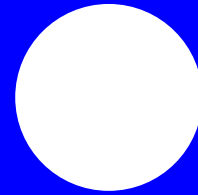


Intuitive operation
and **pilot** training
when using marine
azimuthing
control devices

AZIPILOT



Report Title:

Deliverable 1.4:

**Review of existing modelling
validation methods and available data**

No part of this document may be reproduced or transmitted in any form or by any means, nor stored in any information retrieval system of any kind, nor communicated to any other person without the specific written permission of the AZIPILOT Project Steering Committee.

TABLE OF CONTENTS

EXECUTIVE SUMMARY 3

1 Introduction 4

2 Scaling procedures and recommendations 5

 2.1 General 5

 2.2 Free running model tests 5

 2.3 Captive model tests 5

 2.4 Conclusions 6

3 Extent of validated models from full- and model-scale data 7

 3.1 Source of full-scale data 7

 3.1.1 Pods-in-service 7

 3.1.2 Tempera and Mastera - DAT-tanker 7

 3.1.3 Samsung DAT-tanker 8

 3.1.4 Carnival Elation 8

 3.1.5 Costa Atlantica 8

 3.2 Source of model test data 8

 3.3 Extent of validated (mathematical) simulation models 10

 3.3.1 Validation by comparison with full scale data 10

 3.3.2 Validation by comparison with model-scale data 10

4 Modelling and simulation methods by comparison with manned-model data 12

5 Needs and possibilities to validate capabilities 14

 5.1 Validated capabilities of existing modelling methods 14

 5.2 Further needs of validation data 14

6 References 15

LIST OF TABLES

Table 1 Full-Scale measurement carried out in Pods-In-Service 7

Table 2 Model test data source 8

LIST OF FIGURES

Figure 1 Model with wind fan 5

EXECUTIVE SUMMARY

The aim of this task is to review the compliance to existing modelling validation methods for harbour and at-sea condition for ships equipped with ACD's (Azimuthing Control Devices). The objective is to establish the extent to which existing methods are validated for simulation purposes and to identify appropriate sources of validation data. This is covered in the report by the following topics:

- Survey of ITTC (International Towing Tank Committee) and other scaling procedures and recommendations; specific to manoeuvring related issues.
- Survey of extent of validated models from full-scale data.
- Explore possibility to validate modelling and simulation methods by comparison with manned-model output data.
- Discuss and indicate together with specialists in marine simulations and marine training what capabilities are validated and what capabilities are difficult or impossible to validate.

The ITTC procedure for performance of manoeuvring test has been reviewed and described from a general perspective. One conclusion is that common practise and gathered experience show that there is no need to practically include special modules in manoeuvres forecasting procedures taking into account the scale effect, especially in cases of slow speed vessels.

Extent of validated models from full-scale data has been surveyed. References and descriptions of full-scale test of eight ships are given. Many av these references does also include model test result.

Also extent of validated models from model-scale data has been surveyed. References and descriptions of model-scale test found in public reports and papers are given. A number of projects covering model test, full-scale test and validation to mathematical models are given.

Differences between free running model manoeuvring tests and tests with manned models are explained. One problem to carry out test with manned models is that it is difficult to perform the test procedure in an exact and repeatable manner with the man in the loop. A method is suggested for how to use tests with human control for validation purposes in a simulator.

Needs and possibilities to validate capabilities are discussed and required test is suggested. Besides standard manoeuvres normally carried out in model test and sea trials, test like parametric roll and induced load on ACD during manoeuvres are example of test needed for validation of mathematical models.

1 INTRODUCTION

The aim of this task is to review the compliance to existing modelling validation methods for harbour and at-sea condition for ships equipped with azimuthing control devices. The objective is to establish the extent to which existing methods are validated for simulation purposes and to identify appropriate sources of validation data. The main area of focus will include:

- Survey of ITTC (International Towing Tank Committee) and other scaling procedures and recommendations; specific to manoeuvring related issues.
- Survey of extent of validated models from full-scale data.
- Explore possibility to validate modelling and simulation methods by comparison with manned-model output data.
- Discuss and indicate together with specialists in marine simulations and marine training what capabilities are validated and what capabilities are difficult or impossible to validate.

2 SCALING PROCEDURES AND RECOMMENDATIONS

2.1 General

In manoeuvring tests with free running models, the propulsors are used to give the model the desired speed i.e. to produce the thrust to keep the desired speed and also to produce a propeller induced flow over the rudders.

Froude scaling of speeds is generally applied and turbulizers (wire, sand strips or studs) should be added, as it probably will give a more realistic boundary layer development and pressure distribution along the hull.

Scale effect may be generally neglected, at least for conventional merchant (displacement type) vessels with propellers working in the wake of the hull and the rudder is situated in the propeller slipstream.

Fortunately two phenomena- the larger model wake fraction and the larger model resistance- tend to even out in the rudder force.

As a result of these scale effects, rudder effectiveness of a model may generally be overestimated compared with that of a real ship.

Accordingly, free models tend to be more stable (or less unstable) with respect to course keeping stability. This effect is typically less significant for fine ships because of their inherent stable course keeping ability.

2.2 Free running model tests

In order to minimize the scale events during free running manoeuvrability tests, it is recommended to use as long model as it possible, about 6 meters long. Such tests can be carried out in either model or ship load conditions. The model load conditions correspond with the increased load of the propulsive system of a tested model.

Sometimes, especially for high-speed ships with low wake fractions, it might be necessary to compensate the larger friction resistance of the model with an additional propulsion device, e.g. a wind fan or air jet device.

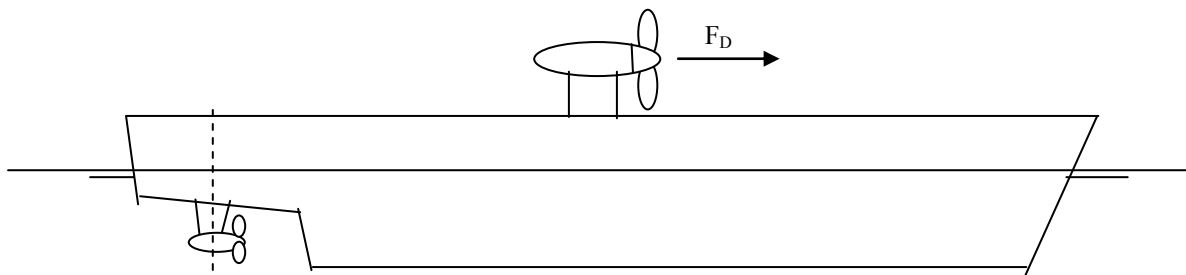


Figure 1 Model with wind fan

Since, rudders are normally positioned in the wake field behind the ship and in the propeller race, i.e. in the very disturbed and turbulent flow, the Reynolds number effect for the rudder force may be neglected. Nevertheless sand strips or studs are sometimes applied to the rudder.

In case of twin propulsors systems, it is recommended to use individual electric motors cooperating with steering computers, instead of complex gears. One complex power, divided equally to each shaftline, results in heavily loaded internal propeller during turning manoeuvres. Such a solution can make the work of the inner propeller more realistic during modelling the turning manoeuvres.

2.3 Captive model tests

Captive manoeuvrability model tests are expected to deliver versatile coefficients for respective mathematical models. In such investigations forecasting accuracy essentially depends on quality of the mathematical model which should include elements of the scale effect.

It results in the fact that shorter hull model, about 3 meter long, can be satisfactorily used for captive model tests. Shorter models can seriously reduce excessive loads of PMM mechanisms bearing systems while models are towed with the biggest drift angles.

2.4 Conclusions

The common practise and gathered experience show out that there is no need to practically include special modules in manoeuvres forecasting procedures taking into account the scale effect, especially in cases of not rapid, commercial vessels. Since majority of results are given in forms of relationships and degrees a possible mistake cannot be so big. It can be included in margins of measurements uncertainty.

3 EXTENT OF VALIDATED MODELS FROM FULL- AND MODEL-SCALE DATA

Two types of data can be used for validation of mathematical simulation models. The first is the full scale measurement data (e.g. in sea trials or specially-targeted full scale measurements). The second and the main source is the experiment data obtained in various model tests.

3.1 Source of full-scale data

In many of the larger ACD research project, full-scale measurements have been conducted. In the following sub-section some sources of full-scale data are reviewed.

3.1.1 Pods-in-service

Pods-In-Service is probably the most extensive project of full-scale measurement of ship with azimuthing pods. The project included full-scale measurement on four ships. Two cruise ships (GTS Summit and Radiance of the Seas), one RoPax (Nils Holgersson) and one ice breaker (Botnica). Pod- and hull forces were measured. Also pressure pulses and cavitation was measured. Measurement was carried out during sea trial and on long term basis during normal operations. In Table 1 are full-scale measurement carried out in Pods-In-Service listed (Pod-In-Service 2004). The major part of these measurements is not reported by public reports and have not therefore been reviewed in detail.

Table 1 Full-Scale measurement carried out in Pods-In-Service

Ship	Type of measurements/report
GTS Summit (Cruise)	Static strain measurements during manoeuvring trials
	Cavitation observation & hull pressures
	Operational data
Nils Holgersson (RoPax)	Instrumentation report
	Preloading calibrations
	Ship Acceptance Trials
	Long Term monitoring data
Radiance of the Seas (Cruise)	Calibrations of strain gauges
	Cavitation and hull pressure measurements
	Static strain measurements during manoeuvring trials
	Statistics measurements
	Pod vibration measurements
	Structural loads in pod foundation during manoeuvring trials
MSV Botnica (Ice breaker)	Pod propulsion loads measurement during sea trials
	Long-term measurements of pod propulsion loads

3.1.2 Tempera and Mastera - DAT-tanker

These ships are so called DAT tanker (Double acting tanker) equipped with one pod unit of 15 MW. The ships were built by Sumitomo Heavy Industries. The first vessel, Tempera, was delivered in 2002. Result from sea trials are reported and compare with model scale tests. These tests include speed-power measurement and manoeuvring test. These tests and measurements are reported by Sasaki et al. (Sasaki 2004) and Trägårdh et al. (Trägårdh et al 2004). The first paper describes and discusses in detail the different methods of prediction from model-scale to full-scale and project it on the sea trials carried out. The paper does also report performance test in ice. The paper by Trägårdh et al. describes the development

D 1.4 Review of modelling validation methods and available data

work and model tests and compare it with full-scale test. The manoeuvring model tests were carried out for pod with and without a fin below the pod house. The tests also show performance when going astern.

3.1.3 Samsung DAT-tanker

This series of 70000 tdw DAT-tankers are built for Sovcomflot by Samsung Heavy Industries. The first tanker was delivered in 2007 and named “Vasily Dinkov” and in total three tankers have been delivered. Yang et al (2009) have reported comparison of turning circles at full-scale and models scale. A difference between model-scale and full-scale of up to 40% in tactical diameter was found. The paper also includes measurement of ACD forces at both model-scale and full-scale. An interesting background and history to the DAT tanker project is given by Niini et al (2007).

3.1.4 Carnival Elation

This is one of the first large cruise ships with pod propulsion. It was built for the Carnival Group and delivered by Kvaerner Masa-Yards in 1998. The ship belongs to a series of four ships. All ships are designed with diesel-electric propulsion but the first two vessels were equipped with conventional twin controllable pitch propellers while the two last vessels were equipped with pods. Kurimo has reported the sea trials (Kurimo 1998) and the hydrodynamic development and model tests (Kurimo 1997).

3.1.5 Costa Atlantica

The twin pod cruise ship was built for the Carnival Group and delivered by Kvaerner Masa-Yards Inc, Helsinki in year 2000. Kurimo and Byström (2003) have reported results from model tests, full-scale trials and simulations. The paper presents a method for scaling model test into a full-scale simulation model.

3.2 Source of model test data

The two research projects OPTIPOD (Woodward 2002a) and FASTPOD (Atlar et al. 2005) have resulted in an extensive set of experimental data that is useful for validation. In Table 2, a number of reports containing model-scale data are listed.

Table 2 Model test data source

Ship Type	Model tests of relevance	Report / Source
Cruise Liner	Free sailing manoeuvring and course keeping performance; Captive model tests (force measurements)	Hochbaum et al. (2001, 2002)
Cruise Liner	Free sailing manoeuvring and course keeping performance. Comparison with full-scale tests and simulations.	Kurimo (1998)
Cruise Liner	Free sailing manoeuvring and course keeping performance. Comparison with full-scale tests and simulations.	Kurimo and Byström (2003)
Cargo	Captive and Free sailing manoeuvring tests	Trägårdh et al.(2002), Trägårdh (2002)
Cement tanker	Captive and Free sailing manoeuvring tests	Kano (2006)
Chemical tanker	Captive manoeuvring tests and ACD force measurement	Tanaka (2009)
Fast Cargo	Captive model tests	Kanar et al.(2005)
Fast Cargo	Free running manoeuvring model tests in an open lake	Kanar et al.(2004a)
Fast Cargo	Seakeeping (parametric roll) tests:	Kanar et al.(2004b)
ROPAX	Captive model tests	Misiag et al. (2002)
ROPAX	Manoeuvring and seakeeping tests	Lundgren (2001)
ROPAX	Free model manoeuvring tests in an open lake	Głodowski et al. (2001, 2002)
Fast ROPAX	Effect of pods on roll damping and roll motion	Turan et al. (2004)
Fast ROPAX	Captive model tests	HSVA(2005)
Fast ROPAX	Seakeeping and manoeuvring tests with a free model	Trägårdh et al.(2004)
Gas Carrier	Manned manoeuvring tests in an open lake	Kobylnski L. (2004)

D 1.4 Review of modelling validation methods and available data

Double acting tanker (DAT, Ice breaker)	Manoeuvring: Turning test 35°, zig-zag test 10/10°, zig-zag test 20/20°, reverse spiral test.	Trägårdh et al. (2004)
Double acting tanker (DAT, Ice breaker)	Turning test including ACD force measurement. Comparison with full-scale	Yang et al. (2009)
MSV Botnica (Ice breaker)	Captive model tests and IMO manoeuvring simulations	Happonen (2001)
Generic full-form ship	Frees running test: Tuning circle tests and zig-zag test with parametric variation of eight pod configurations	Steinwand (2003)

3.3 Extent of validated (mathematical) simulation models

3.3.1 Validation by comparison with full scale data

The full-scale data is a very important source for validation of mathematical models and also for validation of model-scale tests. The advantage to use full-scale data is that there are no uncertainties regarding scale-effect and modelling of propulsion train and control algorithm of various control systems. The main problems with full-scale test are:

- Difficult to control the environmental condition like wind, waves, current and geographic confinements.
- Difficult to control the test procedures (i.e. to do repeatable test in with a high precision and timing in the test procedure).
- Expensive to occupy the ship and test organisation.
- Some tests like crash stops can damage or decrease life-time of components.
- Generally difficult and in some cases impossible to do direct measurement of forces.

These problems are probable the main reason that validation of mathematical models in most cases rely on model-scale data. However, some technical achievement makes full-scale measurement more accessible and attractive:

- Introduction of high precision measurement of position in three degrees like RTK-GPS (Real-Time Kinematics GPS). This makes it possible to measure horizontal and vertical position in the range of centimetre precision.
- Control system and VDR (Voyage Data Recorder) do often allow easy access to a wide range of measured data.

As described in section 3.1, full-scale data are not often reported in a detailed level. In research projects, it seems to be more common to validate mathematical models to model test. However, in commercial project with focus on one specific ship design it is believed the full-scale data is used, when available, for validation of mathematical models. References that cover validation of mathematical models by use of both model-scale, full-scale and simulation are Trägårdh et al 2004, Kurimo et al 2003, Yang et al (2009).

3.3.2 Validation by comparison with model-scale data

The mathematical model developed by Ayaz et al. (2006) is characterised with non-linear 6-DOF, frequency dependent coefficients, incorporated memory effects, no restriction on motion amplitude, and an axis system that allows combination of seakeeping and manoeuvring models. Validation studies of the model for pod-driven ships were carried out by Ayaz et al. with respect to the compliance with IMO manoeuvrability criteria and seakeeping aspects, directional stability and course-keeping ability, and manoeuvring behaviour in extreme astern seas by Ayaz et al. (2004, 2005) in the OPTIPOD project.

The mathematical model by Ayaz et al was further enhanced in the FASTPOD project for fast ships driven by pods. The enhanced software was then utilised to analyse the manoeuvring and course keeping capabilities of two fast vessels in waves. The manoeuvring derivatives were obtained from the captive model test of respective model tests. The modified code was then validated with the free sailing test data in waves for the selected ship types. These results showed in general satisfactory agreement with experiments for the enhanced mathematical model.

Woodward and Clarke (2001) modified an existing semi-empirical method to estimate manoeuvring derivatives of hulls fitted with podded propulsors. The report by Woodward and Clarke (2002b) described the validation of semi-empirical tool. Linear derivative terms were estimated and compared with values obtained through captive testing for the four OPTIPOD ship designs, showing good agreement. A simple stability criteria was identified, and applied and compared with free running test results for the four OPTIPOD ship designs; again showing exact agreement. Suitable turning assessment was identified and comparison with free running tests demonstrated excellent agreement. Finally, a more in-depth manoeuvring performance analysis method was identified and applied demonstrating the usefulness of the proposed design tools.

D 1.4 Review of modelling validation methods and available data

The semi-empirical method by Woodward and Clarke was further extended in the FASTPOD project to take into account the effect of high speed for its application in FASTPOD. The developed tool was validated with the captive tests and free sailing test data. By using the validated tool, manoeuvring characteristics of the selected vessels were analysed in calm water from the safety point of view.

A yet further development of this method was inclusion of propeller effect. The semi-empirical code was improved using the state-of-the-art methods and the input load data from the tunnel test performed in FASTPOD project with a representative fast pod including the effect of propeller. The code developed was validated with the tunnel test measurement. (Tunnel tests were performed on representative fast pod housing with and without the propeller to provide loads and 4 quadrant force data to supply information for the semi-empirical model). The so-developed tools was be combined together to supply the derivatives to an existing simulation package to validate the developed tools using the free sailing tests data. The simulation studies were carried out for each relevant ship type to analyse their manoeuvring characteristics in calm water.

Within the FASTPOD project, another validation and analysis were carried out by Depascale and Sebastinani (2005) using CETENA's manoeuvring simulator tool SIMON II. In order to perform the harbour manoeuvres the mathematical model of the Fast Ropax vessel set up was for the simulator was validated by comparison with the simulated results of the standard manoeuvres with the corresponding model test data by Trägårdh et al. (2004). Then the manoeuvres of the Fast Ropax in the Harbour of Porto Torres (Sardinia Italy) under different weather conditions were conducted and the results were compared with those of a ferry driven by conventional propeller.

4 MODELLING AND SIMULATION METHODS BY COMPARISON WITH MANNED-MODEL DATA

Preamble:

The modelling of the performance of a conventional (rudder and propeller) propulsion and control system or an ASD (azimuthing control device) is different from the simulation technique. Both can be validated separately (e.g. measurement and calculation of forces), but if test results of manoeuvres with models are used for validation purposes, both modelling and simulation are always used in combination and cannot be judged separately.

In comparison with free running model tests the measurements of ship manoeuvres using manned models always contain the human element which influences the results. A comparison of the differences between the two types of model tests illustrates this.

- Free running model tests (See also D1.3, chapter 3)

In free running model tests the model is controlled by a processor which gives the orders to the actuators to perform a special manoeuvre. Dependant on the type of manoeuvre to be carried out a special analysis of available inputs is performed to control the e.g. rudder. Dependant on the type of test this program is more or less complicated but still simple enough to describe the manoeuvre in an unambiguous way.

Turning circle:

Starting with a straight run with constant speed the rudder is deflected to a predefined angle. The manoeuvre is carried out until a certain course deviation e.g. 360° is reached.

Zig-zag-test:

Starting with a straight run with constant speed the rudder is deflected to a predefined angle δ . When the course deviation has reached a certain value ψ the rudder is changed to the opposite angle $-\delta$. When the course deviation $-\psi$ to the other side is reached, the rudder angle is changed again to δ . The ending criterion is fulfilled, when the course deviation reaches the value of ψ for a second time.

Evasion test:

This manoeuvre is carried out on inland waterways, because it gives an indication of the turning ability without using much space to the sides. It is identical to the zig-zag-test with the difference that instead of the course ψ the yaw rate r is used.

All these manoeuvres can be carried out very precise and they can be repeated many times with always nearly identical results. Differences in the results are normally due to slightly different starting or environmental conditions like wind. This fact of the repeatability is of major importance to validate simulations because a simulator is able to carry out exact manoeuvres. In comparison to model tests a simulator is completely independent if the starting and environmental conditions because these can exactly be predefined.

- Tests with manned models

The standard manoeuvres carried out with free running processor controlled models can also be carried out with manned models. The main difference is that the manned model is controlled by human beings, normally a captain and a helmsman.

D 1.4 Review of modelling validation methods and available data

The procedures to be followed for a standard manoeuvre can also be carried out by the way of watching sensors, giving commands and executing them manually, but this incorporates a lot of errors due to the human influence.

Observation and command:

A sensor like the compass is observed by eyes and the values are read with a limited accuracy. The moment, when the operation of an actuator has to be performed is announced by an oral command including delays to reaction times.

Execution:

The helmsman operates the actuator e.g. the rudder. He as human being also has his delays due to reaction times. The result of the execution is a certain value of the actuator which in the rarest case is exactly that what was ordered by the captain. If for example a rudder angle of port 20 is ordered the result will be something between 19 and 21 degrees, which is sufficient for a real time situation where a manned model is used for training purposes of captain and helmsman.

Recorded motion parameters of a standard manoeuvre carried out with manned models are not sufficient for a manoeuvre used for validation purposes.

In spite of the problems with the human influence there is a possibility to use the results of manned model test. Assuming that not only the motion parameters like course, heading, position and speed are recorded but also the rudder angle and the settings of the engine are stored as a time history with sufficient precision a really full set of data is at disposal for validation purposes.

Normally a simulator only has the possibility to execute programmed standard manoeuvres but it is theoretically and practically possible to use the time history of the actuator activities of a manned model test as input stream for a simulator. In that way the problem with the human influence is overcome because the simulator exactly does, what the helmsman did during the execution of the manoeuvre. Now the recorded motion parameters of the manned model test can be compared with the results of the simulation of the human controlled manoeuvre.

By this technique it is not possible to achieve good results regarding the turning ability, yaw checking or course keeping ability but by the fact that the exact human controlled manoeuvre is repeated by the simulator it is possible to use manned model test results for the validation of the modelling and simulation methods.

The explanation above is valid for both conventional propulsion and control systems and ACD. The differences are within manufacturing of the control devices in the scale of the manned model and the modelling of the performance if the devices within the simulator.

In general the common scaling problems for model tests have to be considered, because model tests are carried out on the basis of Froude's law and for the scaling of the flow at propellers and rudders Reynolds's law has to be applied. The larger the model scale is, the bigger is the scaling discrepancy between Froude's and Reynolds's law. While the friction correction could be applied by e.g. an additional force using a wind propeller it is not possible to apply also corrections to the flow regime at the stern of the vessel including wake and slipstream.

5 NEEDS AND POSSIBILITIES TO VALIDATE CAPABILITIES

Two types of data can normally be used for validation purposes. The first is the full scale measurement data (e.g. in sea trials or specially-targeted full scale measurements). The second and the main source is the experiment data obtained in various model tests.

5.1 Validated capabilities of existing modelling methods

To a large extent the following simulation capabilities of mathematical model based methods can be appropriately validated:

Manoeuvring

- (1) Turning circle manoeuvre
- (2) Zig-zag manoeuvre with helm angle 10°/ 10° and 20°/ 20° to both sides
- (3) Astern stopping manoeuvre. The manoeuvres should, if applicable, include the different methods of stopping manoeuvres i.e. reversing propeller rotation, turning propellers 180° and indirect stopping manoeuvre, as by Woodward et al. (2005)

The above simulation capabilities are demonstrated in the reports by Woodward et al. (2003 and 2005), Kanar (2006), Ayaz et al. (2005) and Kano et al. (2006). These capabilities are the most fundamental components of a simulation program for manoeuvring simulations in still water.

Seakeeping

- (1) Parametric roll motion, as by Turan et al. (2008)

Prediction of loads

- (1) Manoeuvring induced side loading

5.2 Further needs of validation data

At present the following simulation capabilities are more difficult to achieve and validate, largely due to lack of relevant experimental and full scale data.

- (1) Response under extreme steering
- (2) Manoeuvring in ice
- (3) Slamming effect

Therefore, there is an urgent need of model test data in these areas for ships fitted with pods. Furthermore, it is noted that the data that can be used to validate detail flow field results (e.g. flow separation at large azimuthing angle) obtained from RANS computations is very scarce due to the complexity involved in measurement. The flow field data is needed for validating RANS computations.

6 REFERENCES

Atlar, M., et al. 2005, "FASTPOD project: an overall summary and conclusions", FAST 2005, St. Petersburg, Russia.

Ayaz Z., Turan O. and Vassalos D. 2004, "Manoeuvring Aspects of Pod-Driven Ships", 1st T-POD Conference, pp. 135-152, University of Newcastle, UK.

Ayaz Z., Turan O. and Vassalos D. 2005, "Manoeuvring and Seakeeping Aspects of Pod-Driven Ships", Proc. Int. Mechanical Eng. Part M. Journal of Engineering for the Maritime Environment, Vol. 219, No. 2.

Ayaz Z., Vassalos, D. and Spyrou, K.J., 2006b, "Manoeuvring Behaviour of Ships in Extreme Astern Seas", Ocean Engineering, Vol.33 Nos. 17-18, pp. 2381-2434. (Ph.D. thesis work)

FASTPOD. Fast Ship Application for Pod Drives. European Commission RTD Project, GRD2-2001-50063, 2002–2005.

Depascale R. and Sebastinani L. 2005, "Evaluation of Manoeuvrability in harbour of the Fast RoPax", Task 4.3.1 Report _ Doc3, CETENA, Italy.

Pods-In-Service, 2004, "Marin Report No. 15416-2-TM - Executive Summary".

Głodowski, R. and Kanar, J., "ROPAX-OPTIPOD Results of free running manoeuvring model tests (influence of stern arrangement on manoeuvrability – Model M 563) CTO-OHO Technical report No. RH-2000/T-230E.

Głodowski, R. and Kanar, J., 2000, "Podded ROPAX Results of free model manoeuvring tests – Model M 563-A", CTO-OHO Technical report No. RH-2000/T-232E.

Głodowski, R. and Kanar, J., 2001, "Podded ROPAX Results of free model manoeuvring tests – Model M 563-B", CTO-OHO Technical report No. RH-2001/T-112E.

Głodowski, R. and Kanar, J., 2002, "Podded ROPAX Results of free model manoeuvring tests – Model M 563-D", CTO-OHO Technical report No. RH-2002/T-054E.

Happonen, K. 2002, "Captive model tests and IMO manoeuvring simulations for the OPTIPOD supply ship", VTT report VAL34-023529.

Happonen, K. 2001, "Captive model tests and IMO manoeuvring simulations for MSV Botnica", VTT report VAL34-01296.

Hochbaum A.C. Wittekind, D. and Oltmann, P. 2001, "Model Tests on the Manoeuvring and Course Keeping Performance of a POD Driven Cruise Liner", HSVA report No. MAN 131/01.

Hochbaum A.C. Wittekind, D. and Oltmann, P. 2001, "Model Tests on the Manoeuvring and Course Keeping Performance of a POD Driven, Optimized Cruise Liner", HSVA report No. MAN 144/02.

Helasharju, H., 2001, "Manoeuvring sea trials for msv Botnica", OPTIPOD WP3-DOC-0053.

Kurimo, R., 1997. "Azipod Propulsion for Passenger Cruisers: Part 1: Details of the Hydrodynamic Development". NAV & HSMV International Conference, Sorrento, 18-21 March 1997, pp. 3-16.

Kurimo R, Byström L, 2003. "Manoeuvring with pods: Model tests and sea trial of the M/S Costa Atlantica", 8th IMDC, Athens 2003, Session B-5

D 1.4 Review of modelling validation methods and available data

HSVA, 2005, "Manoeuvring Model Tests for the Fastpod Ropax Vessel". FASTPOD WP2-Task 2.1.7-Doc0.

ITTC, 2005, Recommended Procedures and Guidelines - Testing and Extrapolation Methods Manoeuvrability Free Running Model Tests

Kanar J. and Głodowski R., 2002, "SUMMARY OF FREE SAILING MODEL TESTS", OPTIPOD report WP3-DOC-0080.

Kanar et al. 2004a, "Free running manoeuvring model tests in an open lake", FASTPOD-WP2, CTO report RH-2004/T-013E and RH-2004/T-152E.

Kanar et al. 2004b, "Seakeeping Parametric roll tests", FASTPOD-WP2, CTO report RH-2004/T-160E.

Kanar et al. 2005, "Captive Manoeuvring model tests", FASTPOD-WP2, CTO report RH-2005/T-047E.

Kanar J. 2006, "Improvement of multipropulsor systems performances by pod unit applications", The 2nd T-POD Intl. Conference on technical advances in podded propulsion, France.

Kano, T., Kayano, J., Sakoda, M. and Takekuma, K., 2006, "Manoeuvrability of 749GT cement tanker with three different Pod propulsion systems", The 2nd T-POD Intl. Conference on technical advances in podded propulsion, France.

Kobylnski L. 2004, "Manoeuvrability tests of a vessel with pod propulsion", 1st T-POD Conference, pp. 135-152, University of Newcastle, UK.

Kurimo, R., 1998. "Sea Trial Experiences of the First Passenger Cruiser with Podded Propulsors". PRADS '98, The Hague, 20-25 September 1998, pp. 743-748.

Lundgren, J. 2001, "Manoeuvring and Seakeeping Tests for Podded ROPAX Vessel", SSPA Report No. 20000157-2, SSPA Sweden AB.

Misiag, W. A. and Glodowski, R. (2002) "Captive model tests - Podded Ropax vessel (WP3-DOC-0071)", CTO Report No. RH 2002/T-161E.

Niini M., Kaganov S., Tustin R.D., "Development of Arctic double acting shuttle tankers for the Prirazlomnoye project", TSCF 2007 Shipbuilders Meeting

Sasaki N., Laapio J., Fagerstrom B., Juurmaa K., Wilkman G., "Full scale performance of double acting tankers Tempera and Mastera" 1st T-POD Conference, University of Newcastle, UK.

Steinwand M, 2003, "MANOEUVRABILITY OF A SINGLE SCREW SHIP WITH POD", 15th INTERNATIONAL CONFERENCE ON HYDRODYNAMICS IN SHIP DESIGN, SAFETY AND OPERATION, GDAŃSK, POLAND, 22-23.10.2003

Tanaka S. Hirata N., Yasukawa H., 2009, "HYDRODYNAMIC FORCES INVESTIGATION ON A SHIP WITH AZIMUTHING PROPELLERS IN MANEUVERING MOTIONS", MARSIM 09.

Turan O., Tuzcu C., Clelland D. and Ayaz Z., 2004, "Effect of pods on the roll behaviour of passenger vessels", 1st T-POD Conference, pp. 125-134, University of Newcastle, UK.

Turan, O. Ayaz, Z. and Vassalos, D., 2005, "Numerical assessment of operational behaviour of high-speed, POD-driven large ships", Maritime Transportation and Exploitation of Ocean and Coastal Resources _ Proceedings of the 11th International Congress of the International Maritime Association of the Mediterranean, Lisbon, Portugal.

Turan O., Ayaz Z., Aksu S., Kanar J. and Bednarek A., 2008, "Parametric rolling behaviour of azimuthing propulsion-driven ships", Ocean Engineering Vol. 35, pp. 1339-1356.

D 1.4 Review of modelling validation methods and available data

Trägårdh, P., Lindell, P. and Sasaki, N., 2004, "DOUBLE ACTING TANKER - Experiences from model tests and sea trials", 1st T-POD Conference, University of Newcastle, UK.

Trägårdh, P. and Byström, L., 2002, "Captive model tests for the Cargo ship", SSPA Report 2000 0157-9.

Trägårdh, P. 2002, "Free sailing model tests for the Cargo ship", SSPA Report 2000 0157-7.

Trägårdh, P., J Hua J. Leer-Andersen M., 2004, "Seakeeping and manoeuvring tests with a free model and assessment of wash waves", FASTPOD WP2-Task 2.1.6-Doc0, SSPA report 20022921-1.

Woodward, M. D. and Clarke, D. (2001) "Semi-empirical theoretical tool development (WP3-DOC-0056)", EU RTD FP5 OPTIPOD GRD1-1999-10294. School of Marine Science and Technology, University of Newcastle.

Woodward, M.D. et al., 2002a, "Final non-confidential report on safety and risk analysis", OPTIPOD report WP3-DOC-091.

Woodward, M. D. and Clarke, D., 2002b "Validation of the semi-empirical tool (WP3-DOC-0068)", School of Marine Science and Technology, University of Newcastle.

Woodward, M.D., Clarke, D. and Atlar, M., 2003, "On the manoeuvring prediction of pod driven ships", MARSIM'03, Kanazawa, RB-7 pp. 1-9.

Woodward, M.D., Atlar, M. and Clarke, D., 2005, "Comparison of stopping modes for pod-driven ships by simulation based on model testing", Proc. IMechE. Vol. 219 Part M: J. Engineering for the Marine Environment, 18 p.

Woodward, M.D., et al. 2005, "Manoeuvring analysis_Technical report on Sub-task 2.3", FASTPOD Deliverable D2.3, UNEW.

Woodward, M.D., et al. 2006, "Report on Manoeuvrability and seakeeping effect on the operational performance of podded high speed vessels_Technical report on Sub-task 4.3", FASTPOD Deliverable D4.3, UNEW.

Yang H. J. et al., 2009, "PREDICTION OF THE MANOEUVRABILITY ON TWIN PODDED VESSEL", MARSIM 09,