Intuitive operation and pilot training when using marine azimuthing control devices

AZIPILOT

Report Title:

Deliverable 1.3:

Review of existing modelling & test methods

EXECUTIVE SUMMARY

The aim of Task 1.3 is to review the compliance to existing modelling and testing methods for ships equipped with azimuthing control devices (ACD) with respect to the operations when the ship is in the at-sea condition and when the ship is navigating in harbours.

<u>At-sea condition</u>

The manoeuvrability and seakeeping characteristics of ships can be investigated by the following four approaches:

- Physical model testing
- Mathematical model based simulations
- Computational methods and
- Full-scale sea trials

Chapter 2 highlights the perceived benefits and negative effects of pod-driven ships based on the previous experience. The existing model testing methods are reviewed in Chapter 3 whereas and computational methods are discussed in Chapter 4. Review of mathematical model based simulations is left out in the present report since they will be reviewed in WP2. The application of autopilots for azimuthing control devices at sea conditions is discussed in chapter 5

<u>Harbours</u>

The navigation in harbours includes the proximity of the

- bottom (shallow water),
- lateral boundaries (bank effects) and
- other vessels or objects (ship-ship-interaction).

As there is the shore always in close distance, at harbour conditions also the

- wash effect is to be considered.

In the second part of the report all these “close-to” phenomena are examined and it is checked, whether there is special knowledge available and a special consideration needed regarding azimuthing control devices.

For the understanding of the basic hydrodynamics in chapter 6 The flow phenomena and the common treatment of them is discussed an applied to the ship-ship-interaction. The bank effect is treated in chapter 7 and the common shallow water influence in chapter 8. In all these chapters a potential or known consideration of ACD regarding these effects is discussed. According to this the wash effect is explained in chapter 9 and brought into connection with ACDs.

As a conclusion the possibilities of future development are explained in chapter 10.

CONTENTS

1 INTRODUCTION

The aim of this task is to review the compliance to existing modelling and testing methods for ships equipped with azimuthing control devices. This will include consideration of two specific conditions, namely when the ship is at sea and when the ship is navigating in harbour conditions. The objective is to map the special considerations that have to be taken into account when modelling and testing ships with azimuthing control devices; when compared to traditional ones. For the condition when the ship is at sea, special focus will be given to the subject of the course-keeping abilities of ships equipped with azimuthing control devices. Studies will be carried out regarding the difference in design of autopilots for azimuthing control devices when compared to conventional arrangements including:

- Survey perceived benefits and negative effects when using azimuthing control devices in the at-sea condition.
- Review existing modelling and testing methods for azimuthing control devices in the at-sea condition.
- Explore possibilities for the development of modelling the at-sea condition and model testing techniques.
- Discuss different needs for autopilots at sea condition for azimuth/conventional propulsion.

For the condition when navigating in harbour, the objective is to explore the key contributing issues and present them in a readily accessible formant. Main points for consideration include:

- Survey effects of ship-to-ship interactions specific to azimuthing control devices.
- Survey effects of ship-to-bank interactions specific to azimuthing control devices.
- Survey effects of shallow water specific to azimuthing control devices.
- Explore the ability to model the environmental impact of thrust wash on man-made and natural structures and banks.

2 POSSITIVE AND NEGATIVE EFFECTS OF USING AZ IMUTHING CONTROL DEVICES IN THE AT-SEA CONDITION

As compared with conventional shaft-line propellers, the azimuthing pod propulsion devices are perceived to have the following advantages and disadvantages.

2.1 Benefits

- Better manoeuvrability (even at very low speed), in regard to the turning, initial turning, and yaw-checking abilities.
- Pod equipped with flap and fins bring with additional manoeuvrability
- Shorter stopping time and track reach in a crash-stop manoeuvre
- Lower pressure pulses and noise

2.2 Negative effects

- Course instability (there has been several reports on course instability of a few podded vessels. See e.g. Woodward (2005b), Trägårdh et al. (2004))
- Large induced roll angle and heel angle in connection with pod-turning manoeuvres
- Induced side loads in connection with pod-turning manoeuvres
- Cavitation and vibration at moderate-to-large azimuthing angles (ITTC, 2008a)

- Slightly degraded propulsive efficiency

(Counter-measures
Course instability can be reduced or removed by installing a steering flap on the trailing edge of the pod strut.

3 MODEL TESTING METHODS FOR PODS IN THE AT-SEA CONDITION

The same model testing methods as for ships with conventional shaft-line propellers have been used for ships equipped with azimuthing control devices for quite some time now. The manoeuvring performance of podded ships has been assessed with the criteria specified by the International Maritime Organisation (IMO) in a document "Interim standards for ship manoeuvrability, Resolution MSC. 137(76)" (IMO. 2002a).

In a dedicated research study, Woodward (2005c) critically analysed and assessed the applicability of the above-mentioned IMO standards for pod-driven ships. Based on this study, the 24th ITTC Specialist Committee on Azimuthing Podded Propulsion (ITTC, 2005a) came to a conclusion that the IMO manoeuvring criteria 'Resolution MSC. 137(76)' provide equivalent information about the manoeuvring response of pod-driven ships as for conventionally propelled ships; and these criteria can thus be applied directly.

3.1 Model tests on manoeuvrability

Manoeuvring tests can be executed in two different ways, dependent on the testing purpose, possessed facilities and equipment, as <u>free sailing</u> or <u>captive model tests</u>. Objectives of manoeuvrability test are:

- Verification of manoeuvrability – the fulfilment of IMO criteria
- Establishment of hydrodynamic coefficients for the manoeuvring equations

If the purpose is to verify the manoeuvrability of ship in compliance with IMO criteria, then the manoeuvring tests are the self-propelled free sailing type. This type of test is also used to determine the directional stability of ship. The ship model must follow the geometrical similarity as the full-scale ship and the model speed is determined by Froude scaling law. The test speed V used in the Standard tests is a speed of at least 90% of the ship's speed corresponding to 85% of the maximum engine output. The test should be performed in deep, unrestricted and calm water with the ship at full load and even keel conditions. In case the model tests are conducted at a condition different from those specified above, necessary corrections should be made in according with the guidelines in the explanatory notes on the standards for ship manoeuvrability from IMO.

IMO standard manoeuvring tests include the following:

(1) <u>Turning circle test</u> (Figure 1)
Turning circle manoeuvre is the manoeuvre to be performed to both starboard and port with 35° rudder angle or the maximum rudder angle permissible at the test speed, following a steady approach with zero yaw rate.

The criteria for *turning ability* are
(a) The advance should not exceed 4.5 ship lengths (L) and
(b) The tactical diameter should not exceed 5 ship lengths in the turning circle manoeuvre.

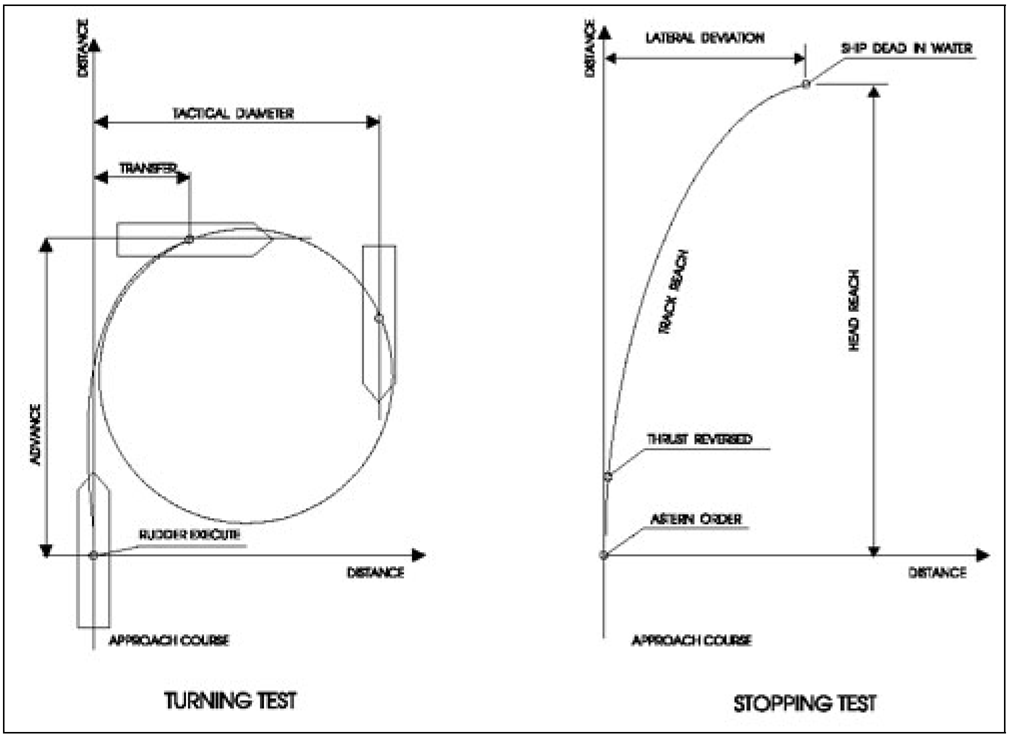

Figure 1 sketch of turning test and stopping test

(2) Zig-zag tests (Figure 2)

Zig-zag test is the manoeuvre where a known amount of helm is applied alternately to either side (port and starboard) when a known heading deviation from the original heading is reached. It includes two tests.

- helm angle 10º/ 10º to both sides
- helm angle 20º/ 20º to both sides

On the base of zig-zag test, initial turning ability, yaw-checking and course-keeping abilities of ship are specified.

The criterion for *initial turning ability* is:
With the application of 10° rudder angle to port/starboard, the ship should not have travelled more than 2.5 ship lengths by the time the heading has changed by 10° from the original heading.

The criteria for *yaw-checking and course-keeping abilities* are:
(A) The value of the first overshoot angle in the 10°/10° zig-zag test should not exceed:
 (a) 10° if L/V is less than 10s;
 (b) 20° if L/V is 30s or more; and
 (c) (5 + 1/2(L/V))° if L/V is 10s or more, but less than 30s,
where L (model-ship length) and V are expressed in m and m/s, respectively.
(B) The value of the second overshoot angle in the 10°/10° zig-zag test should not exceed:
 (a) 25°, if L/V is less than 10s;
 (b) 40°, if L/V is 30s or more; and
 (c) (17.5 + 0.75(L/V))°, if L/V is 10s or more, but less than 30s.
(C) The value of the first overshoot angle in the 20°/20° zig-zag test should not exceed 25°.

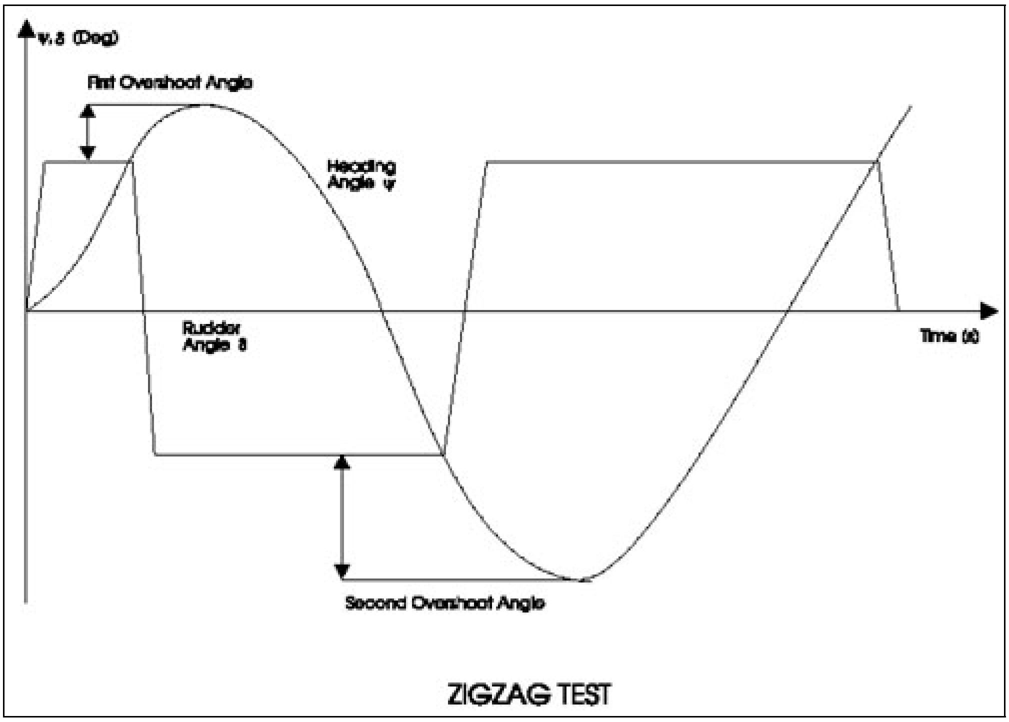

Figure 2 Sketch of zig-zag test

(3) <u>Full astern stopping test</u> (Figure 1)
Full astern stopping test determines the track reach of a ship from the time an order for full astern is given until the ship stops in the water.

The criterion for *stopping ability* is:
The track reach in the full astern stopping test should not exceed 15 ship lengths. However, this value may be modified by the Administration where ships of large displacement make this criterion impracticable, but should in no case exceed 20 ship lengths.

Typical quantities measured during the standard manoeuvring test are:

- Model speed
- Propeller rate of revolutions
- Rudder angle
- Heading
- Position (alternatively 6 DOF position measurement)
- Rate of turn (e.g. by use of gyro)

If test results from the above standard manoeuvres indicate dynamic instability, additional tests may be conducted to define the degree of instability, such as:

(4) <u>Spiral and reverse spiral test</u>

(5) <u>Pull-out manoeuvring test</u>
Details about the additional tests are referred to (IMO. 2002a and 2002b).

The second type of manoeuvring tests, <u>captive model test</u>, is carried out with use of Planar Motion Mechanism (PMM) or its equivalents. They constitute a kind of parametric investigation where a model is towed in the tank and parameters describing its movement are changed according to earlier assumed matrix. During tests, model positions, speed and loadings (as explicitly defined forces and moments) are measured. It makes possible to calculate necessary coefficients and derivatives which afterwards are put to the assumed mathematical model. As a result characteristics of any simulated manoeuvre can be acquired.

(6) Drift angle tests (course stability):

In order to get preliminary information of the course stability of the ship transverse forces fore and aft are measured in combination with the self-propulsion tests. The drift angle tests are carried out at the design speed and at a number of drift angles. The propeller rpm is kept constant corresponding to the self-propulsion point at zero drift angle. From the test results the linear stability coefficients Y"uv and N"uv can be determined. The damping coefficients Y"ur and N"ur can be estimated based on statistical data and the dynamic stability lever (Slev) is given by the formula:

Slev = (xg-N"ur)/(1-Y"ur) - N"uv/Y"uv

Manoeuvring criteria's based on result from drift angle test and use of Nomoto's equation have been proposed by several researchers for example Norrbin and Barr (ITTC 2002).

3.2 Special consideration of manoeuvring tests for pod-driven ships

Through two recently completed EU-financed RTD projects, OPTIPOD and FASTPOD, a number of manoeuvring phenomena that are specific to podded ships are recognised. They call for special considerations in performing model tests in addition to above standard manoeuvring tests. Therefore additional tests may need to be carried out to identify special features related to pod-driven ships.

3.2.1 Course instability

There have been reports that some vessels equipped with pods reveal insufficient directional stability (Atlar et al. 2005). Four podded vessels, (a Cargo ship, a Supply ship, a Ropax and a Cruise liner) are studied in the OPTIPOD project. Using a frequency based simple analysis method, Woodward et al. (2002b) predicted that Cargo ship and Supply ship had dynamic instability. In the later model tests and sea-trials, it was confirmed that one of them, the Supply ship, had insufficient directional stability. The simulation study performed by Trägårdh (2003) also supported this observation for the Supply ship.

The significant modification to the aft-body ('prammed' stern and removal of central skeg) in order to accommodate the pod-units is believed to be the main reason of less course stability observed on some podded-ships. Therefore, in case there is an indication of course instability from the standard Zig-zag test, additional manoeuvring tests like reverse spiral and pull-out tests should be carried out to further study or quantify the extent of instability.

3.2.2 Different stopping modes

As far as crash stop manoeuvre for pod propulsions is concerned, the braking force can be generated by several modes, as contrary to the conventional propellers where the braking force can only be trigger by reverse rotation of propellers.

In a numerical study Woodward et al. (2004 and 2005a) compared the response of ship in four stopping modes including:

1. Changing the direction of propeller rotation (reversing the thrust);
2. Turning the pods around;
3. Turning the pods around while reducing the thrust;
4. Turning the pods to 60° in opposite directions while reversing the thrust called "**Indirect Manoeuvre**".

The results of the analysis demonstrate that reversing the thrust by mode 1 provides a low, continuous load on the pod, resulting in the longest stopping time and distance. The analysis does not however consider the poorly distributed and unsteady forces experienced by the propeller. Comparison of stopping by turning the pods by mode 2 demonstrates that far greater forces can be generated by the pod system than can be generated by the propeller alone. The results show that a reduction in MCR, while extending the stopping distance, does not significantly reduce the peak forces on the pod. This is considered to be due to the propeller/shaft/motor mass inertia, initially sustaining an rpm value not possible with the motor torque alone. Clearly, it is possible that this inertia-sustained rpm could induce high propeller stresses. The indirect manoeuvre mode 4 demonstrates the shortest stopping time and distance. The results show a more sustained braking force but with significantly lower peak loads than when turning the pods around. A further advantage of the indirect manoeuvre is quoted to be that induced asymmetry between pod helm angles can provide large steering forces; resulting in a safer, faster and far more controlled stopping operation. The proposed model does not take into account the effect of interaction between pods nor cavitation which can be apparent, particularly at increasing helm angles.

It is therefore important to clarify in the report which stopping mode is applied in the standard full astern stopping test. It is also recommended to investigate response to other alternative stopping modes whenever applicable.

3.2.3 Response under extreme steering

By *extreme steering* it is meant that the podded propeller is slewed through angles exceeding 7~10°, which in practical terms means a range of 15~30° (ITTC, 2005a). Under such extreme steering of pod units, it has been observed in experiments and also in mathematical simulations that the podded ships exhibit several unique responses, as follows.

Large induced side loads

Turning the pod in the extreme mode will exert large manoeuvring-induced side loads on the entire pod unit due to their high acceleration dependency. Woodward et al. (2005b) present model test results showing spike-like loads experienced on the pods of two different ships. The magnitude of the spike loads is shown to be acceleration dependent and most sensitive to the dynamic course stability of the ship. Though these loads do not impact directly on the manoeuvring response they have significant implications for the structural design of the pod and its seating at the aft end of the vessel.

Induced roll motion

During a steady turning of the pods, a large induced initial roll angle (motion) and a subsequent moderate heel angle was noted by Woodward et al. (2005b) in the same time when the large induced side load was observed, implying a close connection between these two responses under the turning manoeuvre.

Within the same context Toxopeus and Loeff (2002) investigated the merits and drawbacks of the manoeuvring characteristics related to the application of podded propellers. They draw attention to the heel/roll behaviour while manoeuvring with the pod-driven ship; although the turning ability itself was not a problem when judging the applicability of podded propellers. These behaviours are attributed to high turning rates which induce large gyration forces and thus large roll motions. The resulting roll angles in turn can affect the turning rate and the course stability. Based upon their database they demonstrated 28° maximum roll and 17° constant heel at high speed and large steering angles. They claim that maximum roll angle greater than 13° and constant heel angle larger than 8° are cause for concern and these are not covered by the current IMO criteria. The steering related heel/roll behaviour has also been the subject of investigation by others, e.g. Lepeix (2001), Hamalainen and van Heerd (2001). It is advisable to also measure the side force and heel/roll angle variations in a large turning manoeuvre.

Cavitation at off-design azimuthing

As follows from Kurimo (1998), Pustoshny and Kaprantsev (2001), there is a high probability of cavitation when the podded propulsor is rotated by large azimuth angles due to the reduction in the advance ratio and the increase in the incidence angle. Cavitation test at large off-design azimuthing angles appears to be necessary for pod-driven vessels. The test procedure for cavitation observation on podded propeller is described in detail in the ITTC's recommended procedure 7.5-02-03-03.6.

3.3 Model tests on seakeeping

Seakeeping deals with the dynamic motion of ship in a seaway. The complex dynamic motion is a mixture of surge, heave, sway, rolling, pitching and yawing in response to the action of the ocean waves, superimposed onto the ship's ahead motion and any sideways drift it may take due to the wind and/or current. The common understanding of seakeeping capabilities is that the main dimensions of ship and hull type are essential parameters. The shapes of the fore and aft body of hull are also of some importance. The choice of pod propulsion for a vessel and the associated stern shape could consequently have some influence on the seakeeping properties.

Objectives of seakeeping tests are to
- Determine operational limits
- Measure design loads
- Optimize design with respect to seakeeping performance
- Capsize and safety studies
- Development and testing of motion damping systems
- Investigate added resistance and speed loss due to waves

The 23rd and 24th ITTC Seakeeping Committee (ITTC, 2005b) have established procedures recommended for performing seakeeping model tests of ships equipped with conventional shaft-line propellers, including:
(1) Procedure 7.5-02-07-02.1 for model tests on linear and weakly non-linear seakeeping phenomena.
(2) Procedure 7.5-02-07-02.2 for added resistance and power increase in irregular waves.
(3) Procedure 7.5-02-07-02.3 for experiments on rarely occurring events.

These tests are directly applied for seakeeping study of podded vessels today. Analogous to manoeuvring tests, seakeeping model tests can be executed in two different ways, as <u>free sailing</u> (free-running) test or <u>captive test</u>.

The <u>free sailing</u> tests, the most common type of tests, are performed to measure various response of ships (motions and accelerations), as well as the internal global or local (slamming) forces. The <u>captive tests</u> are performed primarily to verify and validate numerical methods or mathematical models. In a captive test for seakeeping study, the total forces on the model are measured. The model may be given forced motions or being fixed in arriving waves.

Typical quantities measured during a free sailing seakeeping test for podded ships are:

- wave height
- ship speed
- rate of propeller revolutions,
- POD x-force, (ship's co-ordinate system)
- POD y-force, (ship's co-ordinate system)
- POD angle
- steering flap angle, if any
- surge, sway, heave
- roll, pitch, yaw
- wave heading
- longitudinal acceleration aft, x
- lateral acceleration fore, y1
- lateral acceleration aft, y2
- vertical acceleration aft PS, z1
- vertical acceleration fore, z2
- vertical acceleration aft SB, z3

3.4 Special consideration of seakeeping tests for pod-driven ships

Slamming

The flat bottom of the aft-body of a podded ship is likely an area subject to slamming due to the special design of the stern to accommodate the pod unit. Slamming loads are often characterised by high peak pressure values in short duration. The noise and vibration problem due to slamming may cause an issue of onboard comfort for cruise liners. Therefore a test of importance for pod-driven ships is to measure the **slamming force** in a free sailing test conducted in selected irregular waves. By placing the proper transducers in the risk area, the local slamming force acting on the model can be measured.

Course keeping in waves

It is of added value to examine the course keeping ability under environmental waves for podded ships, especially when they have revealed poor course stability during manoeuvring tests in calm water.

Dynamic stability in waves (rarely occurring event)

Dynamic stability in waves is related to the property of motions under broaching, bow dive and coupled pitch-roll-yaw motions caused by groups of large regular waves. Dynamic stability and capsize are often tested in large regular waves.

Parametric roll

A very important operability aspect for cargo ships is the risk and extent of parametric roll in head sea and following sea conditions, because excessive roll can result in significant loss of gods from the deck (Atlar et al. 2005, Ayaz et al. 2006).

4 COMPUTATIONAL METHODS AND MATHEMATIC MODELS FOR PODS IN THE AT-SEA CONDITION

4.1 Modelling tools for manoeuvrability

4.1.1 Computational tools

By Computational Fluid Dynamics (CFD) tools (or methods) are meant those that determine not only the motion of the ships but also the flow field around ships by solving a set of equations that satisfy the physical laws of fluid (e.g. 6DOF equations and Reynolds-Average Navier-Stokes Equations). Since the last decade, the number of CFD applications to podded ships has been continuously increasing. However, they are mainly applied for pods operating in straight course with focus on propulsive performance of the azimuth devices, not so much literature could be found with regard to CFD applications to the operation and response of podded ships in at-sea conditions.

Depending on whether the viscous effects are neglected or included, the computational tools can be classified into two categories: Inviscid methods and RANS methods.

<u>Inviscid methods</u>

Ayaz et al. (2006b) developed a coupled nonlinear 6-DOF model with frequency dependent coefficients, incorporating memory effects and random waves. A new axes system that allows straightforward combination between seakeeping and manoeuvring, whilst accounting for extreme motions, was proposed. This 6-DOF model was further enhanced by Ayaz and Turan (2005a, 2006c) and applied for the simulation of manoeuvring and seakeeping characteristics of large pod-driven high-speed ships by introducing thrust and lateral force components of azimuthing and fixed pod drives. The effect of large pod-induced heel angles on the turning and ship motions in waves, the stability and control problems caused by design modifications are demonstrated using the numerical simulations by Ayaz and Turan (2005a, b). Using the same enhanced method, Turan et al. (2008) investigate the parametric rolling behaviour of large, high-speed pod-driven ships in waves. Ayaz et al. (2006d) studied numerically and experimentally the induced heeling during turning manoeuvre for a high-speed POD-driven ROPAX and Cargo ships. They pointed out that large roll motion can be induced for POD ships due to high turning rate and speed.

<u>RANS methods</u>

There has been tremendous development in application of RANS or the inviscid/RANS hybrid methods to manoeuvring analysis of conventional shaft-driven ships for the last ten years. For example, the steady drift or steady rotation of ships have been studied by Campana et al (1998), Alessandrini et al (1998a, b), Cura Hochbaum (1998), Ohmori (1998a, b), and Simonsen et al. (2003). The oscillatory sway an yaw motions have been studied by Tahara et al. (1998), Mascio et al.(1999), Toxopeus (2004) and Gao et al. (2005). Direction simulation of ship manoeuvres have been reported for instance by Sato et al.(1998) and Xing-Kaeding et al.(2002, 2004). One of the significant advantages of RANS methods is their capability to more accurately determine the hydrodynamic derivatives as compared with the traditional empiric formula or methods (Toxopeus, 2008). Furthermore, the RANS calculations provide the added benefit of insight into the flow around the hull.

Only a limited number of RANS applications are found for the manoeuvrability analysis of podded vessels. Using a commercial RANS solver (COMET) and a RNG k-ε turbulence model with wall function, Junglewitz et al. (2004) compare the side force and steering capability of a pod with that of a conventional spade rudder. It is found that at design ship speed the steering capability of a pod is not much superior compared with a conventional rudder. At lower speed the calculations show a clear advantage of steering with a pod over a conventional rudder.

Hong et al. (2010) uses commercial RANS solver Fluent and a SST k-ω turbulence model to study the hydrodynamic characteristics of the podded propulsor in oblique flows. Detailed comparisons with the measurements in terms of propeller thrust, torque, transverse force and steering moment were performed for the podded propulsor operating in both the pulling and pushing modes at the advance coefficient of 0.5, in the range of heading angles from -45 to +45 degrees. With good agreement achieved in the whole validation range, the RANS method demonstrates its capability of simulation of such complex marine systems as podded propulsors. In terms of integral force, the RANS results show a significant improvement over potential and viscous/potential coupled simulations. One of practical outcomes is the quantitatively accurate prediction of the asymmetric behaviour of characteristics of pushing propulsor at positive and negative heading angles.

4.1.2 Mathematical models

By mathematical models are meant those that describe the motion of ships by solving the equation of motions but determine their hydrodynamics forces by means of empirical or semi-empirical formulae, or some mathematical formulae. ?????

Information on mathematical models is referred to the review work in Task 2.1 and Task 2.2.

[A huge number of mathematical models have been developed and used in various research and pilot-trailing simulations for ships with conventional propulsions.

The models mainly differ in the representation of aft-body, drag estimation of the pod body, propulsive characteristics of the pod-units. ???????]

4.2 Modelling tools for seakeeping

4.2.1 Computational tools

<u>Potential flow methods</u>

Thornill et al (2002) applied a potential flow based time-domain seakeeping and manoeuvring code MOTSIM to evaluate the effectiveness of a twin Z-drive propulsion system on a vessel to control the roll motions in regular waves, as compared with that of a conventional rudder/propeller system on the same vessel. They concluded that thought more work was still needed, the simulations demonstrate the potential of using Z-drive propulsion for roll stabilization.

Couser P. (2000) used a frequency domain computational method based on simply the strip theory to evaluate the seakeeping behaviour of high speed crafts in the preliminary hydrodynamic design. Due to its efficiency in computation and analysis, the method is suitable for use in the preliminary design stage.
Ayaz and Turan (2005a, b) use the enhanced 6-DOF numerical model to investigate the directional stability characteristics and parametric rolling in extreme wave conditions for high-speed large pod-driven ships.

RANS methods

Although very few RANS applications are found to study the seakeeping characteristics of pod-driven vessels, there has been remarkable development in the RANS or the inviscid/RANS hybrid methods for seakeeping analysis of conventional shaft-driven ships for the last ten years. For example, ship response and manoeuvrability in waves have been investigated by Deng et al. (2005), Wilson et al.(1998), Cura Hochbaum et al (2002) and Luquet et al.(2005). A number of RANS solvers were further developed or enhanced in the recently completed EU project VIRTUE.

EL Moctar et al. (2004a) predicted the slamming loads on ship structures using a potential flow and a RANS code. They also performed numerical analysis of steering capability of a podded drive EL Moctar et al. (2004b).

Apart from the difference in manoeuvring derivatives and response coefficients for the podded ships, there is not much difference between the podded driven and conventional shaft-driven ships. In principle the equations of motion and numerical models that have been applied to conventional propeller shaft-driven ships can be used to analyse the seakeeping behaviour of pod-driven ships as well.

4.2.2 Mathematical models

Information on mathematical models is referred to the review work in Task 2.1 and Task 2.2.

5 DIFFERENT NEEDS FOR AUTOPILOTS IN AT-SEA CONDITION

The autopilot used at SSPA's MDL to keep the model on course is a simple PD-controller:

$$\delta = \gamma \cdot \Psi + \sigma \cdot r$$

where
δ = rudder angle [degree]
γ = coefficient
Ψ = heading error [degree]
σ = coefficient
r = turning rate [degree/second].

The simple approach is sufficient relative short time measurements. In order to predict steering performance by autopilot one opportunity is to use numerical simulation. The numerical simulation model is preferable tune by result from sea-keeping and manoeuvring test. Computer simulations gives possibilities for implement advanced autopilot algorithms and project them to different environment conditions and sensor limitations.
It is obvious that control of a strongly course unstable ship can put special demands on the autopilot algorithms. Although this is the case for some of the ship with ACD's very few public report of this exists. In the OPTIPOD project a study was carried out in order to compare of a RoPax vessel equipped with conventional twin rudder/propeller arrangement or azimuthing pods (Trägårdh 2002).

6 EFFECTS OF SHIP-TO-S HIP INTERACTIONS SPECIFIC TO AZIMUTHING CONTROL DEVICES

Ship- Ship-Interaction is a phenomenon which is related to the effect of the flow around the ships hull to other ships in vicinity. To understand the physical details which lead to the so called interaction forces and moments the two major effects of the flow have to be considered.

- Water flow

  When a ship moves through the water at a certain speed the body of the ship displaces the water – in motion direction and to the sides. As a consequence of this the water in front of the ship moves in the direction of the ships motion and the water at the side moves against. When the water has passed the ship it comes together and changes direction again and follows the ship. The main effect is the surplus speed alongside the ships side and bottom, which means, that the motion of the ship through the water is faster than over ground even if there is no current.

  This velocity field can be measured in model experiments or it can be calculated by different numerical methods (Potential, Euler, RANSE codes etc.). For the measurement of this surplus speed both in full scale and model tests normally the probes are earth fixed and measure only the swapping of the water in, against and in the direction of the motion of the ship.

  There are several formulae available to calculate the mean surplus velocity in order to correct the frictional resistance calculations. Some of them are: Emerson, Lackenby, Kreitner.

- Water surface

  The flow around the ships hull is (related to Bernoullis law) associated to a deformation of the water surface. In front of the bow and behind the stern an elevation can be found and along the side of the ship a depression occurs. This surface deformation is called the “primary wave system” (see Fig 1), which is moving along with the ship while the “secondary wave system” (see Fig 2, the so called Kelvin-waves) are departing from the ship.

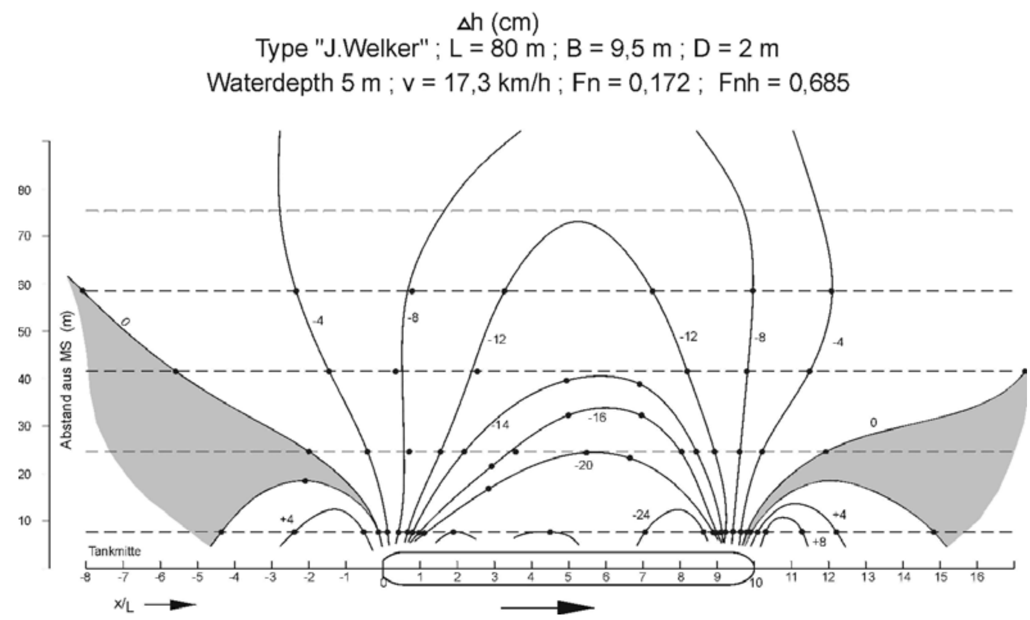

Fig 1 – Primary wave system

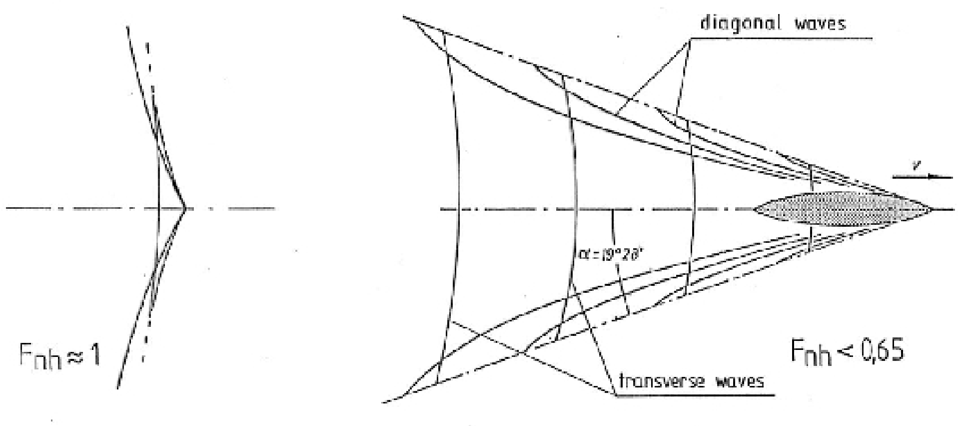

Fig 2 – Secondary wave system

Due to the fact that the depression is longer than the elevation and that the ships hull is mainly in the area of the depression it follows it downwards until weight and buoyancy are in equilibrium – the well known sinkage z.

The level of depression and the sinkage of the ship are not identical because the ships hull is although supported by the elevation in front and behind. The measurement of the sinkage in full scale is always problematic because of the lack of a vertically fixed reference system. In model tests it can easily be measured from the towing carriage.

The calculation of the surface deformation is only possible if the numerical code is able to take the free surface into account. Measurements also have to be carried out earth fixed with probes supported from the top or standing on the bottom.

A lot of empirical approaches have been made to predict the sinkage of ships. Reference can be made to PIANC (1997) and Briggs (2006), who presents several formulae from Barrass. Eryuzlu, Eryuzlu & Hausser, Hooft, Huuska & Guliev, ICORELS, OCADIJ, Millward, Norrbin, Roemisch.

Both effects increase considerably in shallow and confined waters. The reason for that is the decreasing space under (shallow water) and beside (confined waters) the ship. The magnitude of the increase of the effects can be related to nondimensional geometric parameters as statet below.

- Shallow water (no lateral limitations)

  The relative water depth which is normally expressed as the ratio h/T (draught by water depth) or the reciprocal value T/h. The latter formulation has the advantage that the one extreme "infinite water depth" has the value T/h = 0 and the other extreme "grounding" has the value T/h = 1. If using h/T the deep water case is described by the value ∞ and the grounding by h/T = 1.

  It has to be taken into account, that the surface depression reduces the water depth. This is considered by the introduction of the "effective water depth" h_{eff} = h-z. With increasing speed the sinkage increases and h_{eff} decreases with the final consequence of grounding, if the sinkage reaches the under-keel-clearance UKC = h-T of the non-moving ship.

- <u>Confined waters</u> (vertical and lateral limitations = canals and harbours)

  The blockage factor S which describes the ratio of the hull section area As = B * T (breadth times draught) and the canal section Ac = W * h (canal width times water depth): S = As / Ac (see Fig 3). Sometimes the residual area of water in the canal is used to formulate the blockage: S = As / (Ac – As).

  Due to the additional lateral limitations in canals the sinkage and the backflow velocity is always greater than on shallow water only. In many of the squat formulae this is taken into account.

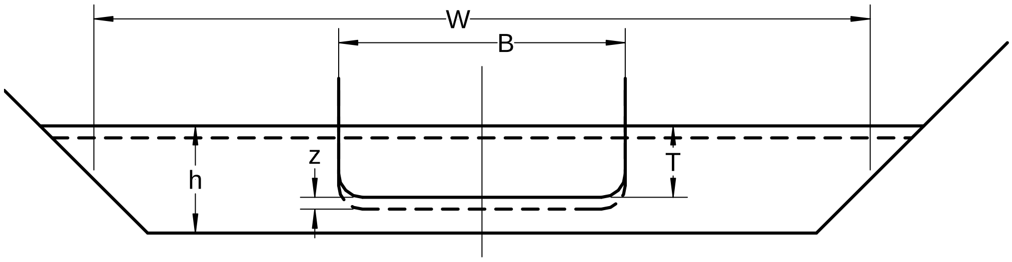

Fig 3 – Ship in a canal

If another ship is in the vicinity of a moving ship which creates a flow field and a surface deformation as described above it is influenced by it. This influence can be measured by the so called interaction forces and moments. Commonly they are described as longitudinal force X, lateral force Y and the yawing moment N. They are induced both by the flow velocities and the surface deformation, but cannot be traced back to a single reason.

- Flow velocity
  The interaction can be treated as an additional current which affects the ship by carrying it with by creating a frictional force.

- Surface deformation
  A ship in a deformed surface is affected by the downhill-slope force which moves into the direction of the lowest level of the deformation.

In general the interaction forces follow the scheme indicated below, which is noted for an overtaking manoeuvre, where the faster own ship (OS) overtakes a slower target ship (TS). Fig 4 shows the general development of the forces X and Y, the moment N and the values for Trim θ and sinkage z. The abscissa is the relative time t_R of the passing manoeuvre.

- Bow of OS meets stern of TS (t_R = -1)
  - Bow trims down
  - Accceleration
  - Repulsion
  - Turning outward
- Midship sections alongside (t_R = 0)
  - On even keel
  - Steady speed
  - Attraction
  - No yawing moment
- Stern of OS meets bow of TS (t_R = +1)
  - Stern trims down
  - Deceleratiom
  - Repulsion
  - Turning inward

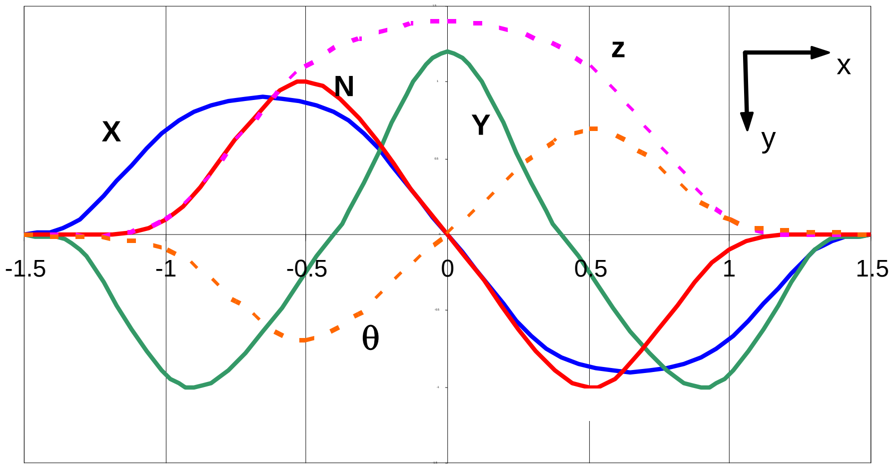

Fig 4 – Forces, moment and motion during ship-ship-interaction

These effects affect both ships and it is regardless, who is overtaking whom. It is also regardless, whether it is an overtaking or an encountering manoeuvre, because in all cases the flow fields of both vessels influence the behaviour of the other one. Dependent on the special geometry of the ships the position and height of the different maxima, minima and zero crossings might alter but the general characteristic is always the same.

It can be said, that the overtaking manoeuvre is more dangerous than the encountering. The simple reason for that is, that the time of an overtaking manoeuvre is much longer and the interaction effects act longer with more pronounced results on both vessels.

The magnitude of the interaction forces is dependent of several parameters. In the table below they are listed and it is mentioned how a certain parameter affects the magnitude if the interaction forces.

Parameter	**Influence**
Water depth h	Decreases with deeper water but never reaches zero
Lateral distance y	Decreases with greater distance and comes down to zero
Speed	Increases with rising speed
Ship size	Increases with rising ship size
Ship length	The peaks move to -1 and 1 and a parallel region in the curves occurs with rising length of only one ship
Ship breadth	Increases slightly with rising breadth
Ship draught	Increases slightly with rising draught
Block coefficient	Increases with rising block coefficient
Propeller revolutions	Increase slightly with the propeller revolutions

The last item is of high importance for the topic of this chapter. The presence of an acting propeller creates a suction at the stern which changes the flow field and therefore also the magnitude of the interaction effects. Comparative measurements at the DST have quantified this influence by performing captive overtaking tests both with the propeller of the overtaking vessel running or standing still.

It can be seen, that the propeller suction increases the yaw momentum for about 10-20%. The same results can be found with slightly less effect for the lateral force Y, but nearly no effect on the longitudinal force X can be detected.

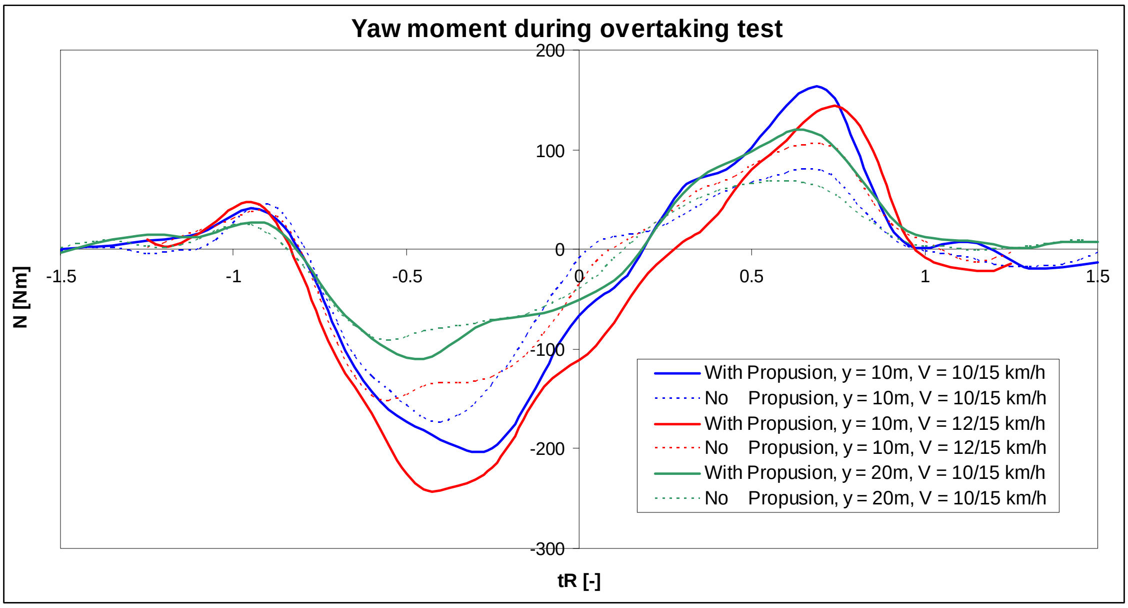

Fig 5 – Lateral force Y and yaw moment N

Unfortunately no test results are available with models equipped with conventional rudders and propellers and azimuthing control devices as alternative. But it can be estimated, that the difference of the suction of these two steering and control systems in comparison is far less than 10% of the total suction effect on the interaction forces.

Thus it can be concluded, that a special effect of the presence of an ACD on the ship-ship-interaction can hardly be identified and les be measured. If a small effect is present, it will definitely vanish within the measurement accuracy and cannot de detected by model experiments.

7 EFFECTS OF SHIP-TO-BANK INTERACTIONS SPECIFIC TO AZIMUTHING CONTROL DEVICES

The presence of an asymmetrical lateral obstacle influences the flow around the ship according to the phenomena explained in the chapter 17. This can be traced by the deduction, that

- a ship with zero speed has still an influence to a passing ship,
- a grounded ship can be seen as bridge pillar, which influences passing ships,
- a bridge pillar of infinite length can be seen as a vertical wall.

Due to the fact, that on the side of the ship, where the wall is present, the flow velocity is higher than on the other side (Bernoulli's law), in general a suction force directed to the bank or wall can be expected. Also a yaw moment can be found, which normally has a tendency to turn the bow away from the wall. The reason for that can be found in the asymmetry between bow and stern.

The presence of an operating propeller creates an additional suction at the stern, which increases both the lateral force and the momentum, because there is a lack of water on the banks side which should be pumped into the propulsion system.

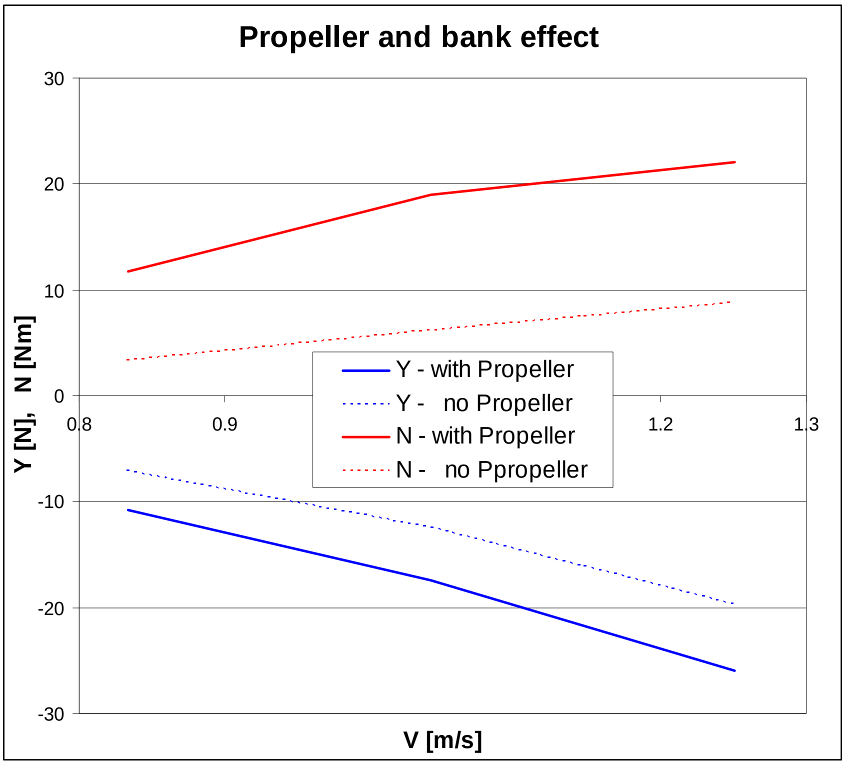

Fig 6 – Bank effect and propeller influence

In Fig 6 the results of a test with a 110 m inland vessel running parallel to a vertical wall with a distance of only 5 m can be seen. The measured lateral force Y is about 50% bigger for the case with the propeller running and the yaw moment N is increased by about 200%. In comparison to the ship-ship-interaction the effect of the propeller suction is significantly greater. There are several reasons for this:

- The lateral distance is smaller
- The obstacle is reaching the bottom
- The effect is occurring at the own ship

With such a great effect of the propeller suction it is expectable, that there is also a difference in the behaviour of conventional rudder-propeller systems and azimuthing control devices. Due to the lack of experimental data this difference cannot be quantified, but it seems to be far away from being negligible.

8 EFFECTS OF SHALLOW WATER SPECIFIC TO AZIMUTHING CONTROL DEVICES

Using the basic hydrodynamic considerations in chapter 6 the special influence of the shallow water to the propulsion system is the inhibited flow to the propeller. Instead of sucking in the water from both the sides and the bottom, the latter input is reduced to the gap under the ships bottom, which is decreasing with the under keel clearance. In order to solve this problem, inland waterway vessels, which mainly are operated on shallow water, have modified stern sections which improve the horizontal flow to the propeller.

ACD-vessels have generally stern sections which are different from conventional propeller installations. This is mainly reasoned by the fact, that a horizontal or flat surface is needed to install the azimuthing devices in the stern. The bottom of the ship is normally rising constantly without shaping around the keel as it is known for single propeller ships. The azimuthing functionality needs this space for unhindered rotation and free inflow to the propeller and free outflow of the slipstream. This difference in shaping can also be observed at twin screw vessels, but in a more moderate way, because the installation of two propellers is normally combined with more flat and u-shaped sections in the stern.

Generally spoke it can be said, that the major difference of the hull shape at ACD-vessels is the layout of the stern. This leads to different flow conditions, but as the difference between the hull form of a twin propeller and the hull of a twin ACD ship is not very pronounced, the change in suction is also small. So a specific effect of the shallow water to ACD's cannot be derived from theory.

If there is an effect, it will mainly deal with the sinkage of the stern, which decreases the powering performance due to the reduced stern draught, if the stern sinkage increases.

9 ABILITY TO MODEL THE E NVIRONMENTAL IMPACT OF THRUS T WASH ON MAN-MADE AND NATURAL STRUCTURES AND BANKS

The wash is the damage of the shore due to the ships waves. As said in chapter 6 already, the waves are divided in primary and secondary waves.

The primary wave system is moving with the vessel. Especially on canals the wave height can reach significant amount, depending on the blockage and the ships speed. In extreme cases (very shallow water) a breaking wave can be observed travelling with the ship. In Fig 7 this is visualized for a case of high speed on shallow water without lateral limitations.

Fig 7 – Breaking wave due to speed and water depth

This wave can enlarge considerable on narrow canals. Due to the backflow velocity there is also a significant current on the bank which also can produce severe damage to the shore. This is illustrated in Fig 8 which shows the breaking stern wave of an inland vessel running too fast on a canal.

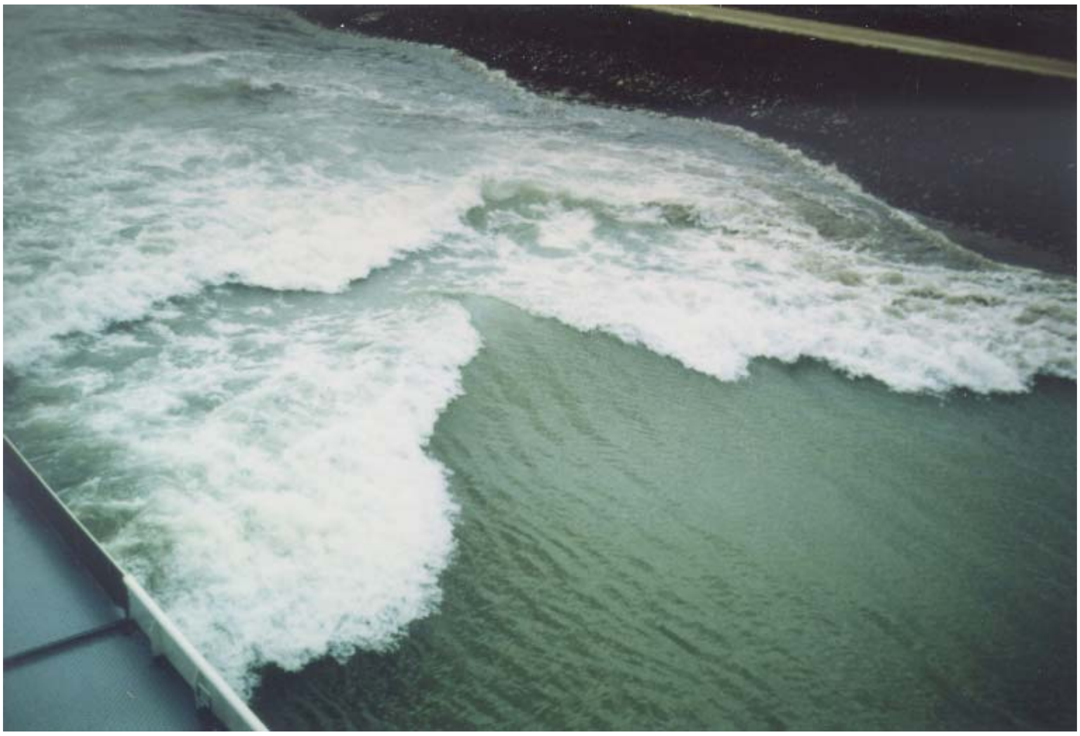

Fig 8 – Wash waves on a canal slope

The secondary wave system, also called Klevin-waves from their constant spreading angle (on deep water), is not moving with the ship, but departs to the sides. Fig 9 gives a good impression of them, compare to the theory displayed in Fig 2.

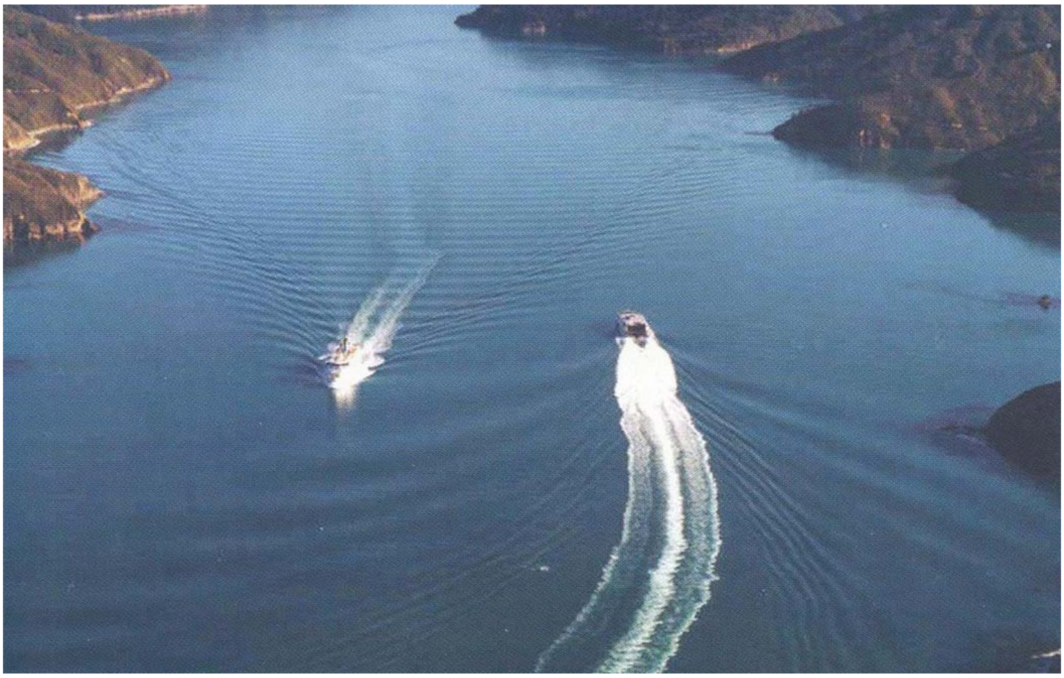

Fig 9 – Kelvin waves

These waves transport energy transversely and due to the speed of the ship it seems that they are left behind. The energy has to be brought up by the ship itself and is called “wave resistance” in the nautical terminology. When these waves hit a shore all the energy has to be reflected or, as it is the case on beaches, consumed by the shore. This is the main cause for severe damages on shores, specially, if the waves show significant heights.

In ship handling simulators the modelling of waves is common practice, but only in a limited way. The following list the waves are broken in the four main categories and discussed.

- Sea state (not mentioned yet)

  On open waters the wind stimulates irregular waves (a spektrum) which is characterized by Frequencies and wave heights. These waves are normally modelled in the visual system using a 3 dimensional deformation of the normally flat water surface. The ship itself floats on this moving surface and follows it which results in a ships motion. This motion is either simulated by shaking the whole bridge, if it is mounted on a hexapod or by shaking the horizon, which gives also a strong impression of the swell.

  As far it is known by the author, no simulator changes the wave spectrum with the water depth. In reality the waves become higher and steeper when the water depth decreases and if it is very shallow as on beaches the waves will break. This is not within the capabilities of simulators nowadays. Due to this lack also the wave impact to the shores is not simulated.

- Ship waves (secondary wave system)

  The ship waves are normally simulated in the visual system. The main reason for that is the intention to give the visual impression of motion and speed in the visuals. These waves are often computed by the superposition of a wave pattern to the flat sea or the sea state surface. The wave pattern is scaled in length and height to fit to the size and the speed of the vessel.

  Because the main goal is the generation of a visual impression, these ship waves are not modelled to create an impact on a shore or to man-made or natural structures. Also reflections are normally not calculated.

- Displacement waves (primary wave system)

  The primary wave system as it is explained in chapter 6 is normally not modelled in simulators. There are some attempts to visualize the trough, which is moving with the ship by superposition of a pattern to the secondary wave system or to modify the wave pattern by a formula which roughly describes this trough.

  This is of major importance for simulators which deal with shallow and/or restricted waterways where this effect occurs more pronounced. Effects to other ships and impacts to the shore (see Fig 8) are not calculated because the main goal is mostly only the visual impression. It is not known, whether other vessels (own ships or traffic ships) also follow this trough by experiencing an additional sinkage.

- Propeller waves (not mentioned yet)

  The suction of the propeller causes an additional trough at the stern of the ship. This surface deformation (see the impressive propeller wave in Fig 7) is additional and only present when the propeller is operating. In shallow and restricted waters it is not negligible and it can produce significant impact to the shore and to other vessels. Due to the fact, that the propulsion system is the originator of these waves it has to be asked, if an alternative propulsion system as e.g. an ACD creates different propeller waves.

It can be assumed, that no simulator is able to model this wave type – neither in the visual system nor in the physical impact to the shore as additional wash.

Even if the visual waves are modelled satisfactory it is doubtful, whether any simulator is able to consider the additional impact to the shore by the operating propeller (see chapter 7 "bank effects"). It is less probable, that an additional effect due to the presence of an azimuthing control device is simulated and considered in the proper physical way.

10 POSSIBILTIES OF FUTURE DEVELOPMENT

10.1 Sinkage of the ship due to propeller activity

The calculation of the sinkage of a ship is done in most simulators, but different approaches are used. The simplest one – using predefined maximum values for bow and stern and a quadratic dependency of the speed – works well for the visual impression but cannot satisfy more profound hydrodynamic aspects.

The implementation of squat formulae will improve this matter, but as no squat prediction takes the additional effect of the propulsion system into account, additional research work on this field is recommended. Special investigations concerning also the type of propulsion system (e.g. ACD) will deepen the knowledge and will lead to more realistic simulation results and more precise predictions.

10.2 Bank effect and additional influence of ACD

The special effect of a propeller to the ship forces when sailing has been identified to be significant. As there is no data available to distinguish between standard propellers and ACD it is recommended to investigate these details thoroughly. The goal should be a modelling technique to consider the propeller suction correctly. Additionally the type and position of the propulsion device should be an input variable to the simulator model.

With these improvements not only simulators for confined waters will benefit from these developments but also simulators which are used for tug operations because the presence of a big ship close to a tug produces forces similar to the bank forces to the tug.

10.3 Ship waves and wave impacts

The ship waves (all four types mentioned above) are modelled in simulators more ore less, depending of the wave type. Normally any impact to a shore or to other vessels is not modelled. In this field special investigations are recommended to improve the ability of the simulators to simulate the physical reality more precise.

In general the visual image of the ships waves should be improved, because e.g. skippers of inland vessels use the optical view of the ship waves (mainly at the stern) to estimate the proper speed of their vessel on restricted waters.

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