indeed the preferred method. This action can also activate the control programme for the propeller revolutions so that they are automatically decreased as the pods reach 90 degrees and as the pods turn through to 180º the power is increased to full, reducing stresses on the pods during rotation. An alternative crash stop method is to turn the pods inboard 90º and use the transverse arrest method to slow the vessel down, but this method not only has the water directed outboard acting as braking force but is also supplemented by the drag effect of the pod unit(s) themselves. From the above it is clear that further trials and testing using both physical and mathematical models are required to evaluate further the above methods and obtain more data, so that can be included in future training programmes. In the course of such trials the stresses placed upon the units and ships structure during this manoeuvre should be explored.

Future Research and Development

The tasks performed as part of Work Package 4 strongly suggest that there is still further work to be done, through research and development to improve the operational practice for vessels equipped with ACD's.

Bridge Hardware Development

Manufacturers of bridge equipment, both hardware and software, should be encouraged to standardise both control handles and modes of operation to avoid confusion and errors among ships officers and pilots. All controllers should be fully synchronized to assist and simplify the transfer of control between consoles during the manoeuvring phase of the voyage. Future development of control handles should consider either an automatic system that prevents large volumes of water being directed onto another pod as standard and/or the inclusion of an alarm system to indicate to the operator when an ACD is not being operated in the most appropriate manner. During the course of the project the use of automatic systems were identified as being used by one ship operator/owner but this was the exception rather than the norm. With regard to the incorporation of an alarm system such warnings are commonly used through the use of haptic controls in aircraft cockpit instrumentation to alert the pilot to a stalling situation and this technology could be extended to the maritime sector. It is often suggested by equipment manufacturers that standardisation leads to a stagnation in development but again drawing comparisons with the developments in aircraft cockpit control and monitoring devices this suggestion cannot be substantiated.

Training Programmes

During the course of the Project it has proved difficult to obtain information issued to ships officers and Pilots from manufacturers and ship owners/operators. One operator had issued comprehensive guidance but the work of the project came to the conclusion that in some areas this guidance was in fact not very practical to apply. The Project has looked at the various training programmes offered by both Manned Model Centres and Bridge Simulator Facilities. Students attending such courses have reported that they have all offered invaluable training into the operation of ACD's while at the same time improving operator confidence. WP 3 has comprehensively examined the current training available, whilst WP 4 has examined the current operational practice onboard ACD vessels.

From the work to date across the whole Project it is recommended that the training courses currently on offer should be further developed to include more technical theory on the operation of ACDs. From this improved technical theory students will have a more comprehensive understanding and better insight into how the ACD's should be operated to obtain maximum efficiency, minimise mechanical failures and thereby prolong the working life of the units. Once developed and agreed between the various training facilities the existence of such a course should then be brought to the attention of Pilot Organisations, Ship Owner Representatives and Maritime Training Facilities. The contents and structure of training courses currently on offer should be reviewed with the objective to gradually introduce the student into the complexities of the operation of such ACD units and gradually introduce in small increments more complex manoeuvres, as the training course progresses. For Pilots in particular the requirement to begin training on such units at a basic level is particularly necessary as the evidence from task 4.2 indicates that they are unlikely to have undergone any basic training with ACDs.

The use of a standard verbal terminology, as suggested by Baken & Berkley in 2008, could be incorporated into the IMO Standard Marine Navigation Vocabulary (SNMV), which was updated by Standard Marine Communication Phrases (SMCP) and adopted in 2001. The use of such phrases, overcomes the problem of language barriers at sea and avoid misunderstandings which can cause accidents. While the operation of ACD units lends itself to on hands operation by the Master or Pilot during the course of the Project it was discovered that as a result of poor equipment layout and/or failure not all vessels were manoeuvred from the bridge wing control console position. This led to the use of verbal orders being issued by the Master/Pilot to the operator at the central console. However, understanding this depends on international definitions of what, for example, 'inboard 30º' or 'positive thrust' means, also the result for pulling pods, may well be different for pushing pods. Other tasks within the project have highlighted the many different types of ACD's are available and as such the use of a standard verbal terminology that would be applicable to all unit types and methods of operation would be difficult to achieve. However the existence of such terminology should be acknowledged. Hence, a language that is 'result orientated' may achieve better universal results.

> During one ship visit it was noted that the Master gave orders by the use of negative and positive numbers in recognition of negative and positive thrust, whilst maintaining both controls in a 'fixed' T bone position. In this instance the units were set at the desired angle and this angle was maintained throughout the manoeuvre, thereby not taking full potential of the azimuthing capability and also produced situations when water was being sent onto the adjacent unit and the fin keel thereby increasing the risk of equipment damage and uncertainty of exactly where the thrust was going. During this visit and observation (which was recorded on video) of this manoeuvre, it was noted that the operator of the controls at one point became confused and in fact placed the thrust levels at something different to that ordered (negative thrust, when positive thrust was clearly ordered), fortunately without any untoward consequences on this occasion. This highlights that verbal commands with multiple units can easily lead to confsion and errors.

Figure 17

However, generally the control of ACDs tends to be a tactile 'hands on' practice and giving verbal commands in a multi unit system would be prone to errors, especially in the translation and a maybe a rather rigid method of using this type of versatile propulsion control. However, it is recognised that any 'hands on' approach does have a tendency for a single point error, that may not be picked up by other members of a 'bridge team' and we would recommend this an area of further research. A pilot of an aircraft has always operated with a 'hands on' approach and has never used verbal commands but is supported by strong procedures and often a co-pilot.

Emergency Stop

With regard to the procedure to follow to execute an emergency stop, information obtained from a manufacturer suggests rotating the units through 180º thereby maintaining positive thrust at all times. During the review phase of the project this approach was supported by an experienced ship master who reported that during sea trials of a large cruise liner, the use of this manoeuvre brought the vessel to a stop in three ship lengths from an initial speed of 15 knots whilst maintaining the ships heading. This emergency stop procedure is to be distinguished from a controlled slow down at the end of the Cruise Mode period and prior to entering the Manoeuvring Mode. During this controlled slow down the vessels speed is slowly reduced by a gradual decrease in revolutions while maintaining the planned course as the vessel approaches the Port Limits.

There is another recognised way of bringing a vessel to a stop quickly and that is through the use of the transverse arrest. The units are operated through 90º so the water is directed away from the vessel. This 'wall' of water at 90º to the direction of travel creates a breaking force, which is further supplemented by the drag effect of the units themselves. There is a need for further research into the above methods to obtain accurate data, from which further development in the use of an emergency stop procedure can take place. The results so obtained could then be programmed into the ships software, so that once the emergency stop is ordered the units will respond automatically to the programmed software.

Deliverable 4.6 summarised the current operational practice and limitations of ACD units that are currently available on the open market. The many different types available at present have many different freedoms that will obviously produce many different results in terms of efficiency and operation. This would suggest that there is room for further testing on scale models to help understanding and development of future systems.

Improvements in Current Operational Practice

Current onboard operational practices and ship designs specifically related to ACD vessels were investigated and recommendations for improvements made. A clear majority of Pilots and ship masters have expressed an opinion that there is the need for specific training courses for ships equipped with Azimuthing Control Devices (ACD's), in particular to enhance knowledge and skill in handling ships in a safe and intuitive manner with Azimuthing propulsion devices in varying critical situations. This is necessary in order to improve safety at sea, especially when berthing or unberthing.

However, whilst Ship Handlers, both Masters and Pilots, overwhelmingly want to be trained to use ACDs and that STCW requires them to be trained, depending on one's interpretation of the Code. Despite this Ship's Officers, Masters and Pilots who operate ACD's have not received training in the use of ACD's. Does this imply that there is something wrong with current regulation, as there appears to be a mismatch between what is expected and what in happening in reality. There are some recommendations to improve safe operational practice:

- Standardisation of ACD design and terminology (either across a fleet or better still across the whole industry)
- Synchronisation of ACD's in the different manoeuvring positions which simplifies procedures for changing control
- Design of Haptic feed-back systems informing the user of the status of the system
- Develop and practise on board procedures
- Be practised in using equipment when a unit fails
- Be familiar with emergency scenarios and procedures
- Promulgate manufacturers recommendations/limitations of equipment
- Mandatory training in ACD ship handling for watch keeping officers, masters and pilots.

Deliverable 4.8 offers a discussion of the general engineering implications when selecting ACDs, and more specifically, azimuthing pod-drives with the aim of providing the practicing naval architect with a background to the technology and general guidance for its application. The potential benefits of ACDs have proved very attractive to ship operators who, in turn, have demanded more and better from the pod manufactures. This forced evolution has placed significant demand on the pod manufacturers to respond, authorities to legislate and on the crews of pod- driven ships to learn how to best operate these new technologies. The modifications in the stern-form can offer better use of space for car decks and the manoeuvring performance is quite suitable for the typical mission profile of Ro-Ro and Ropax applications. Also, while the good manoeuvring performance is most attractive for missions with substantial harbour operating time, the pod solution is shown to be equally applicable for long haul routes; including fast ship applications. Pods can offer advantages for high-speed applications but careful attention must be given to find the optimal balance between motor-size and hydrodynamic efficiency as well as to cavitation performance. The main advantages offered when using pods is the improved manoeuvrability and propulsive performance. However, it is also shown that pods experience significant spike loads that are in origin related to dynamic manoeuvring. Consequently, it is recommended that the preliminary design be as course-stable as possible; reducing acceleration dependent loading and ensuring good course-keeping behaviour.

For the pod structure, and more specifically the bearings, it is important to consider the gyroscopic precession loading, a finite-element analysis using a global-local technique is recommended. One final qualitative advantage of the pod solution is identified as the greater flexibility with the general arrangements. This can have significant impact on both the space arrangements and the redundancy capacity of the ship. With the application to a wider range of ship-types and with increasingly innovative designs, it is certain that we will see many new varieties of efficient and profitable pod-driven ships in the coming years.

Recommendations for Training Programmes

The objective here was to compile the main project outcomes into a form that is readily exploitable for use in Maritime Pilot training and the wider maritime industry. Specifically, the STCW95 (Standards for Training, Certification and Watch-keeping) Code regulates the required competences for all ships operators. According to the STCW95 code, ship masters and chief officers functioning at management level onboard ships more than 500 GT shall possess very specific competences including 'be able to respond to navigational emergencies' and 'manoeuvre and handle a ship in all conditions'.

In theory, everyone with a STCW95 certificate should have met these shiphandling requirements. Experience shows that whilst some shipping companies have met and followed this standard, sadly many have not. Asking why is beyond the scope of this report, but it is a very interesting question nevertheless. Our studies within the project indicate that training for ACD's is necessary and operators are keen to embrace such training. However, before specialist ACD's training can be specified, we have to assume a basic level of competence in shiphandling first. Hence, candidates should have attended a basic shiphandling course prior to embarking on a specialist ACD course. There is nothing in the Code that is specific to training on ACD's. However, some parts could be interpreted as such. This is unsatisfactory, as experience has shown that the 'good operators' do take up appropriate training, whilst many do not. It is recommended that a specific specialist training regime should be added to the Code for ACD vessels.

Pilots are not covered by STCW95, although Resolution 10 invites IMO to consider developing provisions covering the training and certification of Maritime Pilots, through which **IMO Resolution A960 (23)** (Recommendations on training and certification and operational procedures for Maritime Pilots other than Deep-Sea Pilots) has been developed in 2004.

European Training and Certification Standards, ETCS, was developed in 2005 by the European Maritime Pilots' Association as a template for training Maritime Pilots and some European countries have or are currently in the process of embracing these standards. Pilotage is a port state control activity that takes place in territorial waters and is inherently local in nature and therefore difficult, if not impossible, to apply to an International Standard. There are numerous national and international codes and recommendations but little, if anything, is mandatory. STCW95 resolution 10 invites IMO to consider developing provisions covering the training and certification of Maritime Pilots and we would commend ETCS as an appropriate template to take this forward to be developed, whereby provision for specialist ACD training for Pilots could be made.

Further work is necessary to discover a more practical solution to the problem of verbal commands, should they be necessary, on such versatile and tactile equipment. We would recommend a 'result orientated' approach due to the variety of ACD's encountered (pulling/pushing). The many different types of units available at present that have many different freedoms. This would suggest that there is room for further testing on scale models to help understanding and development of future systems. A clear majority of Pilots and ship masters have expressed an opinion that there is the need for specific training courses for ships equipped with ACD's, in particular to enhance knowledge and skill in handling ships in a safe and intuitive manner with Azimuthing propulsion devices in varying critical situations. This is necessary in order to improve safety at sea, especially when berthing or unberthing.

The main advantages offered when using pods is the improved manoeuvrability and propulsive performance. However, it is also shown that pods experience significant spike loads that are in origin related to dynamic manoeuvring. Consequently, it is recommended that the preliminary design be as course-stable as possible; reducing acceleration dependant loading and assuring good course-keeping behaviour. For the pod structure and more specifically the bearings, it is important to consider the gyroscopic precession loading. For the structural analysis, stress concentrations factor methods are found to provide unreliable results due to complicated loading patterns and three-dimensional effects. Consequently, a finite-element analysis using a global-local technique is recommended.

Conclusion

AZIPILOT examined many aspects of the Operational Practice currently engaged by Mariners working onboard vessels propelled by ACD's, the maritime training given to these practitioners, the efforts to simulate as near as possible to real-life situations, and the hydrodynamic modelling underpinning all of this. During this examination it has become apparent that there is still a number of unanswered questions and further work to be undertaken to ensure that procedures are in place and comprehensive training programmes developed and made available to ship owners/operators and Pilotage Authorities responsible for the training of pilots. Manufacturers of bridge equipment, both hardware and software, should be encouraged to standardise both control handles and modes of operation to avoid confusion among ships officers and in particular Pilots. From the work to date across the whole Project it is recommended that the training courses currently on offer should be further developed to include more technical theory on the operation of ACD's.

The IMO STCW (Annex Chapter II) Table A-II/2 (page 42) should be amended to reflect a specific mandatory requirement for specialist training with ACDs and any other unusual or extraordinary manoeuvring/propulsion devices.
The IMO STCW (Annex Chapter II) Table A-II/2 column 3 (page 48) *'Methods for demonstrating competence'* that 'Examination and assessment of evidence obtained' from '*Approved in-service experience'* is removed.
The IMO STCW Annex Chapter 5 Section B-V/a (Page 255) is amended accordingly to specifically detail ACD vessels.
The IMO Resolution A960 (23) Annex 1 - 5.5 is amended with a paragraph detailing 'knowledge of and specialist training in the manoeuvring of ACD's or other unusual or extraordinary manoeuvring/propulsion devices'.
STCW95 Resolution 10 invites IMO to consider developing provisions covering the training and certification of Maritime Pilots, from which A960 (23) has been developed and we recommend that this should be amended to encompass training in ACD's for pilots. (ETCS (Education, Training and Certification Standards) has already been developed in Europe and this would provide a suitable model for the certification and training of Maritime Pilots inclusive of provisions for ACD's)
The IMO Resolution A960 (23) Annex 1 - 5.5 is amended with a paragraph detailing 'knowledge of and specialist training in the manoeuvring of ACD's or other unusual or extraordinary manoeuvring/propulsion devices'.
IMO Model Course 7.01 (1.9 Manoeuvre and Handle the Ship in all Conditions) needs urgent updating to include Full Mission Bridge Simulators (FMBS) and Manned Model Simulators (MMS) as methods of determining competency in Ship-handling. There is a need for further research to obtain accurate data from which further development in the use of an emergency stop procedure can take place.

Table 7

Looking at present development of the world industry and sciences it does not seem that any barriers might stop or slow down implementations of ACDs. The same situation is with noticed gaps to be supplemented. Since, the matter of gaps concerns domains supervised by IMO, classification societies and national regulation bodies, possible compensatory actions can be easily organised at both national and international level. Dedicated thematic conferences can collect all signalled problems by interested in bodies and institutions. It will be natural that specialised bodies like ITTS or ISSC will elaborate due programs of necessary precaution and thematic studies. The quality of results will depend on availability of respective references and degree of difficulties. In order to accelerate necessary development and to guarantee a quality levels, the coordinated research projects seem to be a solution. However, an available system of thematic data bases will be indispensable for reliable and consistent conclusions.

Effective implementation of ACDs introduce new technical and operational problems which can be solved in micro and macro levels due to its weight. In order to formulate the best strategy for addressing industry needs, it is indispensable to elaborate a consistent scheme of necessary activities leading to assumed targets. The scheme of Formal Safety Assessment (FSA) can be considered as a good template for this work. The first item should identify a problem in all possible directions by recognised specialists who will be able describe entirely the actual situation against surroundings against the possible technical risk. Such an analysis will assess importance of a given matter what facilitate further steps. It will determine whether the problem can be solved at the enterprise, branch, national or international level, in respect to available capital. A given technical problem can be solved with assistance of a recognised research institution which can be able to start an internal, national or international research project. It will depend on its complexity and urgency. Also thematic trainings can be useful for solving problems of the minor importance. Independently, specialised bodies like ITTC to be informed so as to start necessary statutory steps.

Impact

The AZIPILOT project aimed to address the multiple issues surrounding the training of maritime operational staff in the specific and particular requirements of piloting vessels fitted with all types of azimuthing propulsion. Bringing together the expertise of the four main disciplines (operational practice, maritime training, marine simulation, and hydrodynamic modelling) for the first time, this project has succeeded in significantly increasing the cross-disciplinary knowledge base for this specific, but vital, discipline. Through a varied and engaged programme of activities over three years, AZIPILOT has amassed a wealth of knowledge which can be used to improve the training provided to mariners of all classification who are likely to come into contact with, otherwise often counter-intuitive, azimuthing propulsion.

The project has produced academic papers focussing on the azimuthing propulsion specific challenges facing each area of expertise, currently in the process of acceptance and publication in peer-reviewed academic journals, the criteria set for selection of journal include maximising the reach of the article (via circulation) and ensuring the message meets its target by aiming to publish in the journals with the greatest scientific track record (impact factor). Other publications have focussed on specific discrete studies undertaken within the project, or on the lessons learnt by each discipline from their interaction with each other, unique to this project consortium. Although an initial business case for a stand-alone project journal was completed, it was concluded that exploitation of existing channels for publication would not only provide better monetary value to the Project, but also would guarantee much greater visibility of project results, and hence impact generated from this dissemination activity.

Presentations have been made at various high profile Conference Series, including MARSIM (Panama in 2009, and Singapore in 2012), RINA Human Factors in Ship Design, Safety and Operation (London, 2009 & 2011), the International Maritime Pilots Association Conference (Brisbane, 2010), and the European Maritime Pilots Association Conference (Amsterdam, 2011). Where allowed, these papers and presentations are available to be freely viewed at http://pilot.ncl.ac.uk. As further papers or presentations become available, these will be added, and thus the AZIPILOT website will remain an up-to-date comprehensive portal for the dissemination of information and research in the area of intuitive operation and pilot training when using marine azimuthing control devices.

A key exploitation aim of the project was to amass sufficient materials, appropriate for the formulation of a dedicated maritime training programme. Issues that are specific to the training of bridge-crews that should operate ships equipped with azimuthing control devices have been addressed, and initiatives have been put in place to provide, freely and without prejudice, a framework for the provision of simulator and manned-model based training programmes in basic shiphandling, generic to all types of propulsion including azimuthing, and a Specialist ACD (Azimuthing Control Device) handling course. The specifics of these frameworks, and the analysis of existing regulations and provision which informed them, is available at http://pilot.ncl.ac.uk.

A critical mass of materials suitable for the formation of a dedicated training program will be compiled and collated into a readily accessible form. The implementation of this material will be addressed by the project by specifying a detailed development plan; which is addressed in each Work Package.

AZIPILOT partners providing maritime training have implemented the recommendations in their own training programmes already, for example, the Foundation for Safety of Navigation and Environment Protection (Ilawa, Poland) have implemented the following changes to their provided courses:

> *"Two types of specialised ship handling courses involving POD propelled vessels are now offered and conducted for participants from different countries.*
>
> ***A]** Specialised 4, 5 days or 3 days handling courses for training on Pod propelled vessels:*
>
> > *1. Specialised TRAINING COURSE FOR SHIP MASTERS AND PILOTS ON AZIPODS DRIVEN SHIPS*
> >
> > *2. Specialised TRAINING COURSE FOR AZIMUTH ASD AND TRACTOR TUG MASTERS AND FOR ESCORTING OPERATIONS (Full Mission Bridge Simulators and Manned Model Simulators)*
>
> *Programmes of both types of courses are included in the publicly available Deliverable 3.5 (pages 43-44), as is detailed information about the courses together with some photos and results of monitoring. The Appendix to this document includes text of specialised lectures given to participants. Participants also receive printed text of those chapters (Chapter S1 and S2).*
>
> ***B]** Short one day training course on Pod propelled vessel was included to all basic and advanced training courses for pilots and ship masters conducted regularly at the Centre. This was done upon request of the majority of participants. Participants also receive the abbreviated version of the above mentioned lecture and its printed version."*

AZIPILOT stated an aim to formulate a dedicated University level engineering lecture series. As direct response to this aim, a Masters level module has been introduced in the School of Marine Science and Technology at Newcastle University which specifically addresses this aim. Formulation of the course content was predicated upon a detailed understanding of the needs of employers of marine graduates, including hydrodynamic test centres, simulation centres and manufacturers, and manned-model training centres. Requirements across the board of industry stakeholders as to the skills and expertise they require in new graduate employees directly informed the composition of this new degree module. As with all deliverables from AZIPILOT, the content and analysis within this study is publicly available from the Project Website (http://pilot.ncl.ac.uk). Interested parties are free to use and exploit these results without prejudice.

The AZIPILOT partners maintained a critical and informative dialogue with industry stakeholders throughout the Project's duration, and through visits to partners' and others' premises whenever an opportunity arose, most often when gathering for a project coordination meeting, gained a unique insight into the real world difficulties facing many different stakeholder groups. Members representing International end user Associations (International Maritime Pilots Association) were able to take advantage of additional training at world leading partner training centres (Port Revel, France and SRTC, Poland), providing the project with a unique insight into that provision from both consumer and provider perspective.

Each work package's efforts culminated in the preparation and publication of a detailed research and development implementation plan (freely available at http://pilot.ncl.ac.uk), summarising the relevant opportunities and challenges in their industry sector. This comprehensive assessment of the best way forward for the whole industry will ensure multi-disciplinary research can be undertaken that best meets the needs of the sector, and provides a comprehensive set of guidelines for policy makers.

Finally, recommendations for specific regulations and criteria related to Hydrodynamic Modelling, Marine Simulation, Maritime Training and Operational Performance have been made; specifically related to the use of azimuthing control devices. In discussion with regulatory bodies and all stakeholders, key shortcomings of existing regulations and criteria have been identified and appropriate alternatives recommended to ensure the sectors are able to move forward.

Socio-economic impacts which reach beyond the sphere of maritime modelling, simulation, operation and training were also realised by the actions undertaken within AZIPILOT. Proper training of maritime personnel has impacts beyond this immeidiate sphere, for example:

- Issues surrounding human factors and ergonomics research feed into all walks of life, and better understanding of the psychological impact of operating in high pressure industrial settings has many applications throughout Europe.
- Better understanding of the challenges facing mariners at work, incorporated into improved training and education programmes will elicit benefits for the mariners and the maritime industry themselves via:
    - Improved employment opportunities;
    - Improved safety record and public perception;
    - Greater employee and customer satisfaction;
- and for society as a whole via:
    - reduced likelihood of accidents causing damage to port infrastructure and natural habitat, for example:
        - groundings causing environmental harm to coral reefs,
        - or oil spills endangering wildlife and marine and coastal habitats;
    - improvements in safety, employee satisfaction and customer satisfaction can all positively influence a company's bottom line, generating indirect benefits to society via, for example, increased tax returns, employment opportunities, and happier citizens.

Engagement with stakeholders throughout the maritime industry was ongoing and exhaustive; methods exploited included questionnaires, research visits, face-to-face interviews, observation of practice onboard, presentation at Conferences, publication in peer-reviewed Journals, and specialist and general press, as well as a flagship workshop held in Rotterdam in February 2011 (further details available in Deliverable 3.8, and at https://pilot.ncl.ac.uk):

> *"The AZIPILOT project conference and workshop, was successfully held in Rotterdam on 24th February 2011. The aim of the day was to involve leading experts in azimuthing control devices (ACDs) with the wider audience to help increase awareness about azimuthing technology. The idea behind the workshop was to disseminate knowledge from the AZIPILOT project to a wider audience, and 49 people not directly involved with the project attended. The conference/workshop was hosted by STC at their premises in Rotterdam, giving delegates the opportunity to visit the simulator facilities on site. The agenda was developed in order to allow maximum time for audience participation and feedback. The morning was occupied by conference style, formal presentations giving an overview of the AZIPILOT project, and the work of each of the four AZIPILOT work packages, with a chance to report findings of completed tasks. The afternoon was an*

opportunity to discuss further on some of the 'hot topics' detected in the course of the project. The session was chaired by Nigel Allen (UKMPA), a representative of the project partner and Pilot in Southampton. He was supported by the following experts:

- *Aidan Fleming: (Dublin Port Company);*
- *Paul O'Regan: (Port of Cork);*
- *Leif Carlsson: (Capt. in Bröstrom and also partner of the AZIPILOT project);*
- *Thomas Lindner: (Hamburg Port Services).*

The session started with a video of an interview with a cruise ship Captain (conducted onboard his ship) and a presentation by Nigel Allen outlining the most interesting and disputed ACD issues. The panel-led discussion which ensued was engaging and informative, focussing on industry 'hot topics'. The workshop was an excellent opportunity for both those who did not have experience of ACD to better understand the operating procedure, and those operating vessels with ACD to ask questions to other users. Overall the workshop promoted greater awareness of key differences between ACD and conventional propulsion systems."

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