Intuitive operation
and pilot training
when using marine
azimuthing
control devices

AZIPILOT

Report Title:

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Map out the landscape of future R&D

Contents

EXECUTIVE SUMMARY

Implementation of Azimuthing Control Devices was connected with new features appeared mainly in resistance, propulsive and manoeuvring aspects of ship operations. It entailed new research works in versatile direction so as to fully recognise new possibilities and drawbacks. So far conducted investigations have confirmed many initial expectations but many new phenomena and qualities have been noticed in respect to classical vessels. Many of them give chances for further development after creative explorations and conclusions.

The aim of this task was to map 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 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. This report concludes with detailed recommendations for future research.

1 INTRODUCTION

The aim of this task is to map out the landscape of future research and development within the widely understood field of hydrodynamic modelling and testing of marine azimuthing control devices both theoretical and experimental. The whole group of such devices, including pump jets, rudder - propellers, Voith-Schneider and azimuthing pod drives, was featured by simultaneous propelling and steering possibilities due to production of vectoring thrust. Since, the pod propulsors have been commonly applied last years on different ship types, they were chosen as a representative type of the ship propulsion system for subsequent analyses. The structure of the whole work package was composed in the way to start with respective reviews of the available Azimuthing Control Device (ACD) knowledge.

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 trainings were 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.

2 CROSS REFERENCE OF THE SUMMARY AND ASSIMILATION EXERCISES TO IDENTIFY KNOWLEDGE GAPS

2.1 Introduction

In order to carry out necessary reviews of respective knowledge concerning azimuthing control devices, it was necessary initially to determine basic groups of interests. They embraced wide scope of ACDs and corresponding ship types, research institutions, pilot and operators:

- Description of ACD Types (Azimuthing Control Devices);
- Ship Types;
- Simulator Manufacturers;
- Simulator Facilities;
- Test Facilities;
- Shipping Companies;
- Pilot Organisations.

According to this scheme, a matrix of respective knowledge sources was determined; it included:

- Past project outputs;
- Ongoing projects;
- Existing conference series;
- Technical maritime forums;
- Maritime associations.

2.2 Explored areas

In order to reasonably explore specified sources of the ACD knowledge, the following areas were identified on basis of possessed experience:

- Relationships between ship manoeuvring performance levels and operational techniques which can result in extreme spike loading on the ACDs and their surrounding structure;
- Risk analyses and hazard identification;
- Modelling and simulation of reliable modern electric motors, conventional or high temperature superconductor (HTS) type suitable for sea borne conditions;
- Modelling and optimisation from a point of view of hydrodynamic efficiency, minimised cavitation and risk to structural integrity;
- Modelling and simulation of the interaction between the ACDs and the ship hull with respect to uniform flow and its safe location;
- Precise definitions and modelling of the propeller working point versus service conditions, including : w_t , t, η_R and η_D, and including simulation that accounts for such sensitivities;
- Modelling of the propeller and nacelle interactions including the gap-effects and obtaining reliable open water characteristics;

- Modelling and simulations of the interactions between multiple units, including the vulnerability to propulsive efficiency drop-off and cavitation;
- Modelling and simulation of operational static loads on slewing bearings with respect to slewing angles;
- Modelling of dynamic loads and risk of waterborne vibrations;
- Simulation of manoeuvring properties at sea and in harbour with respect to geometry and configurations;
- Hydrodynamic tests methods in respect to ITTC requirements and the influence of the scaling effect;
- Present requirements directed to azimuthing pods and accompanying systems and access to rules and regulations;
- Mathematical modelling of ACDs and ship behaviour in calm and rough seas;
- Mathematical modelling specifically for use in simulations;
- Validation of mathematical models with full scale data;
- Numerical simulation tools and present manoeuvring simulators;
- Modern training methods for pilots.

2.3 Obliging regulations

The conducted analyses were to correspond with:

- National regulations;
- Obliging environmental requirements;
- Requirements of classification societies;
- IMO resolutions.

2.4 Main review summaries

The conducted reviews included the following list of analysed topics:

3.4.1 Existing modelling and test methods for ACD:

- Steady-state testing methodologies;
- Azimuthing control device-to-hull interactions;
- Interactions between multiple azimuthing devices;
- Scaling issues and gap-effect;
- Propeller working point and off-design conditions
- Extent of current validation;

3.4.2 Existing modelling and test method in at sea conditions:

- Perceived benefits and negative effects when using ACDs in at sea conditions;
- Modelling and testing methods for azimuthing control devices in the at sea conditions;
- Possibilities for the development of modelling the at sea condition and model test techniques;
- Need for autopilot at sea conditions for azimuthing/conventional propulsion.

3.4.3 Issues connected with navigation in harbours:

- Effects of ship-to-ship interactions specific to ACDs;
- Effects of ship-to-bank interactions specific to ACDs;
- Effects of shallow water;
- Ability to model the environmental impacts of thrust wash on man-made and natural structures and banks.

3.4.4 Validation methods:

- Scaling procedures and recommendations specific to manoeuvrability related issue;
- Extent of validated models from full-scale data;
- Possibility to validate modelling and simulation methods by comparison with manned model output data;
- What capabilities of ACD can be validated.

2.5 Main noticed gaps

The conducted analyses and summaries made it possible to assess critically nearly all analysed topics.

3.5.1. General:

Azimuthing Control Devices combine features of steering device with the possibilities of an innovative propulsion unit. Moreover, they are powered very often by precisely controlled electric motors. This introduces new quality and possibilities to marine innovative propulsors. Such a situation creates new problems and due challenges to ship designers, hydrodynamicists, mechanics and ship operators. Special expectations, aimed to explain noticed gaps, are directed towards versatile researchers. This situation results in the fact causing that gaps connected with new propulsors are summarised with knowledge gaps representative for conventional propulsors and steering devices. That is why it seems indispensable to identify such gaps and show ways of their compensation.

3.5.2. Groups of noticed gaps

1) Gaps of design origin:

The biggest gap in design and application of ACD is being presented by single pod propulsors possessing mediocre both steering and propulsive properties. It results from the fact that single pod vessels were designed the way remembered from conventional vessels. Simply, a single screw propulsor was replaced directly by a pod unit without any critical analyses and adaptations before and after this enterprise.

Specifically, a single pod can have a propeller operating in a wake-field very similar to a conventional ship. However, when the pod is turned, the wake-field can vary greatly. This has big implications for both the propulsive efficiency and the manoeuvring loads. Also, it is noted that single pod ships have a tendency to have low stability characteristics. While not insurmountable, careful attention should be paid to this at the early design stage if a poor design is to be avoided. Tools to perform such preliminary analysis do exist in the open literature but would benefit from wider validation.

Another gap is noticed in the design of pod housing elements. They are usually designed in order to minimise incurred costs. Hydrodynamic influences and requirements are usually neglected what makes there are met versatile shapes of pod units but with different performances. Hybrid propulsor types, based on applications of pod units, create the next design gap that properly analysed and developed may substantially raise performances of respective vessels.

2) Gaps existing in research activities

One prominent gap is in the field of metrology: measurement techniques need refining and standards need to be agreed across the industry. This leads to weak recognition of local flows around a podded vessel resulting in poor recognition of essential local hydrodynamic interactions. The reasons are as follows:

- use of measuring systems not adequate for measured phenomena resulting in partial identification of existing interactions.
- lack of dedicated test procedures giving chances for proper and repeatable approaches to performed measurements;
- weak recognition of scale effects during model based experiments;
- lack of agreed standards for measurement uncertainty analyses leads to poor recognition of particular interactions and their contribution / hierarchy in investigated phenomena.

2.6 Knowledge gaps in ACDs aspects

2.6.1 Podded ship hull resistance characteristics

There is lack of respective procedures concerning predictions of resistance characteristics of pod-driven ships at full scale. 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.

Resistance tests of pod-housings with dummy hubs in uniform flows are not recommended because such a test set-up is slightly artificial, not reflecting real interactions. Such units should be tested in pre-swirled flows, to assess and compare properly their drags. The bare hull performances are scaled in the classical way.

2.6.2 Open water pod characteristics

The pod units introduce some new qualities in respect to classical screw propulsors. It results from the 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 the separate pod unit creates its own wake that has big influence on the pod propeller work point. Pulling pod units themselves are experienced by 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. Such pressure fluctuations generate additional axial thrust that shifts the propeller work point. In such a situation there is lack of a mathematical model taking into account geometrical forms of the nacelle, propeller hub and caps.

2.6.3 Propulsive characteristics of pod driven ships

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 facing direct forecasting is the fact that model and full scale pod propulsors work at different Reynolds numbers, resulting in. It results in higher pod propeller loads than in full scale, so corrections must be applied. The assumed service conditions are simulated by adding a friction correction force during a self propulsion test that should account for scale effect correction. Since, this force is determined on basis of a resistance test its procedure has essential influence on this simulation. If it is taken from the bare hull test and the whole pod is treated as a propulsor, the resulting propulsive coefficients are fully reliable. From other side, if pod unit is treated as an appendage then speed predictions are acceptable but propulsive coefficients are really doubtful.

2.6.4 Manoeuvring characteristics of pod driven ships

Manoeuvring characteristics of pod driven ships are investigated in both experimental and analytical ways. Experiments are performed by means of free-running models or as captive-model tests.

Free running model tests

These tests are carried out on a lake or in dedicated model basins. Tests on a lake are dependent on weather conditions but some manoeuvres can be performed without limitations of the tested space. 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. Model tests in model basins are independent on weather situations and in some facilities it is possible to apply friction correction forces. Small models are necessary to test them at low speeds. It is impossible to use a GPS system under the roof. Main benefits of free-running model tests are connected with realistic presentations of performed manoeuvres.

Captive tests

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

Advanced manoeuvring tests

Recently developed manoeuvrability tests belong to this group:

- 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.

Such tests require specialised model basins and dedicated numerical tools.

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.

Scale-effects by components:

<u>Scale-effect on the rudder forces</u>

For streamline bodies such as rudder, the lift coefficient is assumed to depend only on the angle of attack being independent of the Reynolds number. However, there is a small dependency of the lift-slope on the Reynolds number. It has been noticed that the turning circles at full scale were larger than at model scale. Five potential modelling were 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.

Scale effects on hull forces

The recently conducted tests have not shown out that no significant scale effects 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.

2.6.5 New quality in stopping manoeuvres

ACDs 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.

3 EVALUATION OF BOTH KNOWLEDGE AND INDUSTRY CAPACITY TO ADDRESS SUCH GAPS IN SHORT, MEDIUM AND LONG TERMS

3.1 Knowledge capacity to eliminate identified gaps

The shipbuilding industry and ship operators have always been capable to implement the newest innovations from applied sciences. It resulted not only from relatively high capital and operational costs of ships but from the attractiveness of this domain as well. To cope with specific problems dedicated faculties were established at high schools and specialised colleges. Thanks to it a number of dedicated specialists were always capable to solve any technical problems in ship design, widely understood hydrodynamics, ship structures, new materials and automatics. Maritime academies have always been able to deliver highly educated operators, well prepared to handle up to date ships. Recently, even the human factors aspects, due to their importance, have become the important factor of academic studies. That is why there is available, right away, not only the complex technical potential but specialists from social domains as well.

3.2 Industry capacity to address noticed gaps in reasonable terms

As it was given above there is a large amount of general and specialised knowledge available to solve any technical problem in shipbuilding, and ship operations as well. It is supplemented by specialised design and consulting offices, factories, shipyards, research institutions and high schools.

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. There are also recent trends to resign of fossil fuels and replace them by renewable energy sources like fuel cells or photovoltaic systems. It is possible now to reduce electric current transmission losses by application of superconducting materials based wirings. The immense development of information techniques results in very efficient computer systems and versatile of general destination and dedicated software, available on the market.

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. The more complicated and relatively novel situations demand more time because supplementary studies or personnel trainings seems to be indispensable. The most costly compensation actions will probably demand more time to solve the most complex situations. In order to be up to date, research institutions should execute programs of permanent scientific developments suitable to challenges of the present time.

4 IDENTIFICATION OF ANY TECHNICAL OR PRACTICAL BARRIERS THAt MAY STAND IN THE WAY OF ADDRESSING SUCH GAPS

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.

5 FORMULATION OF THE BEST STRATEGY FOR ADDRESSING INDUSTRY NEEDS

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.

6 RECOMMENDATION FOR FUTURE RESEARCH AND DEVELOPMENTS

The performed reviews and analyses have shown out that there are some gaps and barriers in design, test and operations of ACDs which limit full use of these propulsor benefits. In order to reduce such drawbacks, the future research can be recommended in short, medium and long terms.

6.1 General

- Integration of investigations into dynamic effects is recommended for ACDs;
- Wider use of hybrid investigations joining experiments with advanced CFD 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.

6.2 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.

6.3 Manoeuvring issues

- Further studies on course stability:
  - How should IMO criteria apply to ACD ships considering operation in confined waters?
  - What changes can be introduced to classification society 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.

6.4 Structural loads

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

7 REFERENCES

1) 26th International Towing Tank Conference, Rio de Janeiro, 28Aug. - 3 Sept., 2011. Proceedings.

2) ITTC - Recommended Procedures and Guidelines: 7.5-02-06-03. Validation of Manoeuvring Simulation Models, 2011.

3) A. Gronarz, J. Kanar. AZIPILOT project. Deliverable 1.6. 2011.