Intuitive operation
and pilot training
when using marine
azimuthing
control devices

AZIPILOT

Report Title:

Deliverable 3.5:

Proposed azipod model training programme and its assessment

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CONTENTS

PUBLISHABLE EXECUTIVE SUMMARY

The aims of this task are the rational development of effective training programmes for ships equipped with azimuthing control devices that go beyond what is available today. The results should be capable of meeting requirements from training and customers, under constraints imposed by regulating bodies and by the technology. The objectives are to formulate and to define the methodology and design of new training programmes, exploring the materials worked out in previous tasks and concerning the training needs specification, training capabilities and training program development. The task will examine methodologies through the development of a test training programme, using for this development the best practices as identified in the present study. The objective is also to determine the effectiveness of this process using validation of the training programme thorough its test implementation on simulators (manned models), conducting the test training and subsequent assessment

The report includes background information on basic construction and operational features and manoeuvring characteristics of ships equipped with azimuthing propulsion units that differ considerably from ships equipped with conventional propulsion units. Those differences substantiate the needs for arranging special training courses for azipod driven ships. The need for arranging special training courses for such ships was supported by the majority of ship masters and harbor pilots interviewed. Escorting operations required in certain areas, where tugs equipped with azimuthing propulsion units are employed when escorting ships carrying dangerous goods, require also special training.

Currently available specialized courses, either on Full Mission Bridge Simulators (FMBS) or on Manned Models Simulators (MMS), for ships equipped with azimuthing propulsion units and for ship-tug cooperation where pod driven tugs are essential were reviewed and on this basis model courses for FMBS and for MMS as well as for escorting operations for ships and tugs equipped with azimuthing propulsion units were developed.

Annex 1 includes Azipod Manoeuvring Terminology (paper by J.Baken and G.Burkley) and

Annex 2 includes report on implementation and assessment of thee courses.

INTRODUCTION

The aims of this task are the rational development of effective training programmes for ships equipped with azimuthing control devices that go beyond what is available today. The results should be capable of meeting requirements from training and customers, under constraints imposed by regulating bodies and by the technology. The objectives are to formulate and to define the methodology and design of new training programmes, exploring the materials worked out in previous tasks and concerning the training needs specification, training capabilities and training program development. The task will examine methodologies through the development of a test training programme, using for this development the best practices as identified in the present study. The objective is also to determine the effectiveness of this process using validation of the training programme through its test implementation on simulators (manned models), conducting the test training and subsequent assessment. The main areas of focus will include:

- Condense findings for the development of a test training request for ships equipped with azimuthing control devices, from the view point of training customer, and using the best practices used in the training industry – identifying training needs, requirements, training objectives and evaluation criteria.
- Development of the test training programmes responding to the specified training request to be implemented on simulators – using the best practices from the training industry – converting the training specifications into training programme consisting of exercises, training materials and training assessment methods.
- Implementation of the training programme on simulators and performing test training together with reports on the training execution
- Assessment of the tested training and identifying its short-comings and limitations.
- Evaluation of the current methodology of the development of new training for ships equipped with azimuthing control devices.

The task will culminate in task report that will delineate the above aims and objectives and will constitute one deliverable.

In fulfilling this task results obtained in other tasks of the project, the deliverables of which were available, were utilised with appropriate references given.

Chapter 1 of the report considers needs for training on azipod driven ships and basic features of podded propulsion units, their characteristics and operational aspects of pod driven ships that are important from the point of view of preparation of the training courses.

Chapter 2 includes the proposed developed programme of training courses and

Chapter 3 includes report on the trial programme and its assessment.

It is intended to include in the Annex the paper by Baken and Burkley on azipod manoeuvring terminology and command that is the best reference in that respect and should be observed in azipod training courses. As this paper was included in the deliverable report on Task 3.1, it is not repeated here with only title page attached for reference.

As the programme developed was not implemented at the time of writing this report, the part on implementation of the programme, together with its assessment, will be added when all data on the implementation and assessment of the programme proposed are available

CHAPTER 1.BACKGROUND

1.1. TRAINING REQUESTS AND TRAINING NEEDS

1.1.1 General

During last decades attention of the maritime world has been focused on safety of shipping. Amongst other causes of accidents at sea, casualties related to manoeuvrability happen quite often and analysis of casualties shows that CRG casualties (Collisions-Ramming-Groundings) constitute about 53% of all serious accidents leading to ship loss (Payer 1994). Data on CRG casualties for the year 1982 analysed on the basis of sources provided by LRS and DnV revealed that their frequency was rather high as it is seen from the Table 1.The data showed that 1 ship in 22 took part in CRG casualty this year (Samuelides & Friese 1984).

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

Table 1. Data on CRG casualties

Source	Mean number of ships during the year	Number of CRG casualties	Frequency of casualties [%]
DnV	2816	120	4.3
LRS	3391	170	5.0

Risk of CRG casualty depends on several factors, one of which is human factor, i.e. operators skill. Published analyses associated with commercial shipping during recent years indicated that human errors that occurred during handling operations were responsible for approximately 62 per cent of the major claims figure (Payer 1994). Other sources show, that about 80 % of all CRG casualties are results of human failure. Therefore attention is focused recently to the role of human factor in safety. (US Coast Guard 1995).

As about two thirds of all CRG casualties are caused by human error it is necessary to analyse factors which contribute to the efficiency of the operator. The author discussed this subject (Kobylinski 2009) showing that one of the most important factors contributing to this is training. The set of five features which are attributed to the man controlling the ship is shown in fig 1 (from Balcer&Kobylinski 1997)

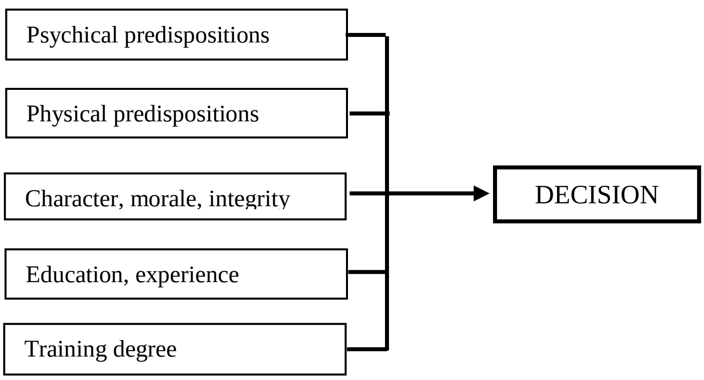


Fig.1 Features attributed to the man at controls

Increasing degree of safety in ship handling requires improvement of all five main features shown above. However the dynamics of features 1, 2 and 3 is not great, although they may be influenced by training. Knowledge and experience and most of all, training degree are seriously affected by training.

Important feature that might be seriously affected by training is way of handling critical situation. A mishap is differentiated into three psychological stages: perceiving, thinking and acting. Fig 2 (from Bea, 1994) shows how training could influence way of handling a critical situation. The perception stage starts with a mishap and is followed by warning. The warning is recognised and mishap source is discovered. Then the thinking stage begins, problem is identified and decision taken. Action is planned and executed and the system is returned to normal operating status if the action is taken in time, otherwise system fails.

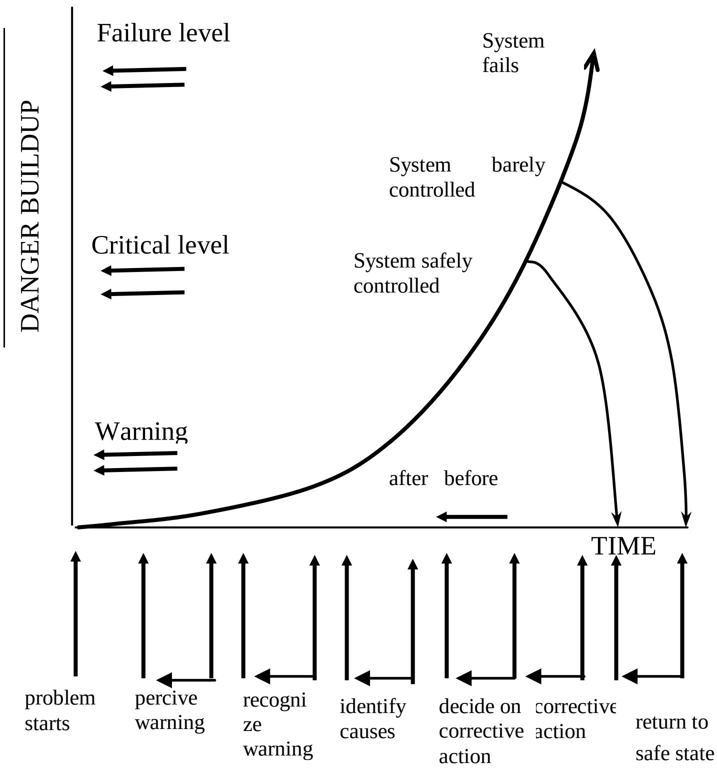


Fig.2. Effect of crisis training

The figure shows how training may affect safety. It underlines also the necessity to training for critical situations. Once people were faced with critical situation during the training they will react quicker when such situation appears in reality. This is very important conclusion for programming of training.

There are several factors contributing to the reduction of the number of CRG accidents, and experience is one of them. Experience is gained over years of practice. Specialized training on simulators accelerates gaining experience, in particular gaining experience in handling dangerous situations that may be rarely met during operation of real ships (Kobylinski 2009).

1.1.2 Simulator ship handling training needs

Training needs for ship handling in general were discussed in the report on Task 3.1 (de Grauaw 2010). In this report reference was made to the requirements of the IMO STCW Convention.

Obviously the best way to train ship officers and pilots in shiphandling and manoeuvring is to perform training onboard real ships. Any use of simulators should be in addition to training onboard ships. However, gaining skill "on job" watching experienced practitioner working is a long and tedious process. Moreover certain handling situations including some critical ones may never occur during the training period onboard ships and no experience how to deal with such situations could be gained this way. When serving on ships engaged in regular service there is little or no possibility to learn about handling in critical situations because such situations must be avoided as far possible. Simulator training is expensive, therefore the simulator courses must utilize time available in the most effective way. In order to achieve positive results simulators must be properly arranged and the programme of simulator exercised should be properly planned in order to achieve prescribed goals.

In general, simulators may be either equipment or situations. A simulator is defined as any system used as a representation of real working conditions to enable trainees to acquire and practice skills, knowledge and attitudes. A simulator is thus characterised by the following:

- imitation of a real situation and/or equipment which, however, may permit, for training purposes, the deliberate omission of some aspects of the equipment in operation being simulated, and
- user capability to control aspects of the operation being simulated.

The effectiveness of a simulator in training mariners depends on the simulator capabilities to simulate the reality. Sorensen (2006) stressed the point that simulators must be realistic and accurate in simulating the reality.

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

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

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

PART 1 – PERFORMANCE STANDARDS

General performance standards for simulators used in training

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

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

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

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

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

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

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

General performance standards for simulators used in assessment of competence

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

.1 be capable of satisfying the specified assessment objectives

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

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

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

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

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

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

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

Azimuthing propulsion is innovative solution revealing several advantages. Within past twenty years podded propulsors with a power up to 25MW per unit have been developed and put into service. Podded propulsors are characterized by two main qualities (Mewis 2001):

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

Fig.3 shows classical podded propulsor as defined above. However, there are known many variations of this type propulsors including many hybrid designs and also other types of azimuthing propulsors of different construction that do not include electric motor inside of the propulsor housing. Some examples of different types of azimuthing propulsors are shown in fig 4. (from Rees 2010). Those are Voith-Schneider propellers, Schottel propellers, outboard motor principle and rotating nozzle propellers. Those types propulsors are known and used for a long time, usually, however, in rather small ships and boats. Real innovation is development and application of high power podded drives as defined above.

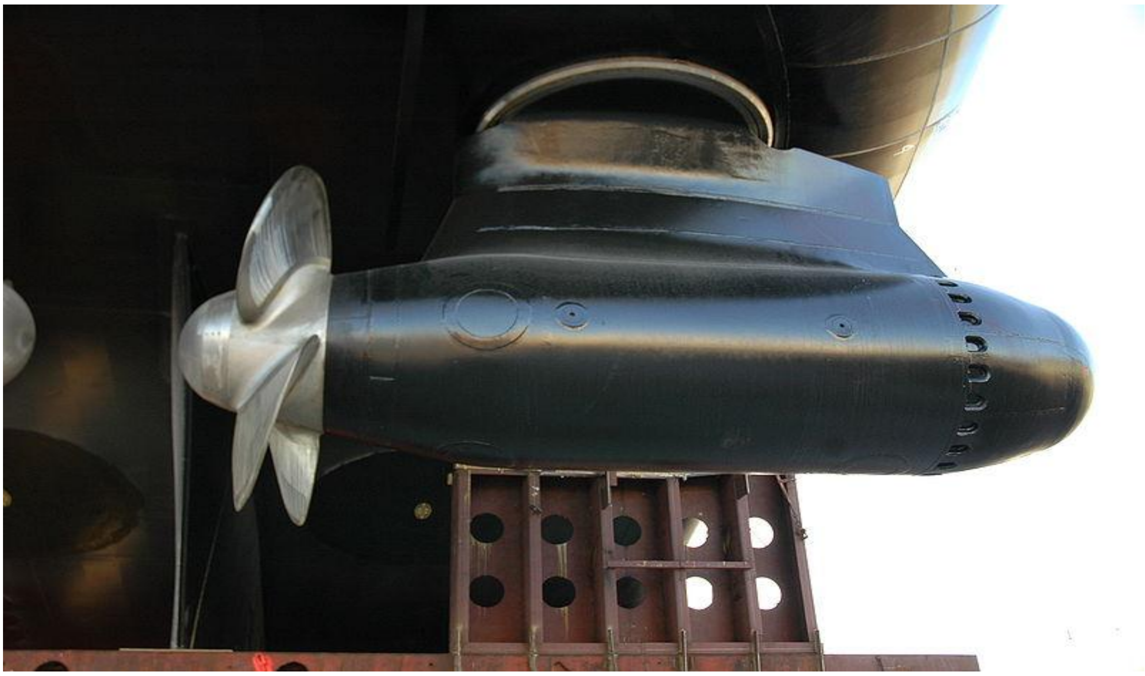


Fig. 3. Typical podded propulsor

Podded propellers are are as a rule installed in pairs because if single unit is installed the ship is usually dynamically unstable and difficult to control

Podded propulsors are well suited for (Mewis 2001):

- Cruise liners
- Ro-ro passenger ferries
- Icebreakers
- Off-shore supply vessels
- Tugs

Not well suited for:

- Container vessels
- Bulk carriers
- Tankers

Fig4. Some types of azimuting propulsors

According to Rees (2010) vessels fitted with azimuting propulsion constitute 6.9% of all vessels, the largest groups being tugs, off-shore vessels and cruise liners.

Rees (2010) reported that 8044 pilots were questioned on the matter of the need for training on azimuthing propelled ships, of which 2334 responded, and of these 96% use azipods. From this number 736 pilots (32%) received some kind of training on azipods and few others received some instruction from manufacturers.. The others did not receive any training on azipods at all.

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

Recently in many districts escorting of large vessels carrying dangerous goods - oil tankers, gas carriers and similar-is required. Escort tugs are almost always fitted with azimuthing propellers and escorting operations in case of emergency require greater skill from the tug masters and ship masters. Training in escorting operations is another fast developing area where azipod propelled vessels are involved and where special training is required.

It may be concluded that there is certainly the need for training on azipod driven ships and tugs for pilots and y for prospective masters of azipod propelled ships.

1.1.4. Existing simulators capabilities to simulate pod driven ships

In general, simulator may be either equipment or situation. A simulator is defined as any system used as a representation of real working conditions to enable trainees to acquire and practice skills, knowledge and attitudes. A simulator is thus characterised by the following:

- imitation of a real situation and/or equipment which, however, may permit, for training purposes, the deliberate omission of some aspects of the equipment in operation being simulated, and

- user capability to control aspects of the operation being simulated.

Capabilities of existing simulators were reviewed under the Task 2.2 of the AZIPOOD project (Kobylinski 2010). The main conclusions of this review are included in this report. The effectiveness of a simulator in training mariners depends on the simulator capabilities to simulate the reality. Sorensen (2006) stressed the point that simulators must be realistic and accurate in simulating the reality. Therefore simulators should, apart from simulating properly the main manoeuvring characteristics of a given ship, i.e.

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

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

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

Simulators used in training in ship handling and manoeuvring are basically of two types : Full Mission Bridge Simulators (FMBS) and Manned Models Simulators (MMS).

FMBS computer controlled simulators are widely used for training of ship officers, pilots and students of marine schools and also for studying various manoeuvring problems, first of all problems associated with the design of ports and harbours.

There is at present a considerable number of such simulators of different types operating throughout the world, starting from desk simulators to sophisticated FMBS where the trainee is placed inside a bridge mock-up with actual bridge equipment, realistic visual scene of the environment, and sometimes rolling and pitching motions and engine noise.

FBMS are working in the real time and are controlled by computers programmed to simulate ship motion controlled by rudder and engine (and thrusters or tugs) in different environmental conditions

MMS use large models for training purposes in specially arranged water areas, ponds or lakes. Models are sufficiently large in order to accommodate 2-4 people (students and instructors) and are constructed according to laws of similitude. Models are controlled by the helmsman and are manoeuvring in the areas where mock-up of ports and harbours, locks, canals, bridges piers and quays, shallow water areas and other facilities are constructed and where also routes marked by leading marks or lights (for night exercises) are laid out all in the same reduced scale as the models. Also in certain areas current is generated. As a rule, monitoring system allowing to monitor track of the model is available.

Important feature of manned model exercises is that all manoeuvres are performed not in real time, but in model time which is accelerated by the factor λ^{-1}. This may pose some difficulties for trainees at the beginning who must adjust to the accelerated time scale.

Currently there are only few training centres using manned models in the world, however, according to the recent information, few others are planned or even in the development stage.

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

Practically all modern FMBS are capable to simulate manoeuvring and ship handling characteristics in open water properly. Usually they are also capable to simulate the close proximity effects based on simplified theory.

Gronarz (2010) investigated capabilities of four advanced FMBS to simulate ship-ship interaction, shallow water and bank effect. The conclusions of this investigation are:

- All special hydrodynamic effects are covered from the simulators investigated.
- The magnitude of the effects is sometimes very different.
- The expectations from theory are satisfied mostly.
- The development of the shallow water effect with decreasing water depth is not always simulated correct.
- The magnitude of the bank effect is very different on the two simulators investigated.
- The ship-ship-interaction effect shows reasonable development with the passing distance but some doubtful results during the time of the manoeuvre.

In the case of manned models the governing law of similitude is Froude's law and all quantities for models are calculated according to the requirements of this law. However, as it is well known, the requirements of second law of similitude which is relevant to ship motion, Reynolds law, cannot be met. This means that the flow around the ship hull and appendages and in particular separation phenomena might be not reproduced correctly in the model scale. Fortunately those effects are important when the models are small. With models 8 to 15 m long the Reynolds number is sufficiently high to avoid the majority of such effects.

One important difficulty with manned models is impossibility to reproduce wind effect. Wind is a natural phenomenon and according to laws of similitude wind force should be reduced by factor λ^3 (λ - model scale). Wind force is proportional to the windage area and to the wind velocity squared. Windage area is reduced automatically by factor λ^2 but wind velocity apparently cannot be reduced. However, actually windage area in models is usually reduced more than by factor λ^2, and wind velocity. due to sheltered training area and low position of the windage area in the model in comparison with the full-scale ship is considerably reduced. Still usually wind force is larger than it should be.

Capability of manned models to simulate shallow water, bank, submerged and surface canal effects, effect of current, close proximity of other stationary or moving objects is automatically assured and is practically unlimited, restricted only by local conditions in the training area.

1.2. MANOEUVRING CHARACTERISTICS OF POD PROPELLED VESSELS

1.2.1.General

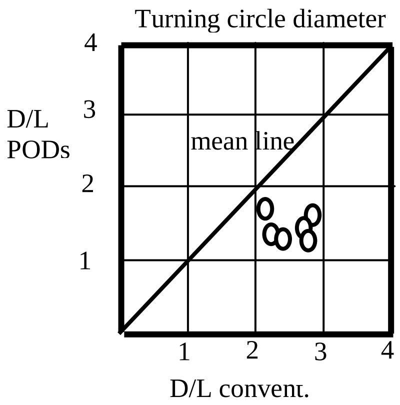
It is well known that manoeuvring characteristics of pod propelled vessels are different from the vessels with conventional propellers. Because of the widely different manoeuvring characteristics of pod driven ships the need to arrange special training courses for pod driven ships is obvious.

Three main manoeuvring qualities are considered;

- Turning ability
- Course keeping ability
- Stopping ability

1.2.2. Turning ability

It is generally known that turning ability of POD driven ships is much better than turning ability of conventional ships fitted with conventional rudder. This is obviously the result of high steering forces created by azipod rotated to certain angle and also possibility to rotate azipod by 360 deg.



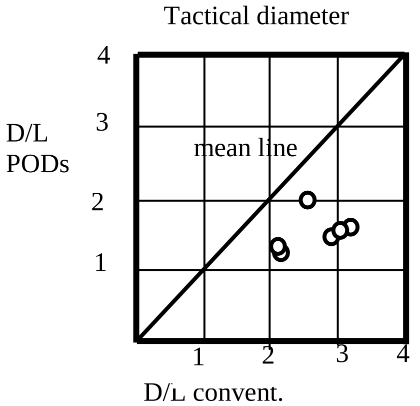


Fig.5. Comparison of turning characteristics for podded and conventional propulsion units

Fig 5 from (Toxopeus & Loeff, 2002) shows comparison of two turning measures – turning circle diameter and tactical diameter for several POD driven ships versus conventional units. The mean line represents the situation when the values for both types of ships are equal. In this comparison the angle of POD or rudder was limited to 35^0, as it is normal limiting angle of rudder deflection

It clearly shows that the turning ability of vessels with podded propulsion is much better than vessels with the conventional propellers and rudder. Moreover, PODs could be rotated to higher angles with the result that the ship may turn even around of its own centre of gravity. Clarification of this behaviour can be ascribed to large steering force generated by POD, where full thrust of the propeller can be created to all directions.

Excellent manoeuvring characteristics of pod driven ships were confirmed by model tests of a very large model (about 11m long) of a gas carrier with single and two podded propellers conducted at SRTC (Kobylinski & Nowicki 2005).

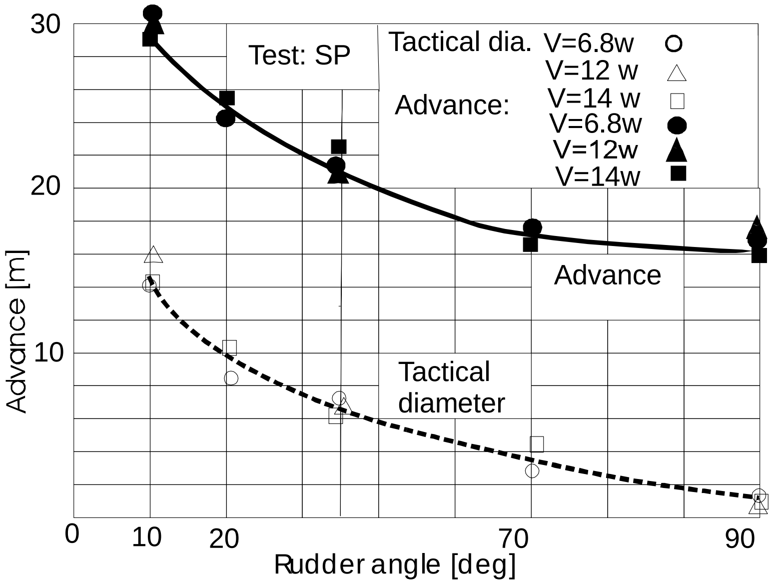


Fig.6. Tactical diameter and advance for single pod configuration

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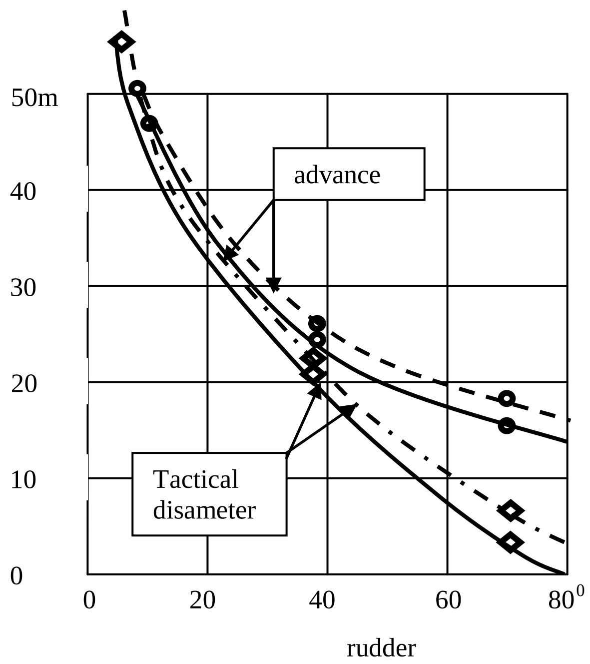


Fig7. Tactical diameter and advance for twin pods configuration. (solid lined –approach speed 6 knots, dotted lines – approach speed 14 knots)

Fig.6. shows results of the turning circle experiments of the model fitted with single pod propeller where advance and turning diameters are shown over the range of rudder (azipod) angles up o 90 degrees. The figure shows that at azipod angles closing to 90 deg. the model turns at the spot (tactical diameter is almost zero and advance is equal to about 1.5 model length).

Tests with twin azipod propulsion were conducted with the same model fitted with several different configuration of skegs and fins that were installed in order to achieve satisfactory course keeping ability (see below). Even with the installation of skegs and fins large enough to achieve satisfactory course keeping ability advance and tactical diameter at high rudder angle were very small (Fig.7).

1.2.3. Course keeping ability

The course keeping ability for pod driven ships is known to be worse than for conventional vessels. The reason of this effect may be attributed to the different form of the stern that is flat in order to accommodate PODs. For sufficient directional stability a suitable arrangements of skegs and fins, either central or in front of each POD is necessary.

The course keeping ability is assessed by the amount of overshoot angle measured during the yaw checking or zig-zag test. The same source (Toxopeus & Loeff, 2002) shows that overshoot angles obtained are in average larger for POD propulsion than for conventional propulsion, but still seem to satisfy manoeuvring standards adopted by the IMO Resolution MSC.137(76) (IMO 2002). (fig.8). The results shown, however, are applicable to fast ships having rather low block coefficient and which usually are inherently dynamically stable on straight course.

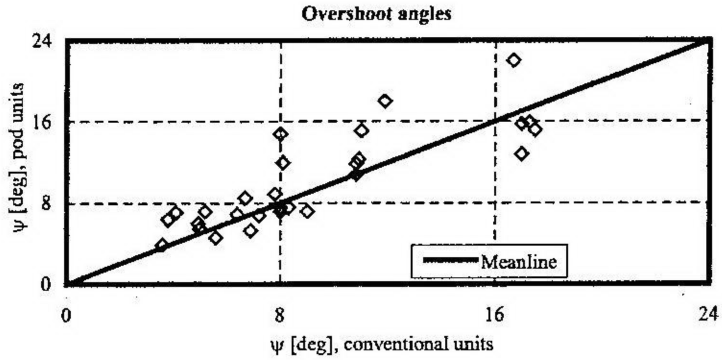


Fig. 8. Overshoot angles of ships equipped with podded or conventional propulsion units

Course-keeping characteristics of pod driven full bodied ships was subject of special investigation by SRTC in years 2003-2005. (Kobylinski&Nowicki 2005). The results of this investigation and extensive model tests with large manned showed that:

- Model driven by single POD was dynamically unstable to high degree and very difficult to control.
- Model driven by twin PODs arrangement without skeg(s) or with small skegs was also dynamically unstable, although to the lesser degree as with single pod propulsion.
- Model with large skegs was still dynamically unstable, but with small amount instability. Model revealed satisfactory course-keeping characteristics.

This last variation was tested by several pilots who handled it in different situations. Their judgement with respect of single POD propulsion was negative. They had also some difficulties piloting model with twin PODs fitted with single skeg, large or small, because insufficient course keeping ability, but were fully satisfied with the final version fitted with two skegs and rudder fin. The model was handled easily, all manoeuvres including slowing down and stopping in the narrow fairway, negotiating narrow passages and tight bends, entering locks and harbour basin, mooring and unmooring could be performed successfully in calm weather and under influence of wind and in the current. This was in spite of the fact, that no thruster was fitted in the model. The usual practice is to install bow thrusters in such ships, which considerably improves handling capability in confined areas.

1.2.4. Stopping ability

Stopping ability is an important element of manoeuvring characteristics of the ship and stopping distance according to IMO criterion should be not more than 15 ship lengths when crash stop test is performed.

With pod driven ships there are several possible modes of stopping the ship:

- Conventional stopping manoeuvre when engines are ordered full astern –(CSM)
- Slew 180^0 stopping manoeuvre when ordering PODs turning 180^0 outwards in opposite directions while maintaining constant shaft torque (SSM1)
- Slew 180^0 stopping manoeuvre when ordering to rotate PODs 180^0 in opposite directions while simultaneously reducing 40% in delivered shaft torque (SSM2)
- Indirect stopping manoeuvre where ordering PODs to rotate by 60^0 outwards in opposite directions while simultaneously ordering full astern – when the ship speed has reduced by 80% ordering PODs back to 0^0.(ISM).

On top of these four modes that were studied by Woodword et al (2004) it is possible to stop effectively the POD driven ship by hard turn. There are several possibilities to perform hard turn without causing overloading the propeller and the struts.

Comparison of simulation of the above four modes of stopping is shown in Table 2 (Woodword et al 2004). Simulated ship was OPTIPOD Ropax of the length 172.2m tested under European Commission RTD FP5 project.

Table 2. Comparison of four stopping modes

Manoeuvre performed	**Stopping distance** (Ship/lengths)	**Stopping time** (s)
CSM	11.97	303
SSN1	6.66	201
SSM2	9.05	299
ISM	5.81	182

1.2.5. Other manoeuvring characteristics

Other manoeuvring characteristics include

<u>Crabbing</u>

For crabbing manoeuvre with pod driven ship more flexibility is available in comparison with the twin screw conventional propulsion (Toxopeus&Loeff 2002). In general the angle of the pod that is close to the quay working ahead is varied, while the other pod running at the same RPM is working astern cancelling longitudinal speed. It was found that optimum results for unberthing are when quay side pod is directed with trailing edge slightly aft of the perpendicular to the quay (between 75^0 to 90^0) and the other pod directed with the trailing edge slightly forward (about 90^0 to 120^0) (Fig. 9).

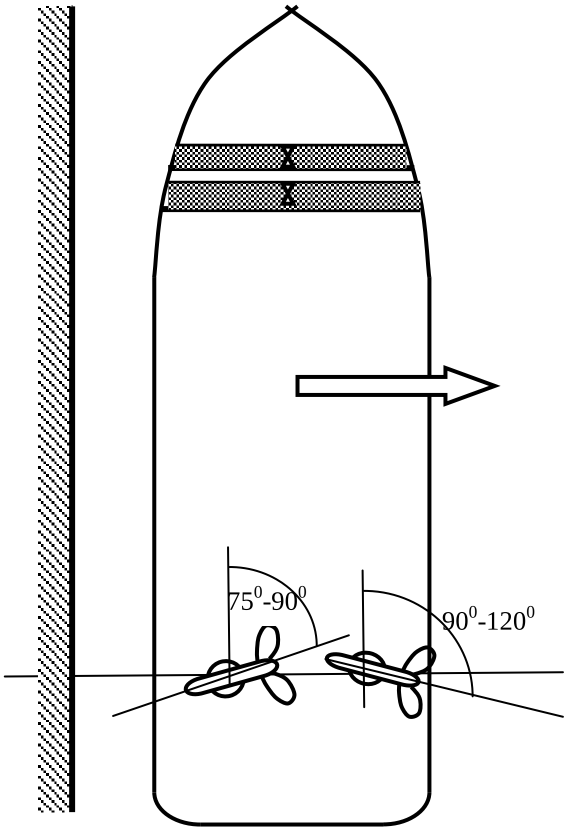


Fig. 9. Best solution for crabbing when unberthing

Low speed Manoeuvring.

The slow speed manoeuvring characteristics are important for vessel' operation in restricted water ares. There are several tests that characterise ship manoeuvring at slow speed conditions (Hwang et al 2003). The basic test manoeuvres are:

- Minimum effective rudder angle (MER)
- Crash stop from half ahead
- Acceleration/decelaration combination
- Backing/stopping combination
- Accelerating and coasting turns
- $20/20^0$ overshoot and coasting overshoot test
- Back and fill test.

Slow speed manoeuvring characteristics of pod driven ships differ considerably from the characteristics of conventional vessels. Pod propulsion provides ample opportunities to perform slow speed manoeuvres in different way. Pods could be rotated 360^0 and also direction of rotation of the propeller may be reversed.

Low speed manoeuvres are performed usually in the "soft" manoeuvring mode when with twin pods arrangement the RPM and rudder angle of both pods are controlled independently.
In general the ship is sailing with the pods running at the same RPM and positioned at an angle of about 45^0 with respect to the ship centreline as shown in fig. 10.. The speed of the ship is controlled by maintaining RPM constant but changing the angle of pods. The heading is controlled by increasing RPM of one pod while reducing RPM of the other. With this approach the heading of the ship remained constant when controlling the speed and vice versa (Toxopeus&Loeff 2002).

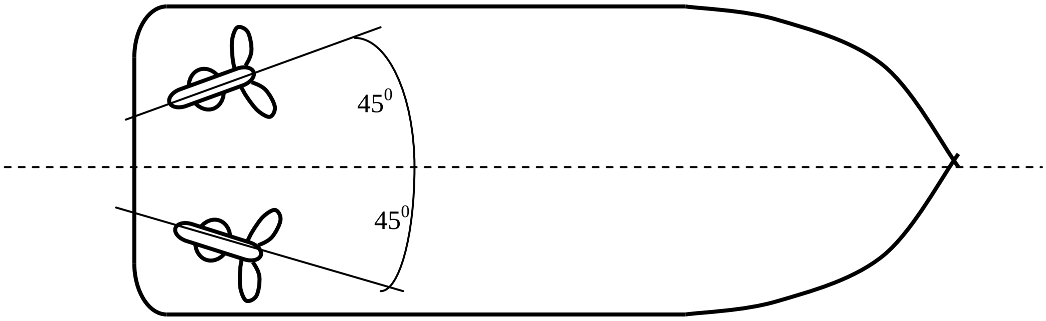


Fig.10. “Soft” manoeuvring mode at slow speed

1.3’ ESCORTING OPERATIONS USING POD PROPELLED TUGS

Escort operations performed over long distances and relatively high speeds require escort tugs. All escort tugs have azimuthing propulsion units, (Voith-Schneider, Schottel or AZIPOD type) The main advantage of escort tugs is the possibility to quickly develop high steering and braking forces to a ship when needed.

Steering forces can be developed at high speeds exceeding 10 knots. In this case tugs are working in the indirect mode (in case of failure or human error.).

The distribution of forces acting in the indirect towing mode in escort operations is shown in Fig.11. (Kobylinski 2010).

Fig. 12. shows schematic presentation of the three arrest (braking) modes, direct and indirect with azipod driven tug. Figs. 9 and 10 show different phases of braking manoeuvre, first one, where rudder is blocked on SB and the ship is stopped by hard turn, the second with black-out occurred on board the ship and tug assists braking keeping straight course until ship stops. In both cases indirect mode is used at the initial phase of manoeuvre.

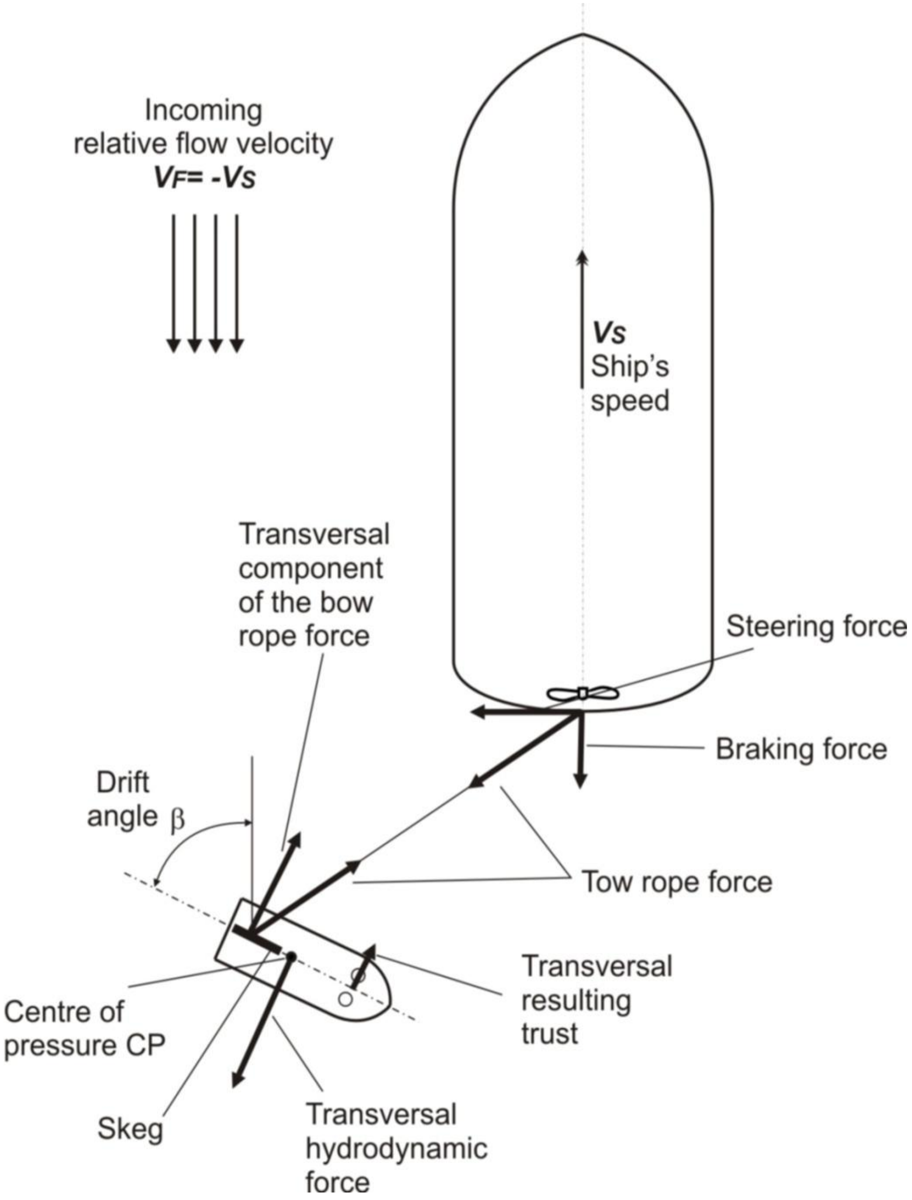


Fig. 11. Distribution of forces in the indirect towing mode

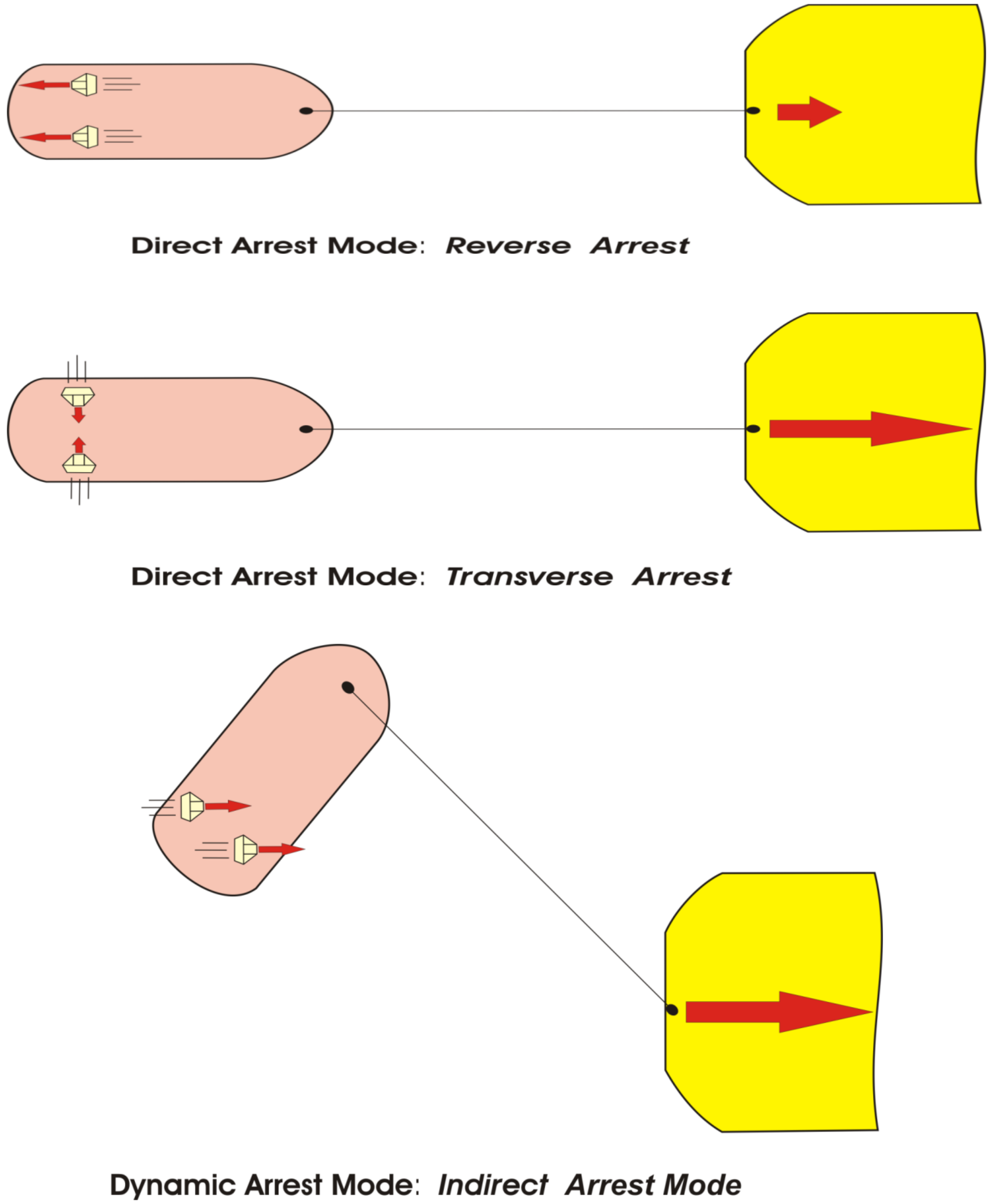


Fig 12. Schematic presentation of different arrest modes.

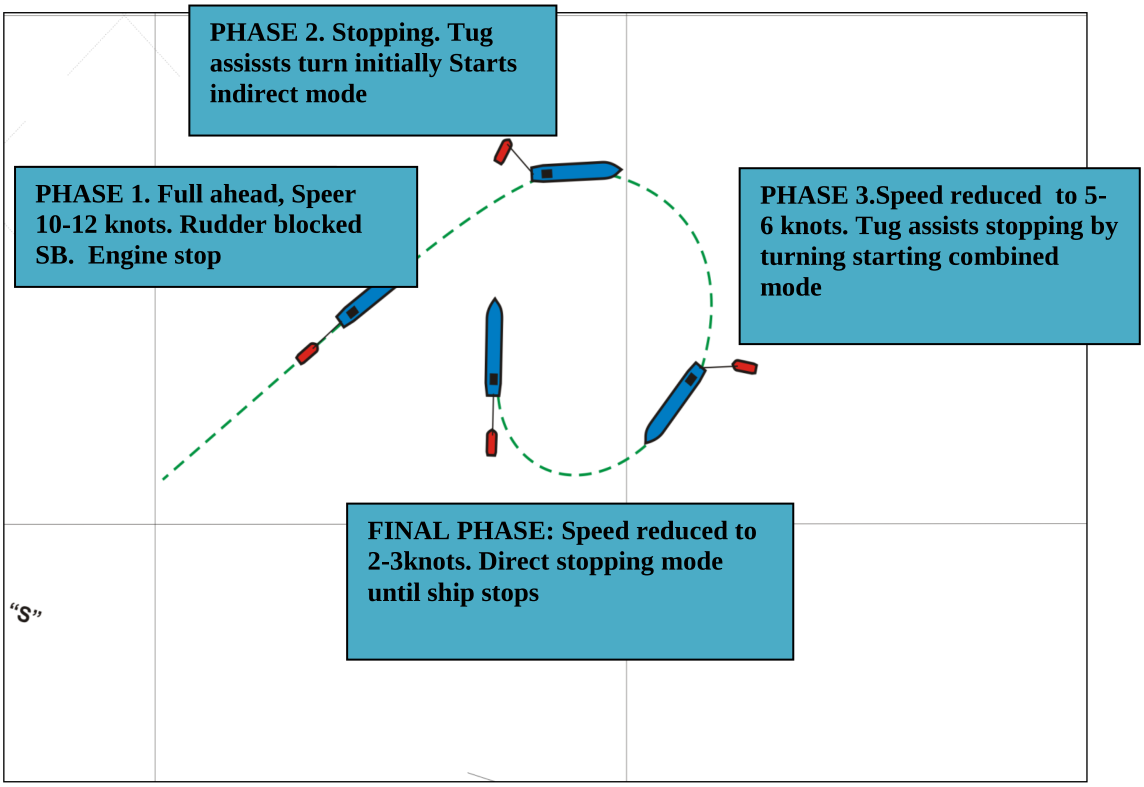


Fig. 13. Assisted braking using hard turn

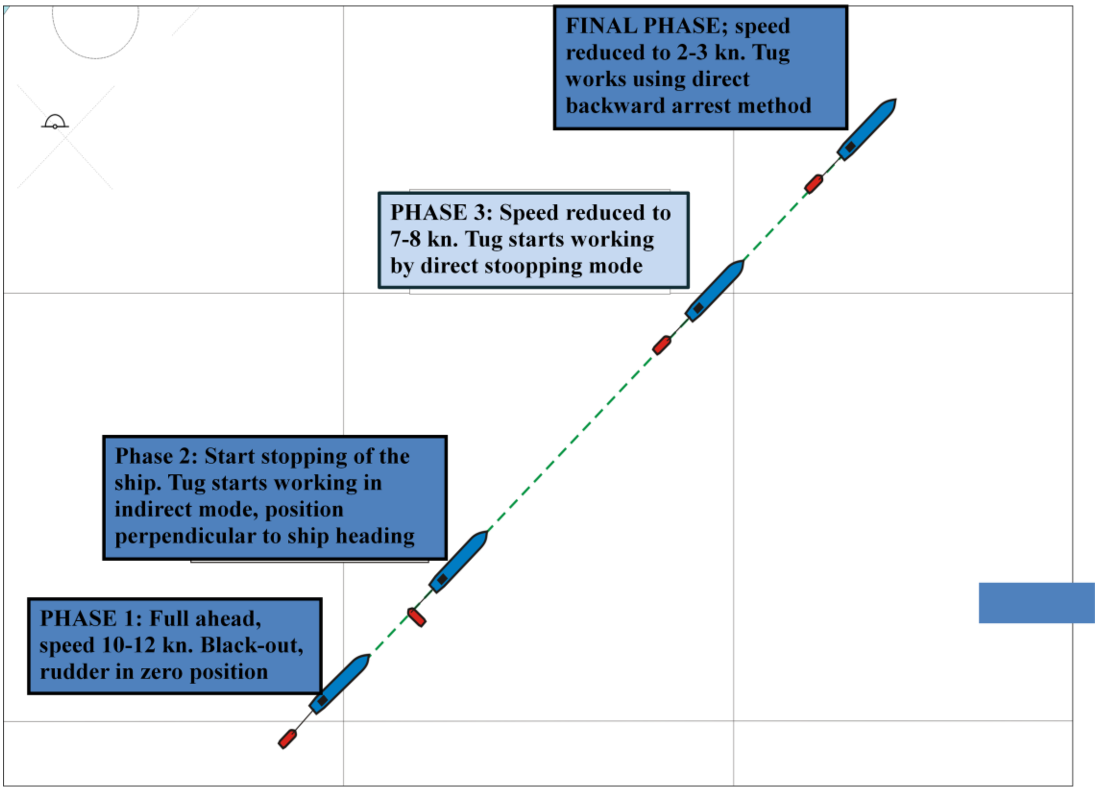


Fig. 14. Assisted braking keeping the ship on straight course

1.4 OPERATIONAL ASPECTS OF POD DRIVEN SHIPS

1.4.1.Basic control modes with twin AZIPOD configuration

Three basic control modes for ships fitted with two azimuthing propulsors (PODs) are as follows (The Naval Architect 1996):

1. **Cruise** manoeuvring mode, using both PODs deflected to the same angle, in a similar way as it is usually done with two rudders in twin-screw ships fitted with conventional propellers
2. **Soft** manoeuvring mode, when one POD (left or right, depending on the direction of turn) is used to perform maneuvers
3. **Strong** manoeuvring mode, where both PODs are used to perform maneuvers

All three control modes are illustrated below Fig.15 :

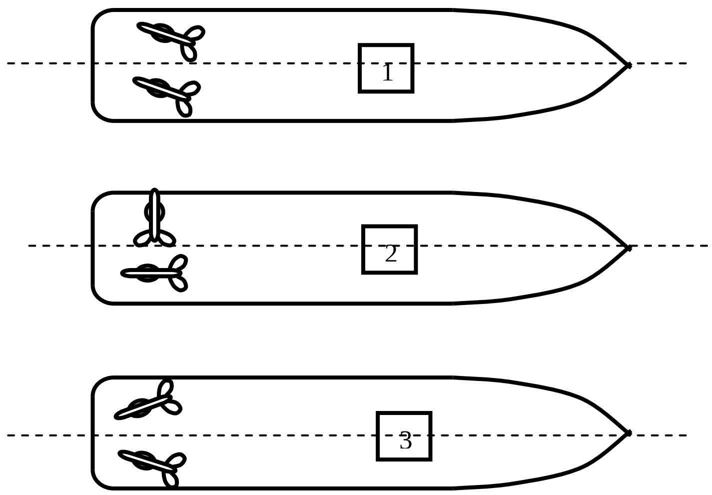


Fig.15. Basic manoeuvring modes of pod-driven ships

Strong interaction may be expected when one POD is working in the propeller slipstream of the other one and this is affecting considerably thrust and torque.

When working in the mode 1 it may happen when PODs are deflected to angles between about 60 to 120 degrees both sides (Fig.16).

Similarly when PODs are working in mode 2 and 3 one may expect strong interactions during manoeuvres if one POD get into propeller slipstream of the other. This is the case with PODs fitted with pulling propellers as well as fitted with pushing propellers. The interaction effect may be different if at the stern of the ship one long skeg or fin is fitted that may distort propeller slipstream.

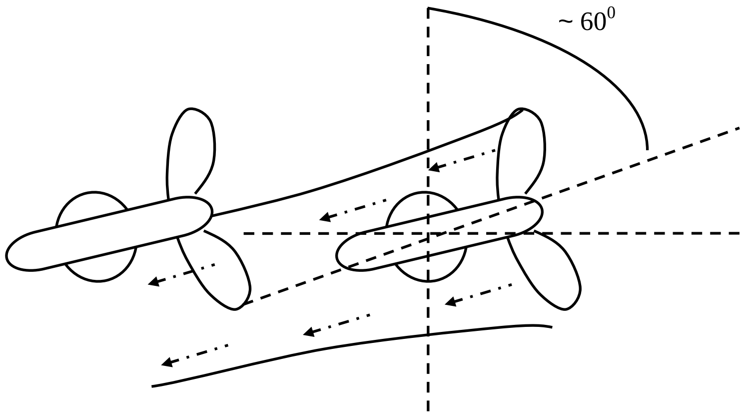


Fig 16. Wash-out of one pod is affecting the other

Strong interaction between pods is expected also in the position when the starboard POD is turned to 90^0 whether the port one is at rest (T position) (fig.17). In this position the propeller race of the starboard POD is against the port POD creating the force reducing the starboard thrust.

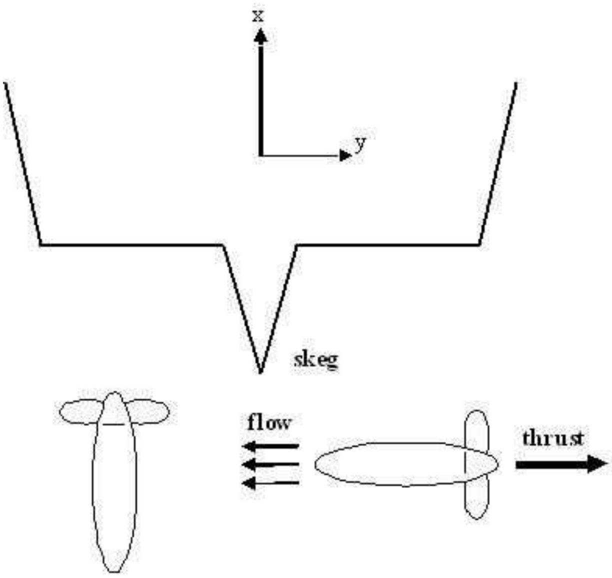
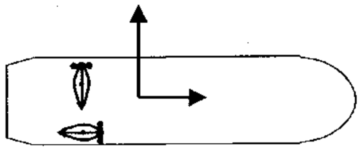


Fig.17.

Rees (2010) shows modes of operation of pod driven ships as follows (see Table 3)

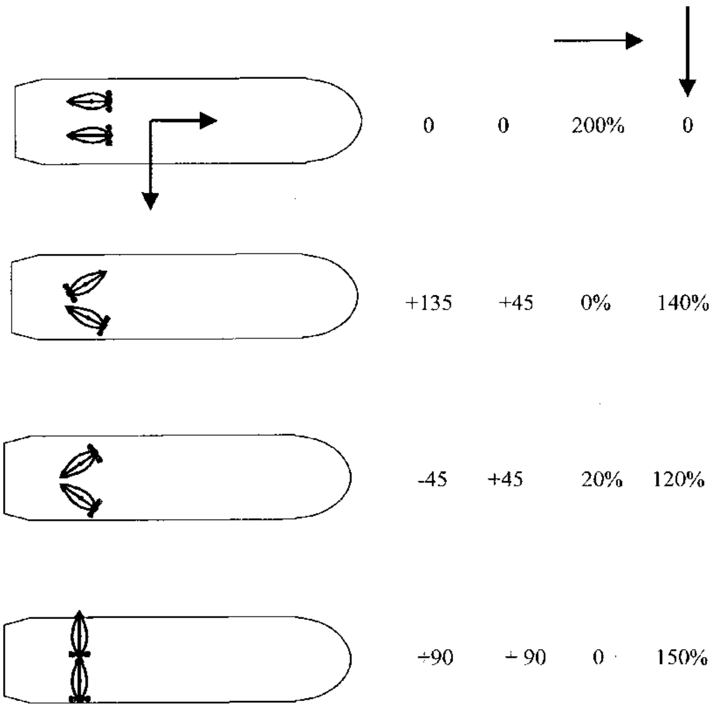
Ankudinov (2010a) provided three diagrams showing effectiveness of azipod propulsors illustrating pod efficiency for lateral movement with different T-positions of pods. Those diagrams are reproduced in figs. 18, 19 and 20

The following tables illustrate **approximate** pod efficiency values for lateral movement with one pod perpendicular to the vessel's centerline. These values are for a typical large cruise vessel whose initial speed is 0. Fx is fore and aft movement, Fy is lateral movement. The vessel's stern is moving to port.

Pod Position	Port	Stbd	Fx	Fy
	-90	0	100%	80%
	+90	0	100%	50%
	0	-90	100%	100%
	0	+90	100%	80%

Azimuth Pod Propulsion and Ship Maneuvering Simulations

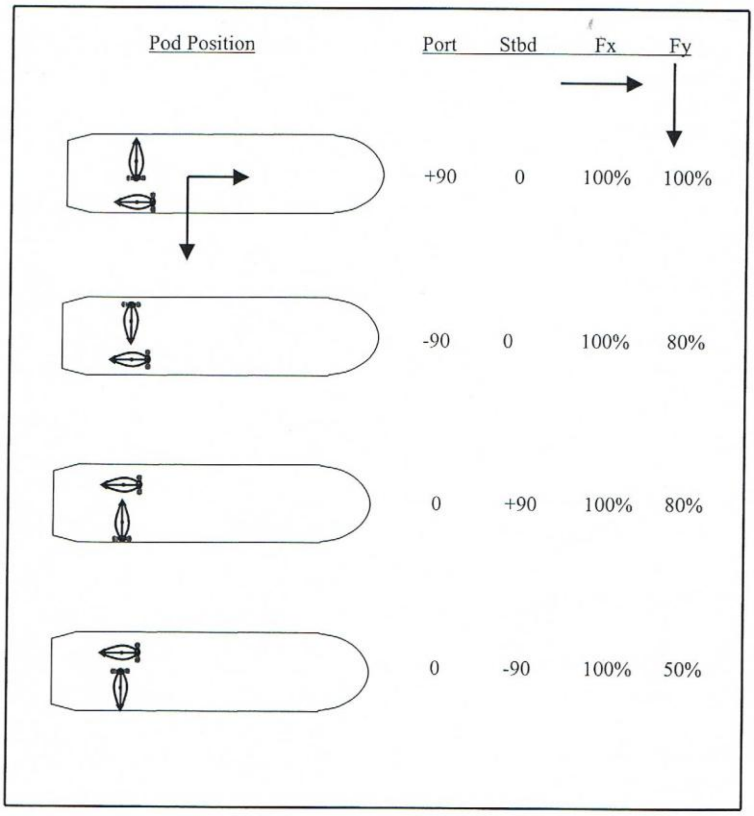
The following tables illustrate **approximate** pod efficiency values for lateral movement using a combination of azimuth angle and RPM to produce lateral movement. These values are for a typical large cruise vessel whose initial speed is 0. Fx is fore and aft movement, Fy is lateral movement. The vessel's stern is moving to starboard.



Pod Position	Port	Stbd	Fx	Fy
	0	0	200%	0
	+135	+45	0%	140%
	-45	+45	20%	120%
	+90	+90	0	150%

Azimuth Pod Propulsion and Ship Maneuvering Simulations

The following tables illustrate **approximate** pod efficiency values for lateral movement with one pod perpendicular to the vessel's centerline. These values are for a typical large cruise vessel whose initial speed is 0. Fx is fore and aft movement, Fy is lateral movement. The vessel's stern is moving to starboard.



Pod Position	Port	Stbd	Fx	Fy
	+90	0	100%	100%
	-90	0	100%	80%
	0	+90	100%	80%
	0	-90	100%	50%

Azimuth Pod Propulsion and Ship Maneuvering Simulations

Figs 18, 19 and 20. Effectiveness of azipod propulsors in lateral motion according to Ankudinov (2010a)

Table 3. Modes of operation as shown by Rees (2010)

MODES OF OPERATION

Mode	Power	Rotation	Syncronised
Open Sea Cruise	Full power i.e. 17 mgw	≤ 10º But may be 35º	pods and rpm
Manoeuvre Manoeuver direct	Reduced power i.e. 12/13 mgw	≤ 35º	pods and rpm
Fast Mode Aziman Azimuth mode	Reduced power i.e. 10mgw	360º	pods and rpm independent

1.4.2. Operation in restricted areas

Ships driven by azimuthing propellers are operated in restricted areas similarly as ships with conventional propulsion units. With different manoeuvring characteristics of pod driven ships it is important that prospective ship masters and pilots are aware of peculiarities in handling those ships when operated in:

- Shallow water areas
- In shallow water with muddy bottom
- Deep and shallow water areas of restricted dimensions, such as harbor basins and similar areas
- Surface an submerged channels of differently inclined banks (feeling canal effect)
- In proximity of banks (feeling bank or wall effect)
- In proximity of other ships, either moving or at rest
- In areas where of current either uniform or not uniform is present
- Berthing and unberthing alongside piers and jetties of different construction (on piles or solid wall) in deep and shallow water

The operation modes and the above effects are discussed thoroughly in the report on Task 2.3 (Kobylinski 2010) and the reference to this report is made here.

The azipod training courses on simulators should include those effects in respective programmes.

1.4.3. Controls

Controls on azipod propelled vessels are generally quite different from controls in conventional vessel and they are not intuitive.

Typical control panels in pod driven ships is shown in fig .21.


4

Fig. 21. Typical control Panel on board pod driven ship –FOX LUNA (R. Gargiulo et al 2010)

In model of pod driven ships similar arrangements of control panel is uses. Examples of the control panels on models in Port Revel and SHRT are shown in figs. 22 and 23.

Fig. 22. Control panel on the model of pod propelled ship (Port Revel)

Fig. 23 . control panel on the model of pod propelled ship (SHRTC)

1.4.4. Limitations in respect of control of AZIPODS

Azimuthing propellers of the type Voith-Schneider propellers, Schottel propellers or conventional outboard motors having limited power (usually not more than 1MW) are known and operated for many years and their operational limitations are well known. It is different for innovative azipod propulsion units, where electric motor is situated in the underwater housing and the power may be as high as 25MW. Main suppliers are Rolls Royce Kamewa/Alstrom, Finland ABB Industry, , Siemens-Schottel, and STN Atlas Marine/ John Crane-Lips.

Experience with operation of these high power azipod units, mainly in cruise liners, did reveal some difficulties from the structural point of view, the critical issues being seals and bearings the result might be leakage, insufficient lubrication etc. This is the result of very high forces created at azipod housing when the unit is rotated to large angles at high speed. Those forces may be to large the housing could withstand. Because of this and bearing in mind several accidents where some damage to the azipods happened, manufacturers imposed some limitations with regard to the operation of azipod driven ships. Those limitations may be different for different manufacturers but general recommendations of manufacturers are summarize well by Rees (2010). They are as follows:

- Operate pods as gently as possible
- Avoid reverse power (reverse rpm)
- Maintain positive rpm
- Crash stop to be avoided
- Avoid wash onto another pod
- Avoid applying large angles of rotation
- Maintain minimum revolutions
- Avoid large differences between rpm and ship speed
- Avoid unpowered rotation at low speed

- Avoid powered rotation below 25rpm and preferably 30 rpm
- Avoid cycling between zero 25 to 39 rpm
- Avoid cycling between forward and reverse rpm
- Avoid wash over unpowered pod
- Avoid flow from a pod directly entering the propeller of the other pod

As it is seen from the list, operation of pod driven ships is not easy and shipmasters and pilots must be fully aware of all the limitations otherwise they may cause damage to the pod. This is an important aspect of the simulator training.

1.5. PRESENT TRAINING AZIPOD COURSES

1.5.1. General

Practically all FMBS capable to simulate manoeuvring characteristics and ship handling in the real time are also capable to simulate manoeuvrability of pod driven ships provided respective data on hydrodynamic derivatives of pod driven ships are available and fed into the computer programs

Direct or indirect information on the capability to simulate manoeuvrability of pod driven ships taking account of the majority influencing factors is available from the following FMB simulators:[i]

- Maritime Institute of Technology & Graduate Studied (MITAGS)
- TRANSAS (Ankudinov 2010)
- NS 5000 simulator by Rheinmetall Defense Electronics
- DMI -Danish Maritime Institute, Lyngby
- Australian Maritime College
- Development Centre for Ship Technology and Transport Systems (DST) Duisburg

Special simulation programs of azipod driven tugs are available in the majority of the above centres. On top of that, according to the information provided by TRANSAS at following simulator centres such programs are also available

- MITAGS, Washington Di, USA: 2 Full-Bridge 360 degree view Simulators and Tug simulator.
- Pacific Maritime Institute, PMI, Seattle, USA: 2 Full-Bridge Simulators and Tug Simulator
- Marine Engineering School, MEBA, Easton, Maryland, USA: 2 Full- Bridge Simulators and 2 Tug simulators
- Georgian Great Lakes Maritime College, Canada, 4 Full-Scale Bridge Simulators in Network. Bridge layouts allow simulation of practically any ship types including tugs with all existing drives (FPP, CPP, Steering Nozzle, Pods, Voith – Schneider, etc), tows, and many others.

The above lists are not complete and certainly all well developed simulator centres have capability to simulate manoeuvrability characteristics of ships fitted with azimuthing devices.

1.5.2.Training available on Full Mission Bridge Simulators (FMBS)

De Graauw in the report on Task 3.1(2010) compiled comprehensive list of training courses available on Full Mission Bridge Simulators. Having reviewed this list that is reproduced below, (Table 4) he pointed out that several courses that directly relate to azimuthing devices are tug handling courses and the generic ship handling courses do not tend to emphasize training on ships driven by azimuthing propellers. Therefore development of special courses on azimuth propelled ships is essential.

Table 4. Training courses available on FMBS

Name of Training Facility	Course Title	Duration (days)	Description
MITAGS Maritime Institute of Technology & Graduate Studies Maryland, USA	Azipod/Kamewa	3	The Azipod/Kamewa orientation course is designed to familiarise the attendee with the unique manoeuvring characteristics of an Azipod propulsion system and a Kamewa control system. The course includes orientation to the transit mode (active rudders), independent manoeuvring mode, and the joystick mode. Simulation exercises are designed to provide a realistic transition from one mode to the next during all phases of manoeuvring that is from berth to berth.
STAR CENTER Dania Beach, Florida, USA	Azipod Familiarization	3	This course will introduce the student to the Podded Propulsion technology. The emphasis will be on honing the individual's shiphandling skills. There will be periods of classroom instruction / discussion with the balance of the sessions devoted to hands-on practice of typical piloting and docking manoeuvres using the 360° full mission bridge simulator in restricted waters, harbour manoeuvring, and docking / undocking simulations. Upon completing this course the student will be able to demonstrate gained knowledge of effective shiphandling using Azimuthing Propulsion Systems.
ABB Marine Academy FINLAND	General Course for Deck Staff	4	Upon completion of this course, the participants will: • Be able to communicate effectively with the involved engineering/electrical personnel. • Understand fundamental open sea operation. • Be able to use the Azipod ® as the manoeuvring device in near-alongside operation. • Effectively use backup functions in abnormal equipment states. • Perform user operations and settings with the Joystick/DP facility
MARIN THE NETHERLANDS	Lamnalco Tug Master Training	Variable	The objective of the basic ASD training was to train new ASD Tug masters in: • General ASD tug handling principles (free sailing, sidestep, keeping position, etc.); • General principles of pushing, towing and escorting in direct and indirect modes (including transverse arrest, indirect steering and breaking); • Specific manoeuvres with marginal manoeuvring space during berthing and unberthing.

CSMART Center for Simulator Maritime Training, owned by Carnival THE NETHERLANDS	Ship Handling course	4.5	The goals of this course are to: • Improve safety at sea by providing participants with knowledge and hands on skills training about methods for the safe operation of ships in narrow fairways, port approaches and during berthing and unberthing operations in varying weather and sea conditions. • Counteract complacency by exposing participants to unique and unusual situations relevant to the maritime environment. • Enable participants to understand the importance to safety by making a risk assessment and to develop a strategy for the operation.
STC B.V. Centre for Simulator Maritime Research & Training owned by STC Group, Rotterdam, The Netherlands	Ship Handling course (with or without Azimuthing drives)	3-5	Basic and advanced ship handling courses are given by STC. Depending on the wishes of the clients these courses can be given for ships with/without azimuthing drives.
STC B.V. Centre for Simulator Maritime Research & Training owned by STC Group, Rotterdam, The Netherlands	Tug Handling course (with or without Azimuthing drives)	3-5	Basic and advanced ship handling courses are given by STC. Depending on the wishes of the clients these courses can be given for ships with/without azimuthing drives.
FORCE Technology DENMARK	Tug Handling Course	Variable	During theoretical lessons and practical simulator exercises, the participants shall: • Enhance their knowledge of, and skills in – ASD tug manoeuvring. • Enhance their knowledge of Human Factor Issues and skills in the use of Human Factor Issues, such as communication, planning, briefing and situational awareness. • Enhance safety by applying the proper procedures for conducting safe tug operations.
South Tyneside College UK	Tug Handling Course	Variable	The content will vary after a needs analysis has been completed of the attendees but would vary from basic handling of ASD or Voith tugs when free running , to ship operations – vessel stopped up to operations on bow and stern of a moving vessel. Failure of ship and/or tug can be looked at as desired.

In the report by de Grauuw (2010) some of the courses are described in more detail.

3-day Azipod Familiarisation Training at STAR CENTER

This course will introduce the student to the podded propulsion technology. The emphasis will be on homing the individual’s ship handling skills The course will include classroom instructions and practice of typical piloting manoeuvres using FMBS in restricted waters, harbour manoeuvring docking and undocking.

Operation of diesel electric Azipod vessels in a safe and economical manner by ABB MARINE ACADEMY

Operation of a twin Azipods vessel with emphasis on pilot voyage and harbor manoeuvres. Training consists of practical lessons on diesel electric Azipod propulsion and bridge simulator exercises.

After completion of the course the participants will be:

- Familiar with the operational principles of diesel-electric Azipod propulsion systems taking into account :
    - Passengers safety and comfort
    - Environment requirements
    - Economical requirements
- Able to utilize the flexibility of the propulsion system
- Able to identify potential malfunctions of the propulsion system and to cope with them without sacrificing passenger safety
- Able to communicate about the different aspects of the propulsion system in a clear and coincise manner.

Ship handling course offered by CSMART

The course shall provide the following format to benefit participants:
- Conduct training during the critical stage of transferring controls from the centre console to the
- bridge wings
- Provide full bridge team participation using procedures for error management combined with safe and efficient communication
- Utilize mentoring techniques for captains to effectively develop ship handling skills combined with a healthy level of self confidence in more junior members of the bridge team
- Offer a tailor made course for every customer and ship type with various propulsion and rudder configuration

The course is designed for masters and senior officers. Duration of the course is 4.5 days with 36 hours of training.

Ship handling course offered by STC

The course focuses on the following subject matters:

- The basic theory of ship handling
- The formation of a bridge team, all members participating well via correct procedures and working together towards the single goal of proper ship handling
- The minimization of possible errors
- The transferring of ship controls from the centre control to the bridge wings to the aft console (if present) and vice versa
- Efficient communication bridge team internally and externally (tug boats, harbor authorities, etc)

Although standard course us given, often these courses are tailor made (i.e. ship type and/or harbor configuration etc) and can also be given at advanced level.

Tug handling course by STC

STC has a basic course and advanced course for tug handling for all types of tugs including Azimuth Stern Drive tugs. These courses are for tug captains and officers. Custom made courses for these tugs are also available upon request. The course is mix of relevant theory followed by dedicated training sessions through practice on the simulator.

The objectives of the courses are:

- An increase in knowledge and insight into tug handling procedures and thus reach a higher overall safety level regarding tug operations
- An increase of their knowledge (and hereby skill) of ASD tug manoeuvring
- An increase of their knowledge regarding situational awareness, planning, briefing, communication and working as a team.

ASD tug handling course by FORCE TECHNOLOGY

FORCE TECHNOLOGY DMI has developed a 3 level training programme for Azimuth Stern Drive tug captains and officers. During the course relevant theory is taught and then tested in “real life” on the simulator.

The objective of the course is as for conducting safe tug operations.

follows:

- Enhance knowledge of participants and skill in ASD tug manoeuvring
- Enhance their knowledge of human factor issues and skills in the use of the human factor issues, such as communication, planning, briefing and situation awareness
- Enhance safety by applying the proper procedures

Level1: Safe handling of own tug during navigation, manoeuvring and basic towage operations

Level 2: Safe handling of own tug and towed vessel during normal towage operation

Level 3: Safe handling of towage operations in extraordinary conditions.

All levels of tug handling courses include the following issues:

- Familiarization with the simulator
- Procedures for start-up and stop
- Familiarization with the manoeuvring handles and equipment
- Back-up procedures
- Ship/tug handling theory on different levels.

The course is flexible as the contents can be adjusted to the wishes, qualifications and experience of the participants. Special emphasis on e.g. escort towage can be included and the exercises maybe conducted in areas selected by the participants, if available.

1.5.3.Training available on Manned Models (MMS)

Manned models are used for training and for research and accepted as an excellent method for simulation of ship manoeuvring behavior.

Both training centres, PORT REVEL near Grenoble, France (PRL) and Ship handling Research and Training Centre near Ilawa, Poland (SRTC) own manned models with podded propulsion units. There is full information available on the programme of courses and equipment used in both training centres.

Port Revel (France

The 5-days course on azipod driven ships is offered since 2006. (de Graauw 2010)

On day one, some general information on podded ships is presented and then a few explanations regarding the use of pods on the model and the day's exercises are given. For their first contact with the podded ship students must leave the quay, follow a circuit with different modes (pods synchronized or independent, fast or normal mode) and then betrth in the "T-bone" m0de (One pod aligned and one pod at 90^0). The students are monitored and observed constantly in order to adapt their manoeuvre if necessary and, especially , be able to discuss it during the evening debriefing,

On day two, students are introduced to the various ways to stop the podded ship. Then they are shown various modes for precision steering at low speeds in restricted waters using pods with inboard or outboard rotation. The torque generated by the pods is explained emphasizing their efficiency, which depends on interactions between pods and with the quay structure, the various positions of the control units and their ergonomics. The exercises give students an opportunity to test the various types of crash stops and the different pod positions for following a straight course or entering a lock forwards and backwards. Berthing manoeuvres are chosen depending on wind conditions on the lake; they also highlights the torque generated by various pod positions.

On day three the students carry out the exercises in various currents as this forces then to use more power and helps them to develop reflexes in the proper use of pods.

On day four, exercises are performed with a beam current in front of a harbor basin. Some of the previous exercises may be repeated depending on the students' difficulties and specific requests regarding local conditions and configurations

Day five is dedicated to exercises involving engine failures forcing the students to manoeuvre with a single pod and help from a tug and/or anchors. If necessary, we go back over some of the previous exer5cises to clarify certain points which are considered difficult.

At the end of the course, 80% of the students steer accurately in narrow passages with current abeam, then turn at slow speed in the current and dock without losing time. Most vstudents carry out this kind of exercise quite intuitively, which is considered a good result of the course.

The model of a container single screw vessel used in the PRS, of the capacity 4400 TEU may be converted to azimuthing propulsion by removing propeller and installing two azimuthing control devices of 21,5 MW (full scale). The parameters of the model and full scale ship are shown in the table 6 (references 9 and 10 and information provided by PRS).

The model is then controlled from the wheelhouse and control panel is located in the forward part of the model. Fig 2 shows photograph of the model. The location of the control desk close to bow was chosen in order to simulate the arrangement specific to those used in cruise liners, therefore this model is intended to simulate approximately ship of the type of cruise liner.

The PODs are controlled the same way as those of a real ship with all the real automatic limitations notably depending on orientation. Fig. 24 shows control desk of the model. They can be controlled by the port or starboard lever or be coupled.

Training areas in PRS comprise large shallow water areas of different depth in which various maneuvers could be performed when training ship masters and pilots. They include shallow water docks and harbor basins, canal of restricted cross-section and unrestricted width shallow water areas. Therefore all manoeuvres with azipod propelled model could be performed in those areas with shallow water effect automatically included.

Table 5 Parameters of the model (PRS)

Parameter	Ship	Model
L_{PP} [m]	261.0	10.45
B [m]	37.1	1.48
Displacement [tons]	75000	4.67
Draft [m]	12.48	0.5
Shaft Horsepower [HP]	52000	-
Block coefficient	0.60	
Model scale	25	

Fig 241. Model of container vessel with azimuting propulsion (Port Revel Shiphandling)

Shiphandling Research and Training Centre, Ilawa, Poland

At SHRTC three days (32 hours) course designed for masters, chief officers from ships equipped with podded propulsion units and pilots from harbours operating such ships is offered. The course objective is to understand better complex physical phenomena affecting manoeuvrability of ships with azipod propulsion and to gain more detailed practical knowledge on handling such ships. For pilots involved in escorting operations a special 5 days course on tugs-ship cooperation are also offered on request.

Within standard shiphandling 5-days courses for pilots and ship masters, upon request, one day may be devoted to exercises on pod propelled vessel model and/or on pod propelled tugs exercising escort operation.

In the three days course on day one, a lecture is given on the principles of manned model, and laws of similitude, principles of handling ships equipped with azipod propulsion and their manoeuvring qualities., The practical exercises include turning using one or two pods, backward motion, crabbing, stopping , navigation onto leading marks, negotiating narrow passages, sharp turns and bow thruster work.

On day two, the lecture covers cooperation with tugs , interaction effects such as shallow water, bank and canal effects and also effect of wind. The practical exercises include harbor manoeuvres, canal navigation and the effect of wind on ship' manoeuvrability. Night exercises are performed upon request.

On day three the lecture covers the effect of current and the practical exercises include navigation in current in the river estuary and when entering harbor basin. The exercises are performed in deep and shallow water areas.

In SHRTC model of the gas carrier of capacity 140 000 m^3, fitted with two POD propulsion units is available for training. The model was build in model scale 1:24. Fig. 25 shows the photograph of the model, and the dimensions of the model are shown in the table 7. (references 11 and 12 and information from SHRTC)

Fig.25. Model of POD driven gas carrier in SHRTC

Table 6.Dimensions of the model used in SHRTC

Dimension	Real ship	Model
Length [m]	277.45	11.56
Breadth [m]	43.2	1.80
Draft [m]	12.0	0.50
Block coefficient [-]	0.79	0.79

The SHRTC uses also the POD driven models of tugs. They are equipped with two propulsion units, one with pushing propellers, the other with pulling propellers at the bow, that are controlled separately, no reverse revolutions, but they can be rotated 360 deg. The models are shown in fig 26 and 27.. The tug models are used in escorting operations. Fig 28 shows escorting tug at work with the model of the large tanker.

Fig. 26. Manned model of tug used in SHRTC

Fig. 27. Manned model of Azipod tractor tug used in SHRTC

Fig.28. POD driven tug model working with the tanker model at SHRTC

CHAPTER 2. PROPOSED PROGRAMMES OF TRAINING ON POD DRIVEN SHIPS

2.1. GENERAL

As construction features, manoeuvring and handling characteristics of ships driven by azimuthing propulsion units differ considerably from vessels with conventional propulsion and also their modes of operation are widely different, there is obviously a need for specialized training courses. This was discussed in Chapter 1 of this report.

The opinion of the majority of pilots who expressed their views such training is really necessary, and many of them were of the opinion that 5 days simulator courses on azipod driven ship s are the best solution.

Bearing this in mind, and taking into account that there are two types of simulators used at present for training, namely Full Mission Bridge Simulators (FMBS) and Manned Models Simulators(MMS) two different training model programmes for (prospective) ship masters and pilots are proposed to be used in these simulators. On top of that, because recently in many parts of the world large ships carrying dangerous goods are required to be escorted by escort tugs equipped with azimuthing propulsion devices and these operations require great skill in operating tugs and good co-operation with the tug master(s) and ship master or pilot, there is a need for specialized courses on escorting operations. Such model programme is also proposed.

It is necessary to stress, that experience in conducting training courses shows need for flexibility in arranging course programmes because in many cases programmes should be tailored to meet the particular requirements of the students, pilot organizations and ship owner companies.

Taking this into account the proposed programmes are intended to constitute groundwork on which individual programmes for each course and each simulator could be developed taking into account their capabilities and the level of education, experience, practice and needs of participants. Therefore the proposed programmes are not providing detailed day-to-day timetable of lectures and practical exercises because timetable for each course have to developed individually taking into account the above mentioned factors. In the development of the timetable of training course the objectives of the course together with subjects of lectures and practical exercises have to be observed.

As there are basically two types of simulators in use that differ in many respects, FNBS with bridge mock-up and working in real time, and MMS , working in model time in natural environment the objectives of courses and programme of practical exercises arranged on those simulators are different and geared to the characteristics and capabilities of those simulators. The main difference is that FMBS are working in real time whether MMS are working in model time that is accelerated usually about five times in comparison with real time. The result is, that in MMS it is possible to arrange during five days course about five times more practical manoeuvring exercises. Another important difference is that in FMGS there is mock up of the bridge , usual with several additional consoles enabling to arrange team work, whether in MMS , there is no such arrangement and the model is controlled by one master/pilot eventually with the help of instructor and having to his disposal tug simulators or models of tugs either manned or remote controlled..

Both types of simulators have also some shortcomings. De Graauw (2010) points out that in FMBS when the model for a ship have to be developed for use in the simulator, extremely detailed information is needed about real vessel including all hydrodynamic coefficients needed in manoeuvring mathematical model equations and together with many operational data on rudder, engine and other characteristics. This information is usually exceedingly difficult to obtain, due to the fact that it is confidential or not available at all, because hydrodynamic coefficients may be obtained only by specially arranged model tests in towing tanks (planar motion mechanism). After the model has been developed with the information that is available, it is then rigorously tested and tweaked. This tweaking, however, is not usually how the mathematical algorithms in the software are intended or designed to be used, leading occasionally to unexpected results

In MMS in order to simulate different ship, new model must be built that requires large investment and this, quite often, is impracticable. However, data on hydrodynamic coefficients are not needed in this case, although other data on engine and rudder characteristics and operational data are still necessary.

The model courses developed go beyond what is available today, but they take into account present and possible in the near future capabilities of both types of simulators and also possible needs and requirements of Maritime Authorities, ship owner companies and other institutions as well as wishes of prospective participants that could be realistically met.

The scope and programmes of model courses that are proposed are intended to be 5 days courses with 40 t0 52 hours of lectures and practical exercises. MMS courses may include few hours night training upon request.

2.2. MODEL TRAINING PROGRAMME ON AZIPODS DRIVEN SHIP FOR MASTERS OR PILOTS FOR FULL MISSION BRIDGE SIMULATORS

Objectves of training
Improve safety at sea by providing participants with knowledge and skill about methods of safe operation of ships driven with azimuthing propulsion devices in different situations, including harbour approaches, berthing and unberthing, docking, negotiating narrow passages, in wind and current conditions. Help participants to understand interaction effects, such as effect of shallow water and canal effect, bank effect, interaction between two ships when passing or meeting. Counteract complacency by exposing participants to unique and unusual situations relevant to marine environment. Provide experience in full bridge team participation using procedures for error management combined with safe and efficient communication. Conduct training during critical stage of transferring controls from the centre console to the bridgwe wings.
Lectures
General information on the simulator facility. Principles of work and operation of azimuthing propulsion devices. Types of ships with azimuthing propulsion devices and types of azimuthing propulsion. Manoeuvring characteristics of ships equipped with azimuting propulsion devices. Pivot point. Basic manoeuvres. IMO requirements related to manoeuvrability. Forces acting on the manoeuvring ship. Human factor issues. Effect of human factor on failure probability. Communication, planning, briefing and situation awareness. Bridge team work. Operation modes of azipod driven ships. Various modes of stopping. Slow speed manoeuvring. Harbour manoeuvres. Tugs assisted manoeuvres. Effect of wind, current, shallow water, canal effect, and bank effects and ship/ship interaction effect. Operational recommendations and limitations for ships driven by azimuthing propulsion devices, Principles of risk analysis and planning to avoid risks to occur and to handle cases of failures on board.
Pratical exercises
Familiarization with the simulator. Procedures for start-up and stop. Familiarization with controls and equipment. Unberthing and berthing; crabbing towards the jetty or away from the jetty without or with bow thruster used. Navigating in different modes: cruise, soft and strong. Turning ahead, astern, and when stopped using one or both pods, different modes. Stopping in different modes Negotiating narrow passages and entering lock, bow first or stern first. Manoeuvring feeling interaction effects - shallow water, bank effect and canal effect. Manoeuvring in current, from different directions. Emergency manoeuvres involving engine failure forcing to steer with one pod only, the other blocked in different position. Exercise the critical stage of transferring controls from the centre console to the bridge wings

2.3. MODEL TRAINING PROGRAMME FOR SHIP MASTERS AND PILOTS ON AZIPODS DRIVEN SHIP FOR MANNED MODELS SIMULATORS

Objectives of training
Enhance the knowledge of and skills in handling azipod propelled ships. In particular enhance the knowledge of manoeuvring characteristics and specifics of operation of azimuth propelled ships, various factors affecting their manoeuvrability including environment. Help the participants to understand the importance of safety by showing the effects of handling errors. Show the participants the ways to handle critical situations. Enhance safety by applying the proper procedures
Lectures
General information on the simulator facility. Principles of manned models technique. Similitude laws. Characteristics and types of azipod driven ships and azimuthing propulsion. Principles of work and operation of azimuthing propulsion devices.. Forces acting on the manoeuvring ship. Manoeuvring characteristics of ships equipped with azimuthing propulsion devices. Pivot point. Basic manoeuvres. IMO requirements related to manoeuvrability. Operation modes of azipod driven ships. Various modes of stopping. Slow speed manoeuvring. Harbour manoeuvres. Tugs action. Operational restrictions related to azimuth propulsion. Principles of interaction effects – bank effect, shallow water effect, canal effect, ship/ship interaction effect. Sailing in current. Current forces. Manoeuvring principles in current from different directions. Inertia effects in current. Effect of wind. Wind force. Manoeuvring principles under wind effect. Human factor issues contributing to safe operation. Handling emergency situations.
Pratical exercises
Familiarization with the simulator. Procedures for start-up and stop. Familiarization with controls and equipment. Unberthing and berthing; crabbing towards the jetty or away from the jetty without or with bow thruster use. Leaving the harbor basin making turns with different modes , pods coupled or independent, steering in different modes, cruise soft and strong. Steering onto navigational marks. Executing standards manoeuvres: turning circle and zig-zag manoeuvres. Slow speed manoeuvring in different modes.. Stopping in different modes Negotiating narrow passages and entering locks, bow first or stern first. Steering in narrow fairway with several bends. Manoeuvring feeling interaction effects - shallow water, bank effect and canal effect. Meeting and overtaking other ship in a narrow canal feeling interaction effects between two ships. Manoeuvring in current, steering with or against current, entering dock with current, from different directions, bow or stern first, turning in current, feeling inertia effects in non-uniform current, entering lock with or against weak current. Emergency manoeuvres involving engine failure forcing to steer with one pod only, the other blocked in different positions.

2.4 . MODEL TRAINING PROGRAMME FOR AZIMUTH ASD AND TRACTOR TUG MASTERS AND FOR ESCORTING OPERATIONS (FMBS and MMS)

Objectives of training
Gain more detailed theoretical and practical knowledge of handling ASD and tractor tugs. Enhance knowledge and skill in handling large ships using conventional tugs and tugs driven with azimuth propulsion devices. Enhance knowledge and skill in tug manoeuvring in escorting operations with the use of escort tugs including handling of emergency situations. Enhance knowledge of human factor issues and skills in human factor issues such as communication, planning, briefing and situation awareness Improve safety at sea by applying the proper procedures for conducting safe escorting operations
Lectures
General information on the simulator facility. Principles of manned models technique. Similitude laws. Principles of work and operation of azimuthing propulsion devices. Types of tugs with azimuthing propulsion devices. Ship-tug handling co-operation theory. Forces created by tugs and their effect on the assisted ship. Manoeuvring characteristics of ships with azimuthing propulsion devices. Different modes of handling azimuth propelled vessels. Pivot point. Various methods of stopping azimuth driven ship. Basic theory of tug action during escorting. Assisted turning and stopping of escorted ship. Human factor issues contributing to safe operation. Handling emergency situations. Communication, planning, briefing and situation awareness. Effect of current and wind forces on the behavior of the ship. Manoeuvring principles in current from different directions. Inertia effects in current. Wind force. Manoeuvring principles under wind effect.
Pratical exercises
Familiarization with the simulator. Procedures for start-up and stop. Familiarization with controls and equipment. Navigating with the ASD and tractor tug, ahead, astern, turning using one or both pods, different modes. Unberthing and berthing ASD and tractor tugs, leaving the harbor basin steering in different modes. Making turns with different modes, pods coupled or independent,. Steering onto navigational marks. Slow speed manoeuvring in different modes. Different ways of stopping azimuth driven tugs. Handling large vessel with conventional and ASD or tractor tugs. Approaching and connecting to different positions on a vessel, pulling, pushing. Direct and indirect arrest mode using azimuth driven tugs. Assisted braking using hard turn. Assisted braking keeping the vessel on straight line. Escorting the vessel with one or two tugs on pre-determined route. Assisted emergency manoeuvres in case of blocked rudder or in dead ship condition. Assisted passage in the narrow canal feeling bank and shallow water effects. Assisted entering the lock. Escorted passage of the river with current. Feeling the effect of current forces. Operation of the assisted passage when manoeuvring from the bridge of assisted vessel.

Conclusions

Azipod propulsion is the novel type of propulsion. Review of basic construction and, operational features of ships fitted with azimuthing propulsion units as well as their manoeuvring and handling characteristics shows that those features are substantially different from ships equipped with conventional propulsion units. Safe operation of ships equipped with azimuthing propulsion units requires thorough acquaintance with this type of propulsion and its handling specific features.
Great number of pilots and ship masters interviewed expressed the opinion that there is the need for arranging special training courses on ships equipped with azimuthing propulsion units, in particular in order to enhance knowledge and skill in handling safety and intuitively ships driven with azimuthing propulsion devices in different situations. This is necessary in order to improve safety at sea.

The review of special training courses arranged on some Full Mission Bridge simulators (FMBS) and Manned Models simulators (MMS) revealed that there are rather wide differences between those courses in relation to their objectives, duration, scope and programmes. In order to reach some common objectives model programmes for training courses for azimuthing propelled ships were developed for FMBS and MMS with addition of the model course for escort operations when azimuthing propelled tugs are employed.

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ANNEX 1. Azipod Manoeuvring Terminology.

Annex 1 contains the paper by Jeff Baken and George Burkley headed Azipod Manoeuvring Terminology. This paper was attached to the deliverable on Task 3.1.by de Grauuw. Only title page of this paper is attached here for reference.

Azipod Maneuvering Terminology

Presented to the APA West Coast Pilots Conference

March 2008

Co-Authored by:

Capt. Jeff Baken **Pyxis Nautica LLC** **Southeast Alaska Pilots' Association**	**Mr. George Burkley** **LOCUS LLC** **Maritime Pilots Institute**

Publication by:

Maritime Pilots Institute

401 North New Hampshire St.

Covington, LA 70433

(985) 867-7989

www.maritimepilotsinstitute.org

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ANNEX 2. Implementation and assessment of the test programmes

ANNEX 2

IMPLEMENTATION AND ASSESSMENT OF THE TEST PROGRAMMES

Test training course on ship equipped with azimuthing propulsion devices performed at SRTC (SHIP HANDLING RESEARCH AND TRAINING CENTRE ILAWA)

CONTENTS

1. INTRODUCTION

As stated in the main body of the report on the task 3.5, test course on the model equipped with azimuthing propulsion devices was arranged in Ship Research and Training Centre in Ilawa, Poland (SRTC) with the purpose of implementing proposed programme as given in paragraph 2.3 of the said report.

The test course was arranged on 13th to 15th May 2011 at SRTC for two partipants and the full report on the course is given below.

2.TRAINING METHOD

Training method using large manned models exercising manoeuvres in open waters (training areas) ponds or lakes are reported in many places and is widely used since late sixtees of the last century.

First training centre using manned models was established in Port Revel near Grenoble in France in 1966. Because of high demand for training Polish masters, in 1975 an attempt was undertaken to establish ship handling training centre in Poland. Location of the centre on the lake Silm near Ilawa was then proposed because at that time experimental station belonging to the Technical University of Gdansk existed in Ilawa that had already wide experience in testing models in open waters. Actual training started in 1981 when the first model for training purposes was constructed and experimental training courses for a number of polish masters were arranged using existing facilities in the experimental station in Ilawa mentioned above.

In the years 1986-1989 basic facilities of the new centre were constructed on the shores of lake SILM, three kilometers from Ilawa, and from 1990 onwards ship handling courses are being held regularly there. At the same time the Foundation for Safety of Navigation and Environment Protection was created which is running the centre. Since then more than three and half thousands of ship masters and pilots from about 40 countries were trained in the Centre in weekly courses. Foundation, being non-profit organisation is re-investing all spare funds in new facilities and research projects and each year to the existing facilities new models and training areas were added.

At present the Ship Handling Research and Training Centre (SRTC) represents a modern facility perfectly capable to perform research projects related to manoeuvrability as well as to conduct training of ship masters and pilots in manoeuvrability. Currently nine models of different ship types including two tug models are available at the centre. As several of them are constructed in such a way as to be operated in more than one variation, they represent wide spectrum of ship types available in SRTC for training purposes.

Manned scale models are used for training purposes in open water areas. Models are sufficiently large in order to accommodate 2-4 people (students and instructors) and are constructed according to laws of similitude. This means that not only geometry of the ship hull is properly reproduced according to chosen scale, but also dynamic characteristics of the ship such as speed, centre of mass, mass moments of inertia and other characteristics are correctly reproduced in the model. Also characteristics of the propeller (thrust, revolutions), characteristics of rudder engine (time from hard over to hard over) and characteristics of the main engine (power, time of reversing etc.) are reproduced according to the scale. Models are fitted with anchors, thrusters and tug simulators where appropriate. Tug model are also available. Models are controlled by the helmsman and are manoeuvring in the areas where mock-up of ports and harbours, locks, canals, bridges piers and quays, shallow water areas and other facilities are constructed and where also routes marked by leading marks or lights (for night exercises) are laid out all in the same reduced scale as the models. Also in certain areas current is generated. As a rule, monitoring system allowing to monitor track of the model is available.

In the case of manned models the governing law of similitude is Froude's law and all quantities for models are calculated according to the requirements of this law. However, as it is well known, the requirements of second law of similitude which is relevant to ship motion, Reynolds law, can not be met. This means that the flow around the ship hull and appendages and in particular separation phenomena might be not reproduced correctly in the model scale. Fortunately those effects are important when the models are small. With models 8 to 15 m long the Reynolds number is sufficiently high for avoiding such effects.

One important difficulty with manned models is impossibility to reproduce wind effect. Wind is a natural phenomenon and according to laws of similitude wind force should be reduced by factor λ^3 (λ - model scale). There are attempts to reduce wind force in model scale by reducing windage area in comparison with full-scale ship and also by choosing sheltered area for exercises, but even so the wind force is usually to large.

Important feature of manned model exercises is that all manoeuvres are performed not in real time, but in model time which is accelerated by the factor λ^{-1}. This may pose some difficulties for trainees at the beginning who must adjust to the accelerated time scale.

3. TRAINING AREAS AND MODEL USED

3.1. Training areas

The SRTC training centre is located on the shore of the small lake (about 40 ha) surrounded by hills and forest and sheltered from strong winds. The lake is used solely for the purpose of training and research and provides sufficiently large areas for performing of all kinds of manoeuvres with ship models including manoeuvres requiring large area (for example ship-to-ship or escorting manoeuvres on long routes) As safe handling of ships is much more difficult in restricted areas and in presence of the current, in SRTC there are artificially prepared training areas that, on top of the standard model routes marked by leading marks, leading lights (at night) and buoys, comprise also routes particularly suitable for training on ship handling in shallow and restricted areas in canals and waterways.

General plan of training areas is shown in fig 1, and in figures 2 to 5 particular areas used for training are shown.

Table 1 shows particular training areas and facilities arranged on the lake and their usage.

The above arrangement of training areas provide ample opportunities to train ship masters and pilots to handle ships in difficult navigation situations, in particular in those, that may be present, harbour approaches in restricted areas, waterways etc, where strong interaction effects between ships and environment are present.

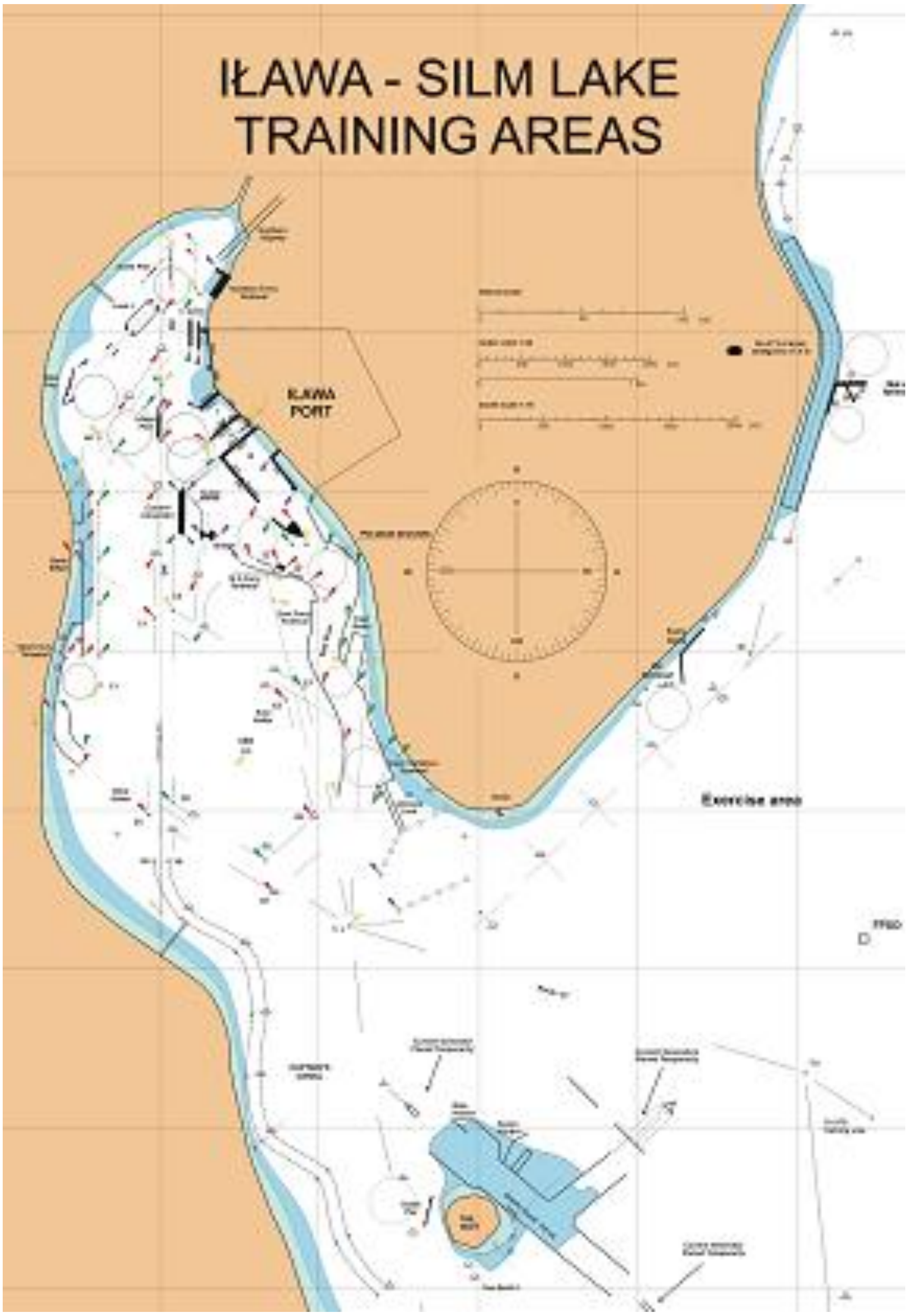

Fig.1. Training areas in SRTC

Table 1. ***Exercise areas and their usage***

	Area	Area and usage
A	Open training area	Feeling behaviour and manoeuvring characteristics of the ship: Turning circles, initial turning test, zig-zag test, pull-out test, crash stopping, stopping by rudder cycling procedure, accelerated turn Williamson turn etc
B	Piers and jetties	Berthing and unberthing manoeuvres, bow and stern first, different configuration of piers and jetties
C	Harbour basins (3)	Turning and berthing in the confined space, crabbing towards or away from berth
D	Deep water channel and buoyed route	Keeping the ship within limits of the fairway directed by leading marks or leading lights (at night), making 60 deg left hand and right hand turns
E	Bank Effect Route	Feeling bank suction force Proceeding along bank, both ways; Meeting two ships along the bank, Overtaking another ship along the bank
F	Captain's Canal	Passing the narrow deep water buoyed route with several bends, both ways, slowing down in the canal, Stopping
G	Chief's Canal -with or without current	Wide (corresponding to about 360m width in reality) shallow water canal of the length corresponding to about 1.5 km, where current could be generated from both sides (chiefs canal), Passing the shoal– feeling slowing down and squat, Berthing at shallow water pier bow and stern first, Berthing and unberthing against and with the current, bow and stern first, Turning in current, Entering the canal with or against current and berthing in sheltered dock, Entering the canal from the side canal and berthing against or with current
H	East River (River estuary mock up)	River estuary area where several current generators installed create current. Several mooring places are provided in the estuary, including sheltered dock. Current pattern and velocities could be adjusted by activating particular current generators, the maximum current velocity correspond to 4 knots in full scale.(fig.7) Berthing and unberthing in current alongside pier –bow or stern first, Entering the harbour basin feeling cross-current, Unmooring in current and turning by stern, Passing the river with and against current, Unmooring in river entering harbour basin against strong current, Entering the dock in the river bow or stern first, Turning in river current, starting with or against current, Feeling effect of momentum when leaving the current area feeling effect of inertia in non-uniform current, use current force to manoeuvre the ship in non-uniform current
I	Locks	Two locks (one representing Antwverp lock) Entering lock No1, both directions, Entering lock No 1 one ship moored at side, Passing lock No 2(Antwerp lock), both ways, entering the lock closed on one side feeling piston effect
J	Narrow passages	Narrow passages including narrow passage under the bridge. Transit through a very narrow passage, both ways feeling suction forces, Transit narrow passage under the bridge, Negotiating 60 deg narrow buoyed passage
K	Pilots Canal	Restricted cross-section canal of the length 140m (corresponding to 3.3 km in reality) (pilots canal). Cross-section of the canal with two ships at meeting situation is shown in fig. 5.
L	FPSO and SPM	Off-shore operations

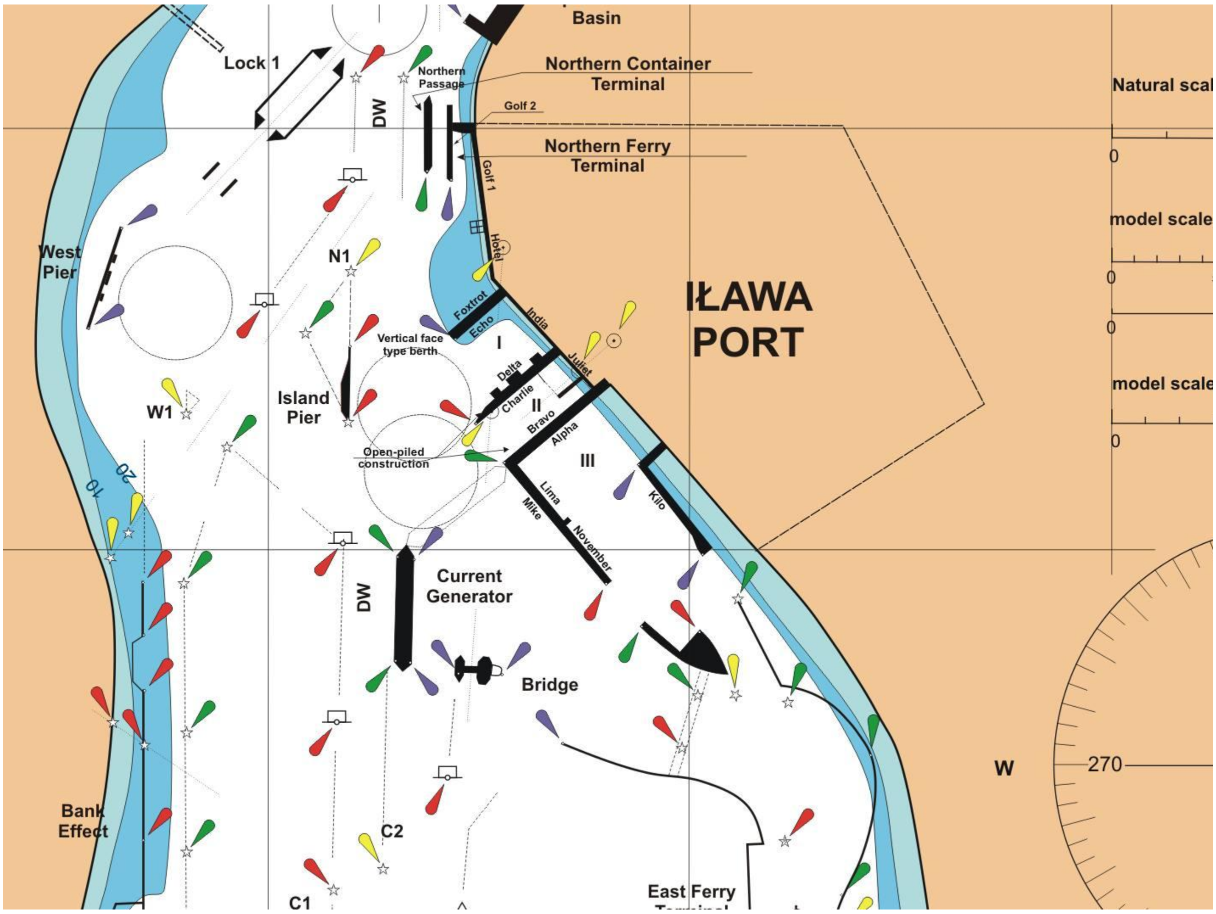

Fig.2. Northern part of the training areainluding Ilawa Port

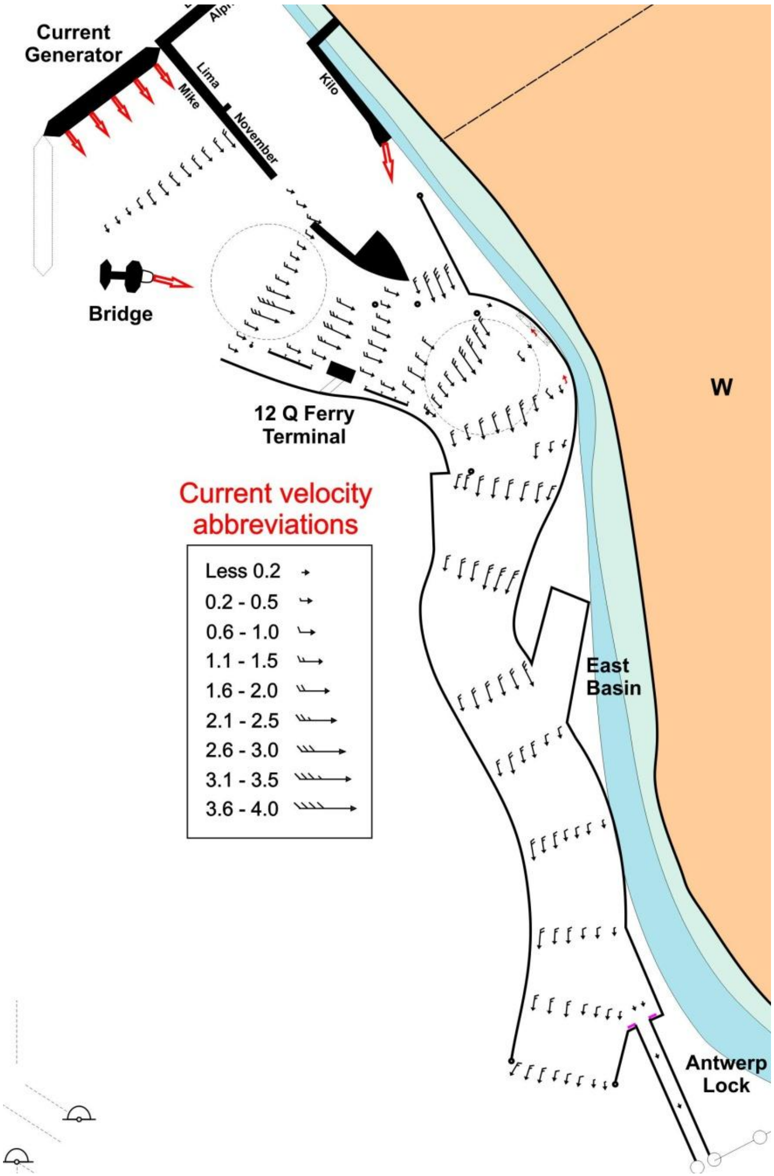

Fig3. East River training area (mock-of a river estuary)

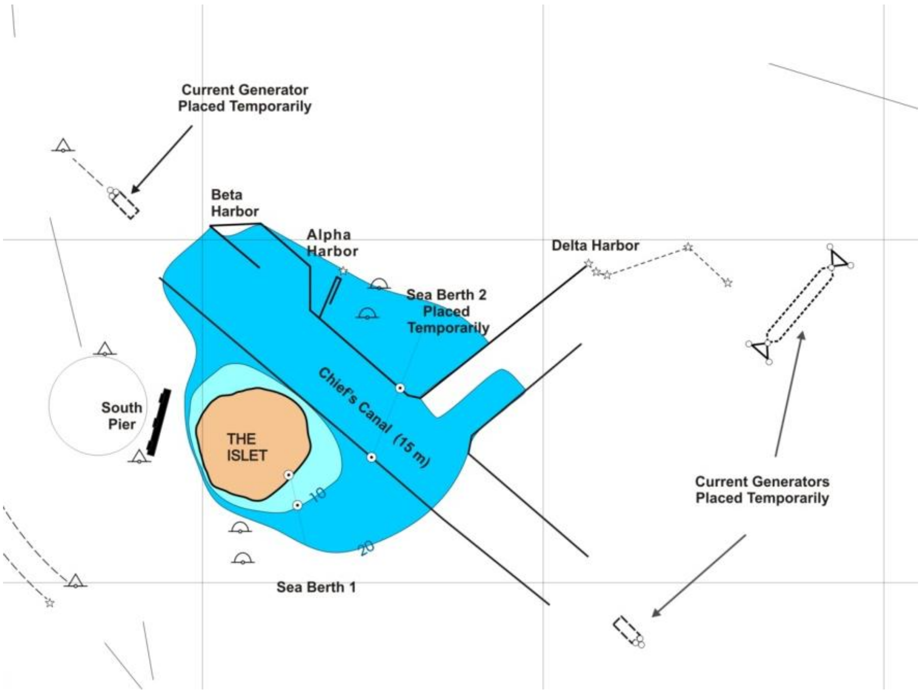

Fig. 4. Chiefs Canal and shallow water training area

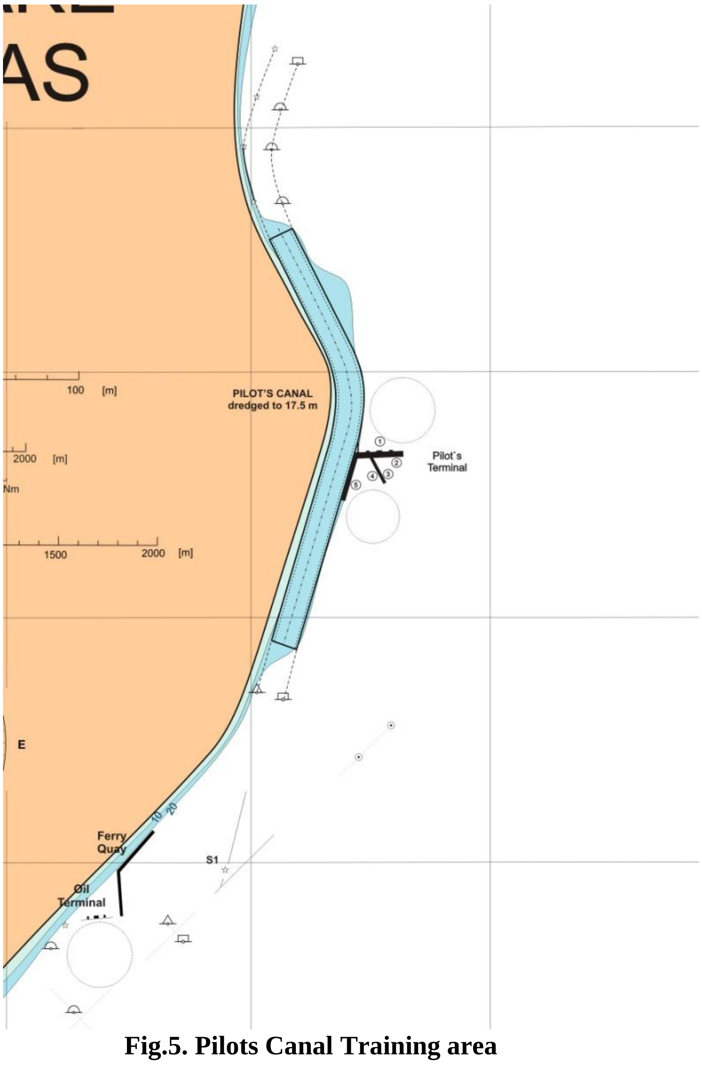

Fig.5. Pilots Canal Training area

3.2. Model

In SHRTC model of the gas carrier of capacity 140 000 m^3, fitted with two POD propulsion units with pulling fixed pitch propellers is available for training. The model was build in model scale 1:24. Fig. 27 shows the photograph of the model, and the dimensions of the model are shown in the table 6.

Fig.6. Model of POD driven gas carrier in SHRTC

Table 2. Dimensions of the model used in SHRTC

Dimension	Real ship	Model
Length [m]	277.45	11.56
Breadth [m]	43.2	1.80
Draft [m]	12.0	0.50
Block coefficient [-]	0.79	0.79

Fig. 7. Model equipped with azimuthing propulsion device at SRTC

4. SIMULATION METHOD. FROUDE’S LAW

Model is geometrically similar to the full scale ship. Then the geometric similitude is ratio of all linear dimensions of the full-scale vessel to the corresponding dimensions of the model must be the same and equal to the model scale - λ (fig, 8):

$$\frac{L_{\text{ship}}}{L_{\text{model}}} = \frac{B_{\text{ship}}}{B_{\text{model}}} = \frac{X_{\text{ship}}}{X_{\text{model}}} = scale = \lambda$$

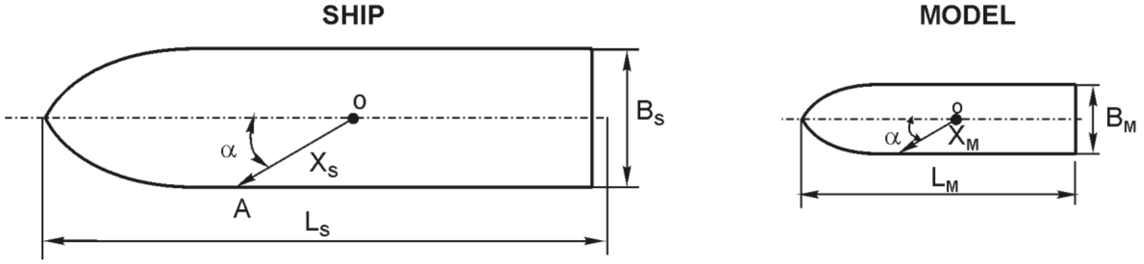

Fig. 8

Although the dimensions of the model are reduced, it is seen from the above figure that the corresponding angles for the model and the full- scale vessel have the same value.

relationship between any area for a model and a ship.

$$\frac{A_{ship}}{A_{\text{mod}l}} = scale^2 = \lambda^2$$

Corresponding volumes of the full-scale ship and the model are proportional to the model scale in the power 3:

$$\frac{V_{ship}}{V_{\text{mod}el}} = scale^3 = \lambda^3$$

The ratio of the corresponding mass (and also corresponding displacement) of the full scale ship and model is

$$\frac{m_s}{m_m} = \frac{\Delta_s}{\Delta_m} = \lambda^3$$

***The governing law for the ship model work is* FROUDE'S law of similitude**

FROUDE'S law of similitude says that: the Froude's numbers for the ship and its model must be equal:

$$\boldsymbol{Fn_{SHIP}} = \boldsymbol{Fn_{MODEL}}$$

$$\frac{V_S}{\sqrt{g \cdot L_S}} = \frac{V_M}{\sqrt{g \cdot L_M}}$$

where g is the acceleration due to gravity.

From the Froude's law we have:

$$\frac{V_S}{\sqrt{g \cdot L_S}} = \frac{V_M}{\sqrt{g \cdot L_M}}$$

and from this equation it is possible to calculate the model velocity:

$$V_M = V_S \cdot \frac{\sqrt{g \cdot L_M}}{\sqrt{g \cdot L_S}} = V_S \sqrt{\frac{L_M}{L_S}} = \frac{V_S}{\sqrt{\lambda}}$$

For example with the model scale equal to 24, we have:

$$V_M = \frac{V_S}{\sqrt{24}} \cong 0.2 \cdot V_S$$

If Froude's law is applied, then $C_{RS} = C_{RM}$, and knowing that $V_S/V_M = \sqrt{\lambda}$; $S_{WS}/S_{WM} = \lambda^2$, and neglecting the difference of densities of sea water and fresh water (lake), that is rather small, we get:

$$\frac{R_S}{R_M} = \frac{V_S^2}{V_M^2} \cdot \frac{S_{WS}}{S_{WM}} = \lambda \cdot \lambda^2 = \lambda^3$$

This applies also to the inertia forces. The ratio of the inertia forces for the ship and the model is:

$$\frac{R_{iS}}{R_{iM}} = \frac{m_S \cdot a_S}{m_M \cdot a_M}$$

Knowing that the ratio of the mass of the ship to the mass of the model is: $m_S/m = \lambda^3$, and the ratio of accelerations is: $a_S/a_M = 1$, we get:

$$\frac{R_{iS}}{R_{iM}} = \lambda^3$$

This ratio applies to all forces acting on the manoeuvring ship.

Scale coefficients applicable to other physical quantities are shown in the Table 3.

Table 3: relationship between geometric and kinematic parameters for Froude identity

Item	*Value of ship / model ratio*
Length, Beam, Draft, Turning, Diameter, Stopping, Distance, and other linear dimensions	Scale
Windage, Rudder area, etc	$scale^2$
Volume, Displacement, Force	$scale^3$
Speed	$scale^{1/2}$
Angle	1
Rate of Turn	$1/scale^{1/2}$
Time	$scale^{1/2}$
Acceleration	1

From the table it is seen that applying the Froude's law of similitude the time scale is equal to the square root of the model scale. This is important conclusion meaning that in the model work the time is running faster than in reality. With the model scale equal to 24, the time scale is approximately equal to 5. This means that all manoeuvres are performed faster than in reality. For example, if some manoeuvre in the full scale requires one hour, then the same manoeuvre in the model scale takes about 12 minutes.

Models work in the model time, not in the real time!

This must be remembered when manoeuvring the model. It results from this that "feeling for a ship" based on correct timing can be affected by the above time scale, however trainees raise this problem very rare.

This important conclusion means that all actions that depend on time must be appropriately scaled down. On the model the times to reverse the engine, times to put the rudder from zero position to full rudder or times to operate tugs are properly adjusted – see Figs. 9 and 10

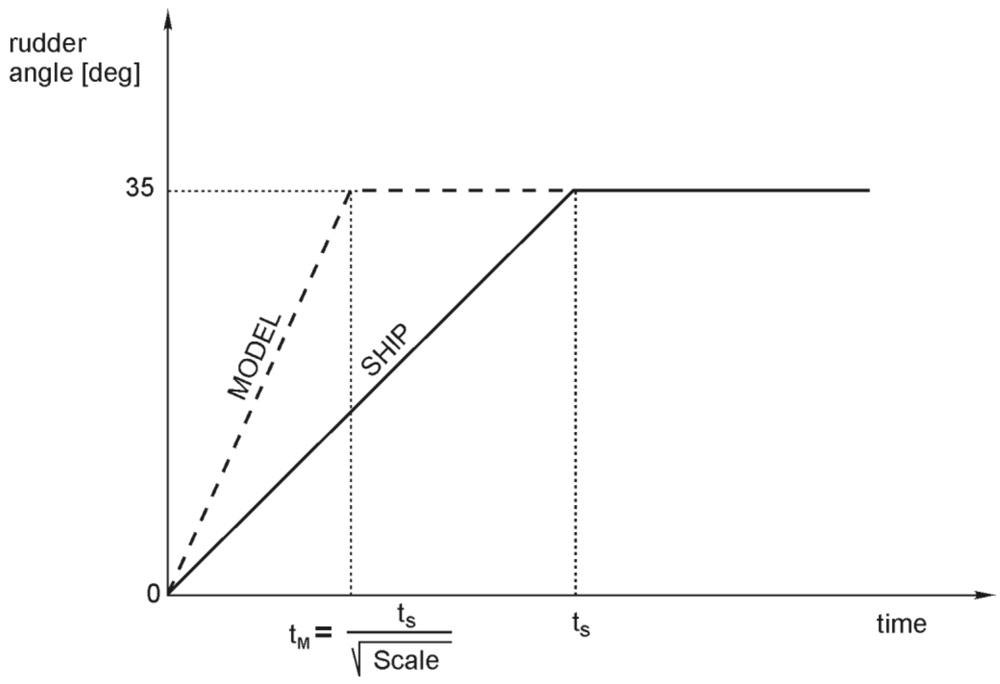

Fig.9. History of rudder deflection for a ship and a model

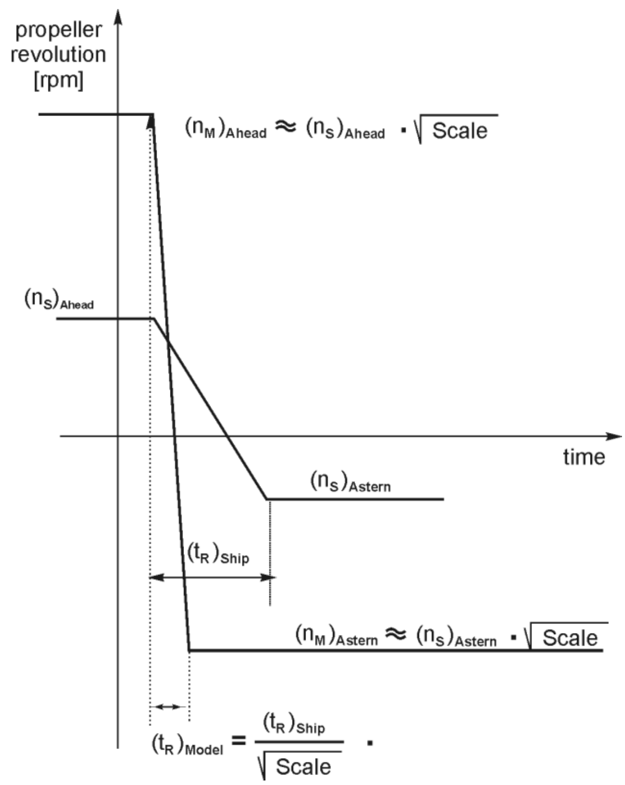

Fig.10. **Reversing of engine for a ship and a corresponding model**

5. COURSE PROGRAMME AND SCHEDULE

Model training programme proposed in the report on task 3.5 is copied below. This programme originally proposed for five days course was accordingly adjusted for three days test course with extended hours of work therefore number of hours for practical exercises remained the same as in five days course. However, because participants already completed the standard and advanced courses on manned model and were well familiar with the general theoretical background normally included in the lectures, the lectures were limited only to particular problems related to characteristics and operation of azipod propulsion.

It is, however, understood, that normally in the specialize training course on manned models of ships equipped with azimuthing propulsion devices each day introductory lectures will be given as in the proposed programme.

The text of the relevant lectures on Azipod propelled vessels is attached in the Appendix to this Annex.

“2.3. MODEL TRAINING PROGRAMME FOR SHIP MASTERS AND PILOTS ON AZIPODS DRIVEN SHIP FOR MANNED MODELS SIMULATORS”

Objectives of training
Enhance the knowledge of and skills in handling azipod propelled ships. In particular enhance the knowledge of manoeuvring characteristics and specifics of operation of azimuth propelled ships, various factors affecting their manoeuvrability including environment. Help the participants to understand the importance of safety by showing the effects of handling errors. Show the participants the ways to handle critical situations. Enhance safety by applying the proper procedures
Lectures
General information on the simulator facility. Principles of manned models technique. Similitude laws. Characteristics and types of azipod driven ships and azimuthing propulsion. Principles of work and operation of azimuthing propulsion devices.. Forces acting on the manoeuvring ship. Manoeuvring characteristics of ships equipped with azimuthing propulsion devices. Pivot point. Basic manoeuvres. IMO requirements related to manoeuvrability. Operation modes of azipod driven ships. Various modes of stopping. Slow speed manoeuvring. Harbour manoeuvres. Tugs action. Operational restrictions related to azimuth propulsion. Principles of interaction effects – bank effect, shallow water effect, canal effect, ship/ship interaction effect. Sailing in current. Current forces. Manoeuvring principles in current from different directions. Inertia effects in current. Effect of wind. Wind force. Manoeuvring principles under wind effect. Human factor issues contributing to safe operation. Handling emergency situations.
Pratical exercises
Familiarization with the simulator. Procedures for start-up and stop. Familiarization with controls and equipment. Unberthing and berthing; crabbing towards the jetty or away from the jetty without or with bow thruster use. Leaving the harbor basin making turns with different modes , pods coupled or independent, steering in different modes, cruise soft and strong. Steering onto navigational marks. Executing standards manoeuvres: turning circle and zig-zag manoeuvres. Slow speed manoeuvring in different modes.. Stopping in different modes Negotiating narrow passages and entering locks, bow first or stern first. Steering in narrow fairway with several bends. Manoeuvring feeling interaction effects - shallow water, bank effect and canal effect. Meeting and overtaking other ship in a narrow canal feeling interaction effects between two ships. Manoeuvring in current, steering with or against current, entering dock with current, from different directions, bow or stern first, turning in current, feeling inertia effects in non-uniform current, entering lock with or against weak current. Emergency manoeuvres involving engine failure forcing to steer with one pod only, the other blocked in different positions.

6. . EXERCISES PERFORMED DURING TEST COURSE

During the three days test course a number of exercises with the model fitted with azimuthing propulsion devices were performed. The basic programme of exercises is given below and in the figures attached in Chapter 7 the results of monitoring of the majority of exercises performed are shown. As many exercises were repeated few times, as a rule, only one result of the few realized is shown

Day 1.

- Exercises intended to familiarize with the manoeuvring characteristics of ships equipped with azimuthing propulsion devices such as turning ability (turning circle tests), yaw checking ability (zig-zag tests), stopping ability (stopping tests, different methods).
- Exercises intended to familiarize with possibilities to perform manoeuvres in very confined areas, such as harbour basin) -crabbing, berthing and unberthing in confined area, shifting from one pier or quay to the other with or without rotation
- Exercises intended to familiarise with course keeping ability and the possibility to pass very narrow passages

Day 2.

- Exercises intended to learn about the possibility to negotiate hard turns at speed and to keep the ship within limits of the narrow fairway
- Exercises intended to learn the effect of the effect of shallow water on ship behaviour
- Exercises intended to learn about interaction effect between moving ship and the bank and the effect of the restricted cross-section of the canal

Day 3

- Exercises intended to learn about the effect of current on manoeuvrability of ships
- Exercises intended to learn appropriate tactics when berthing and unberthing different berths and docks with the current present

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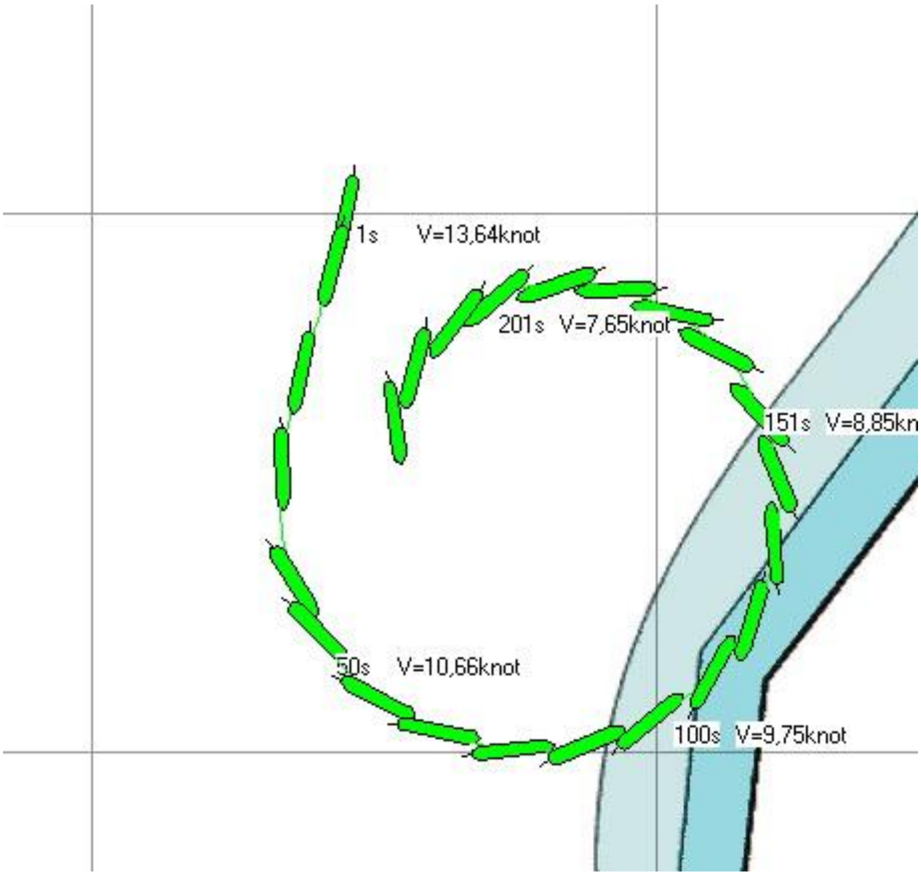
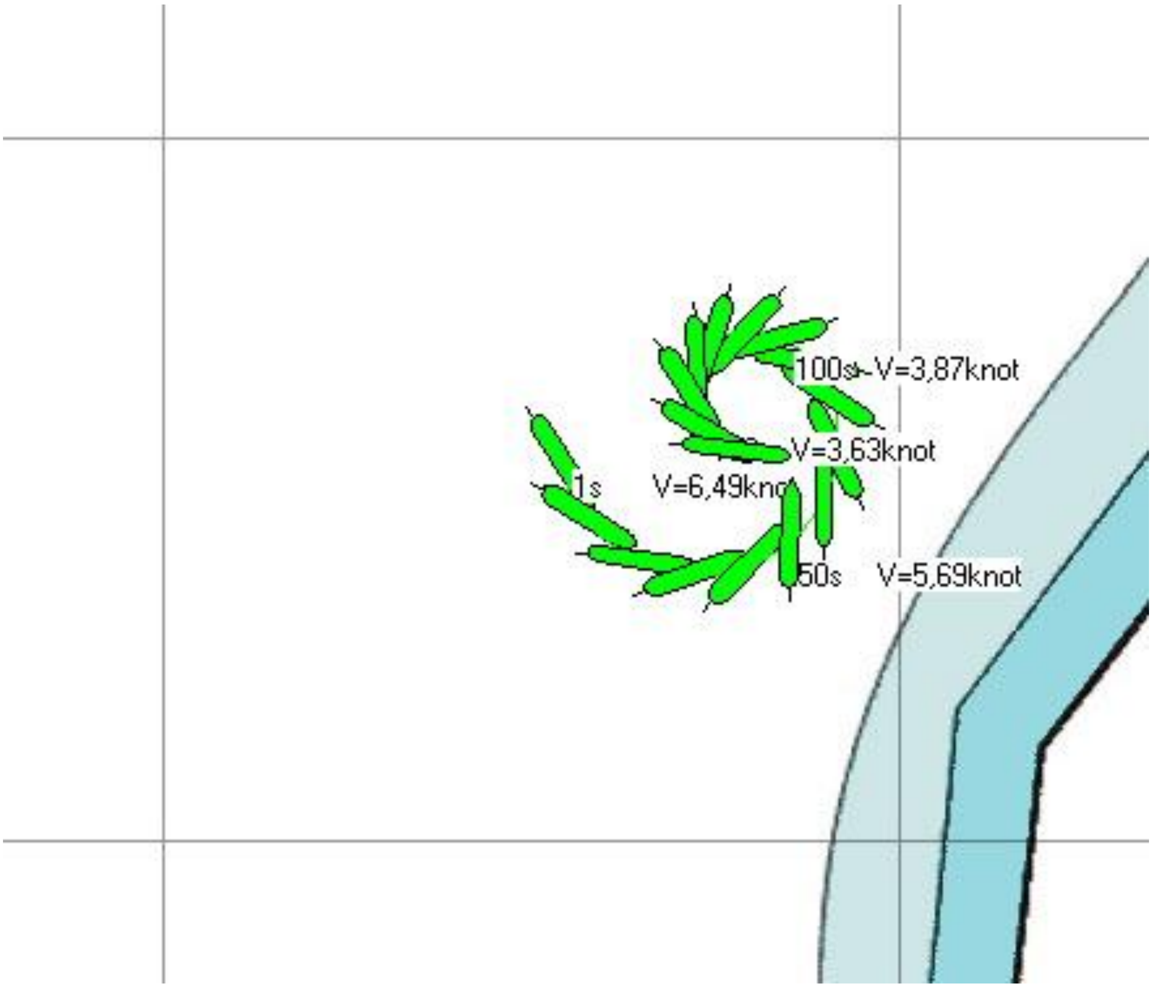
7. EXERCISES. RESULTS OF MONITORING.

(prepared by Piotr Michałowski)

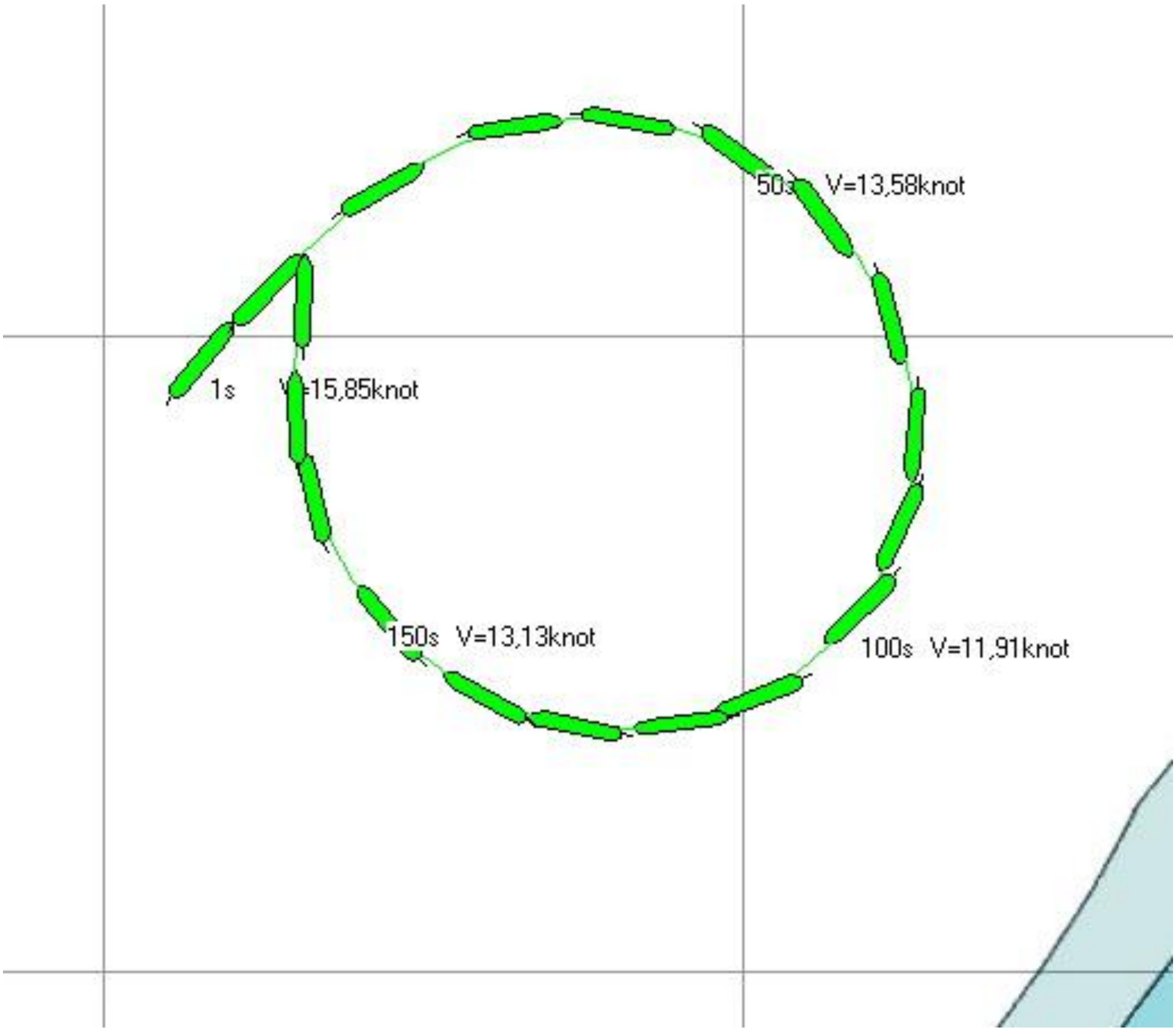
7.1. Turning. Turning circles



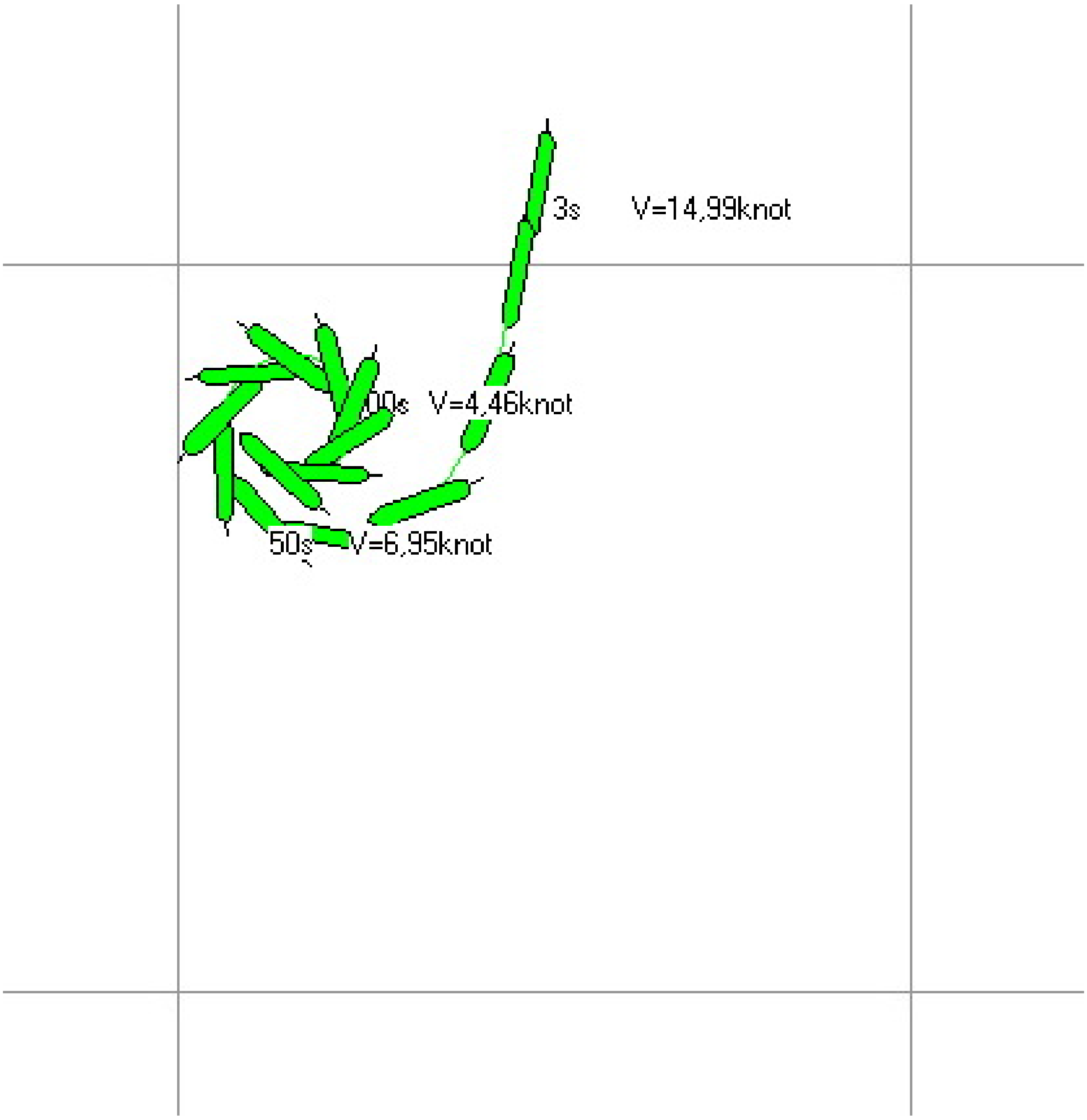
Turning circle, Soft mode, 10^0 Port Pod



Turning circle, Soft mode, 30^0, Port pod

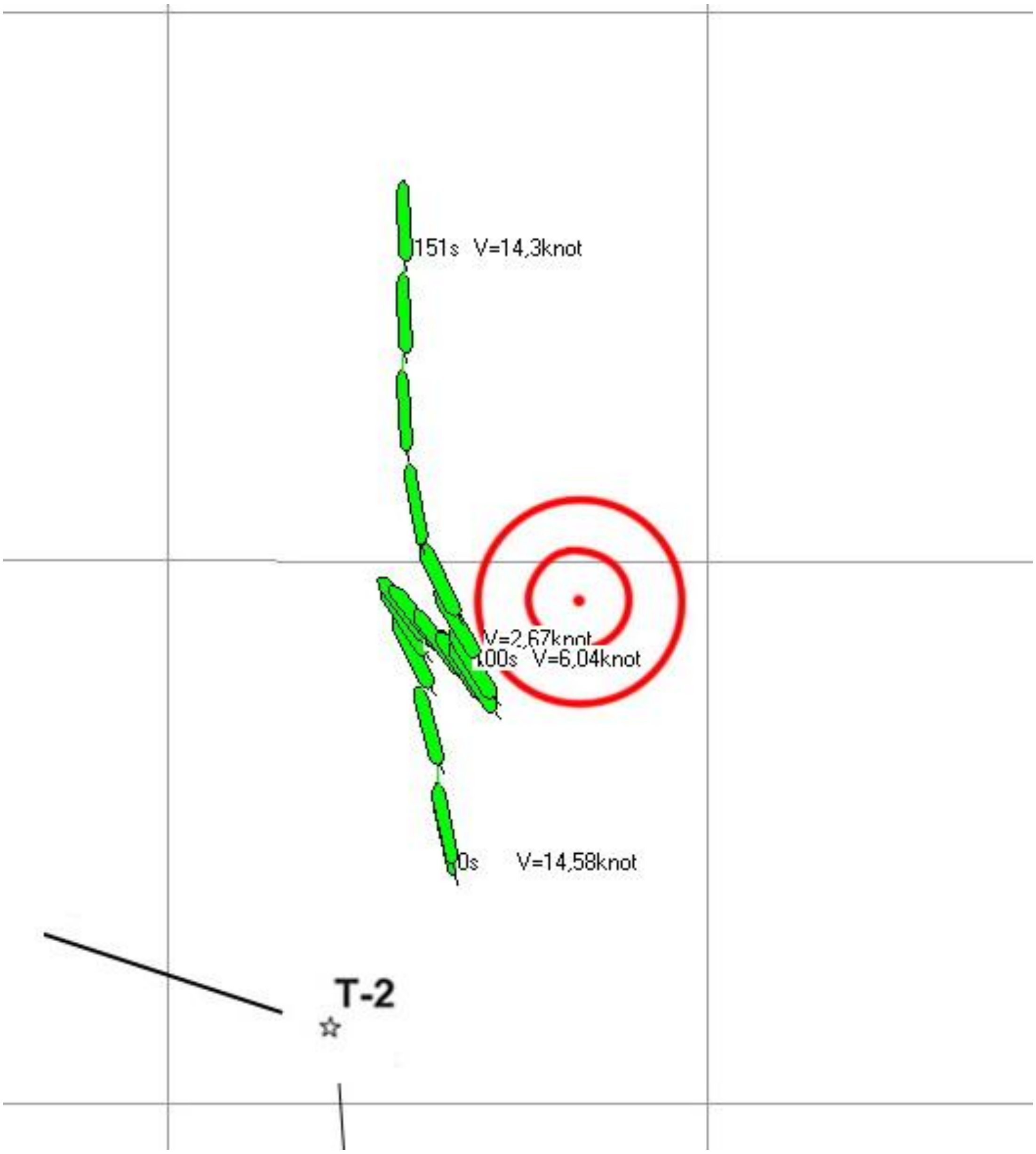


Turning circle, cruise mode, pods synchronized, 10^0 Starboard



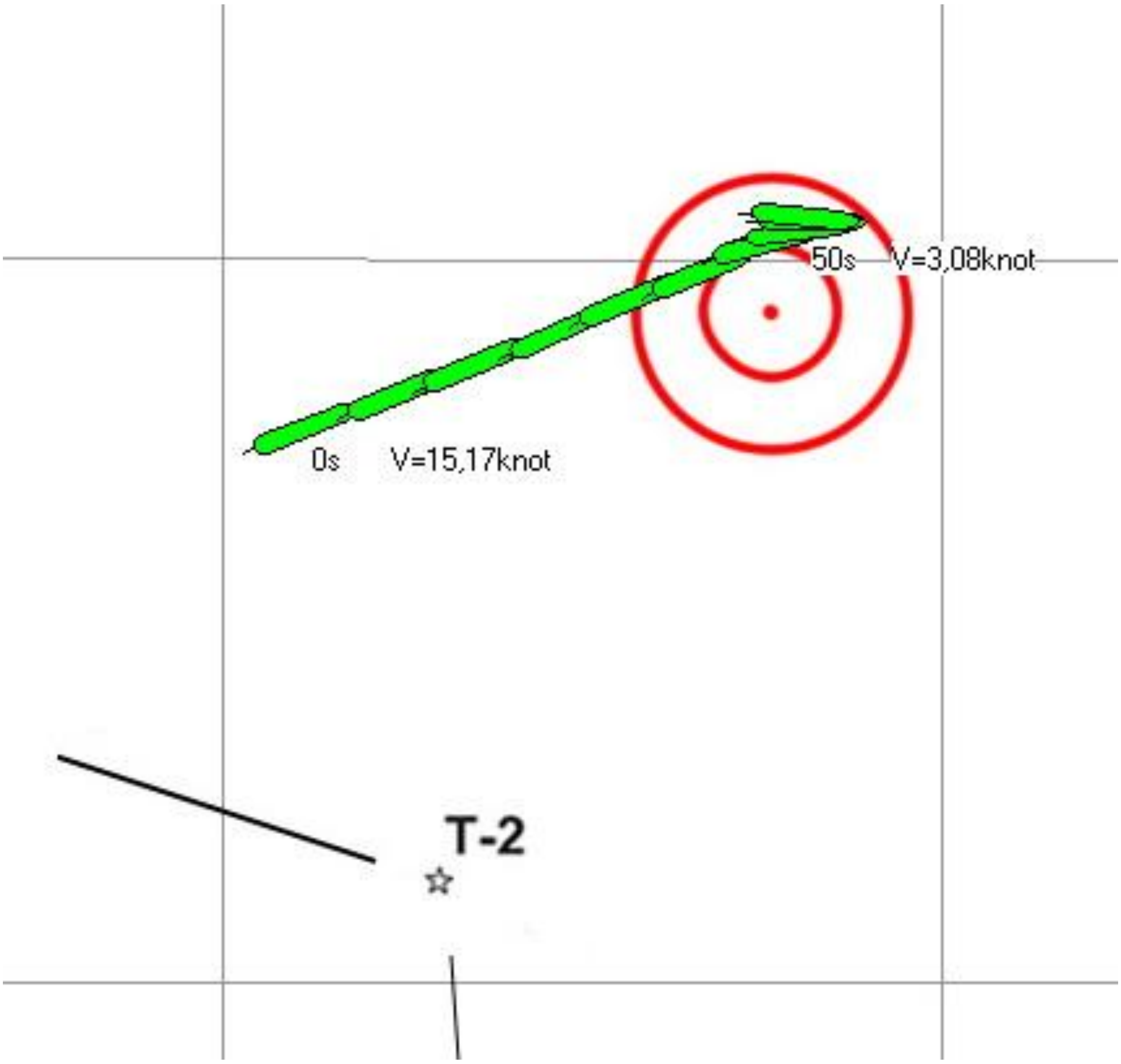
Turning circle, cruise mode, pods synchronized, 30^0 Starboard

7.2. Stopping

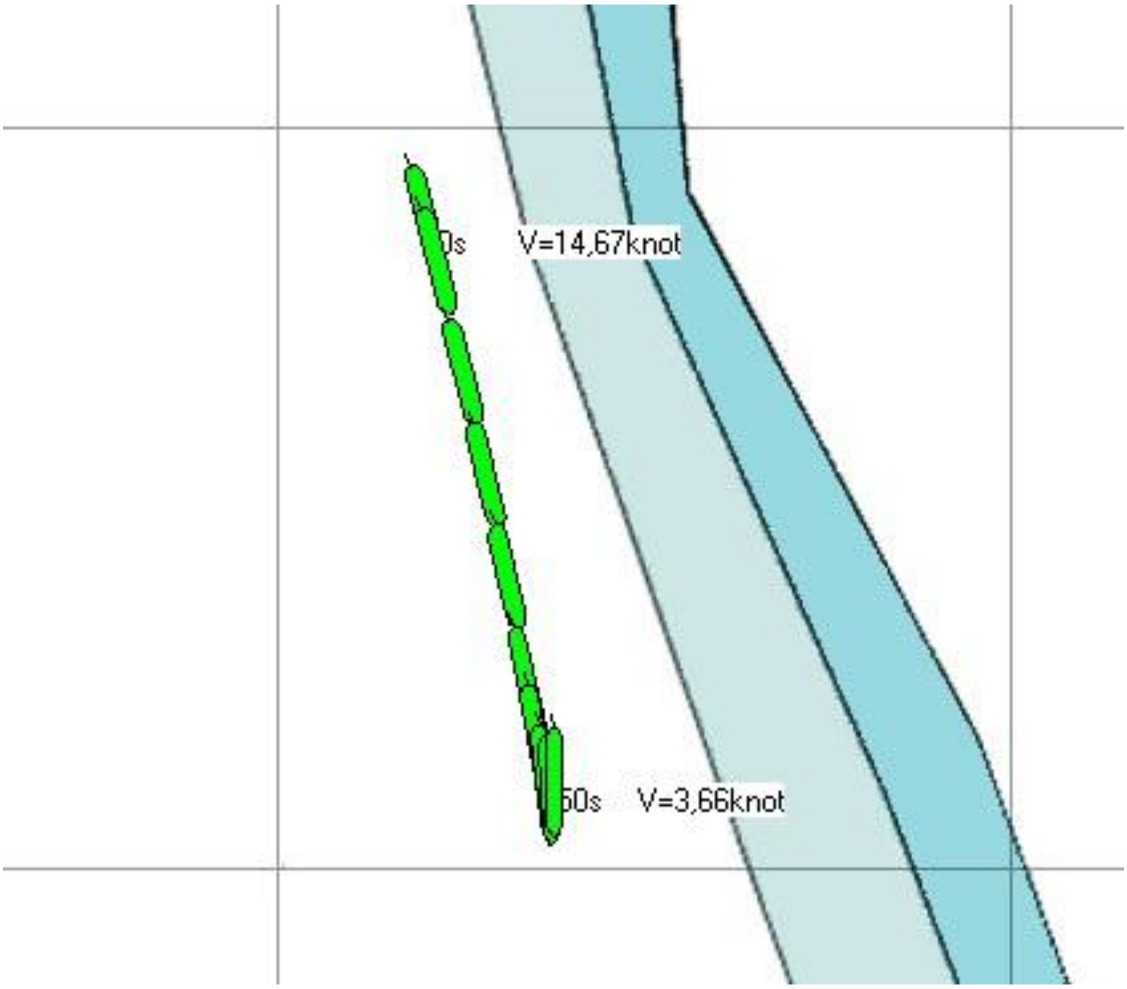


Stopping, Crash stop, RPM reversed

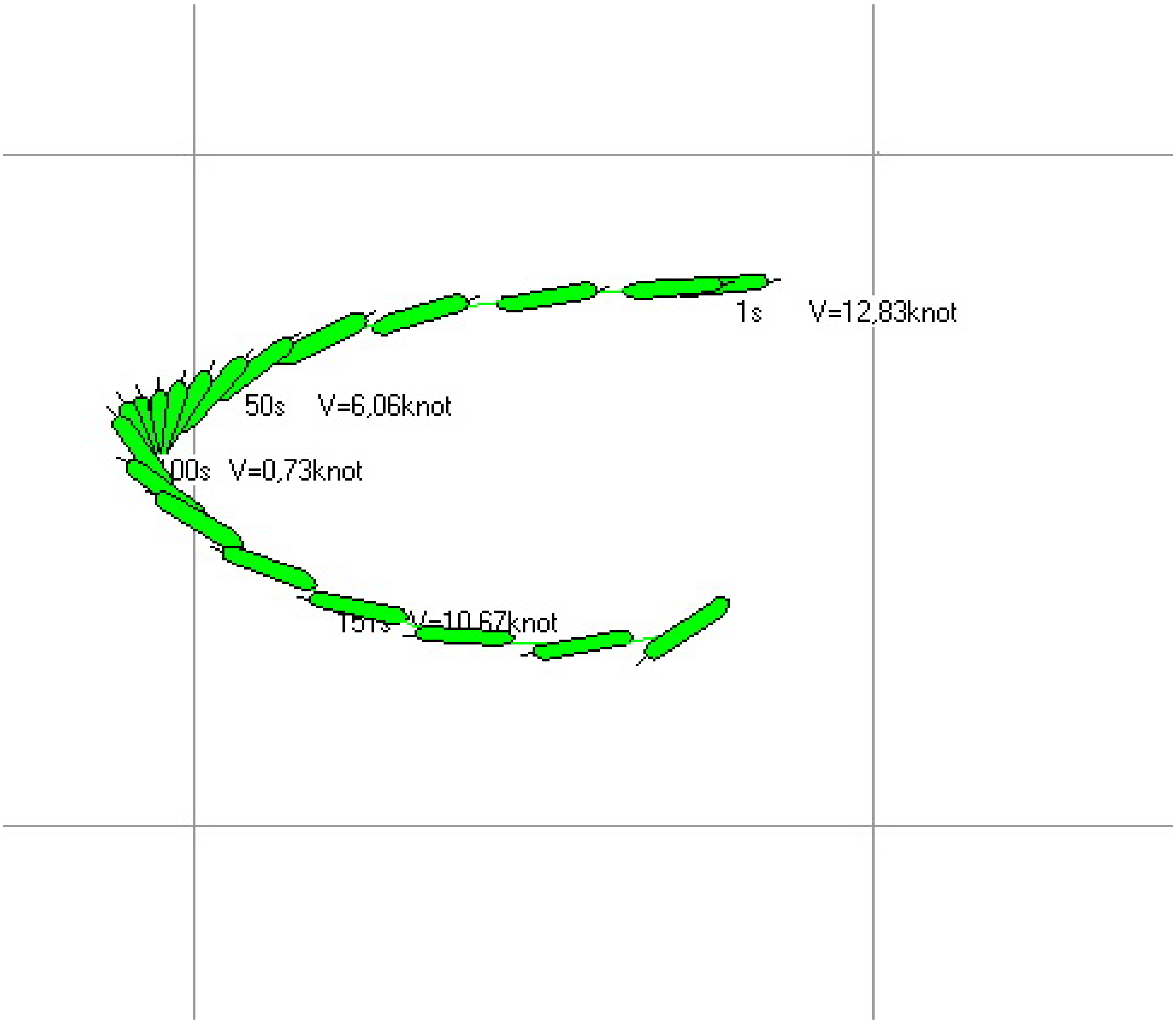
Stopping, Crash stop, RPM reversed



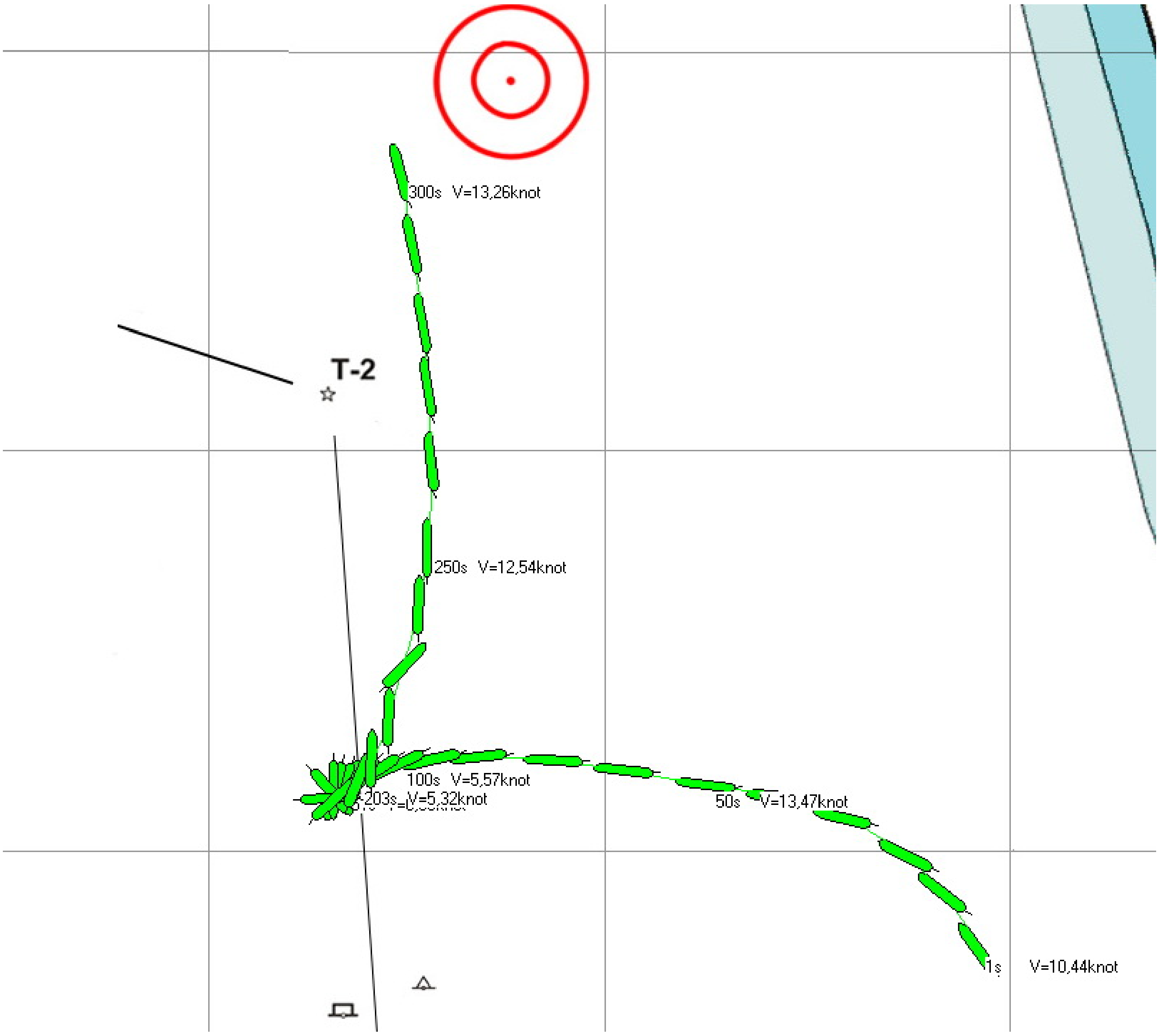
Stopping Pod Way



Stopping Pod Way

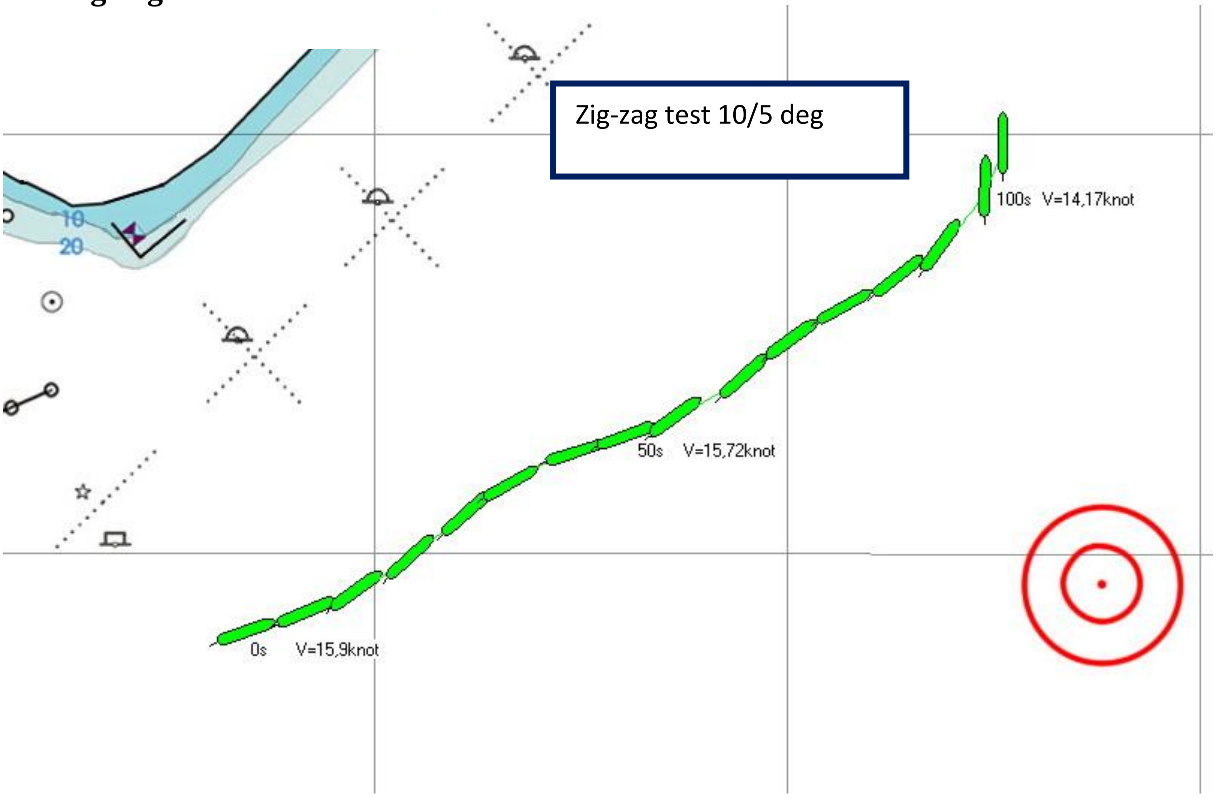


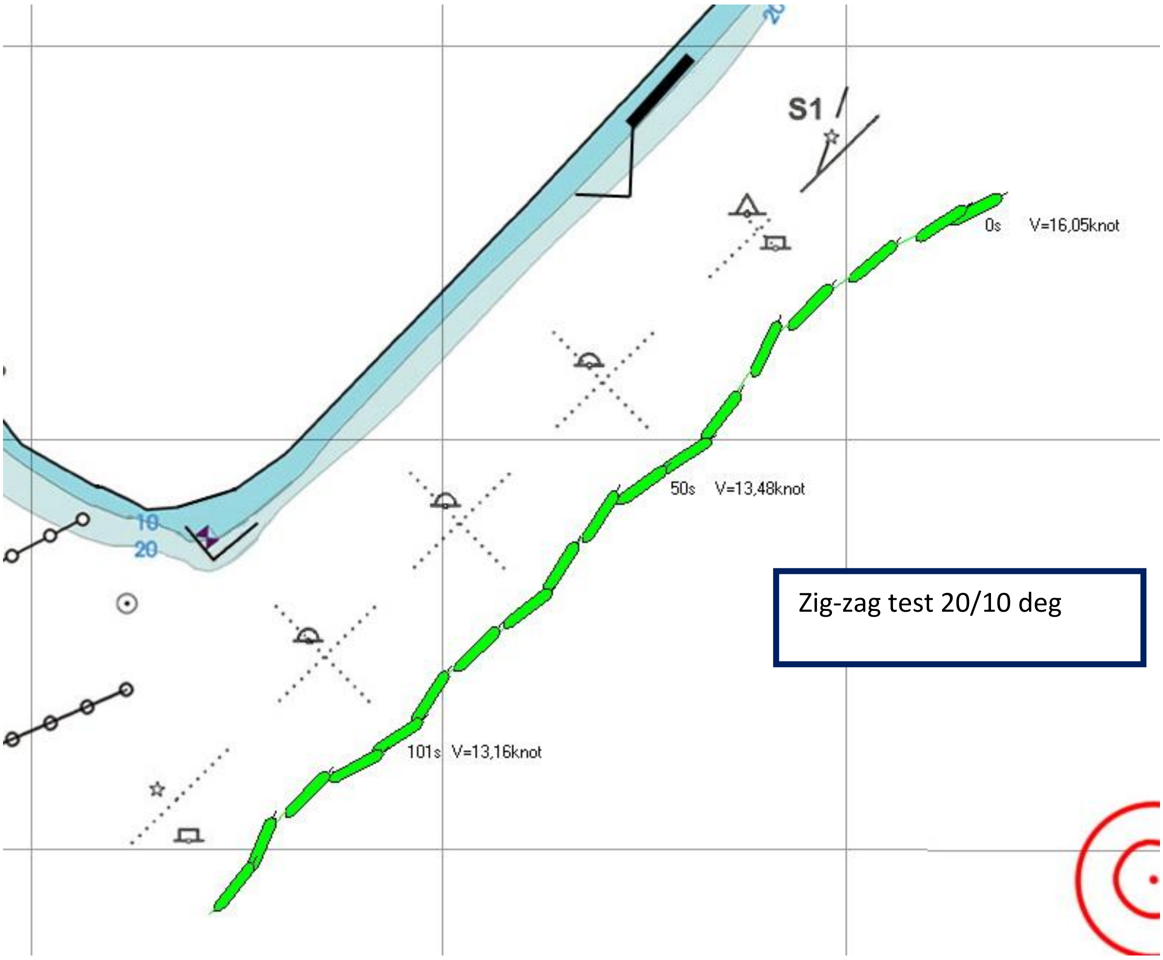
Stopping 90^{0} Pod turn

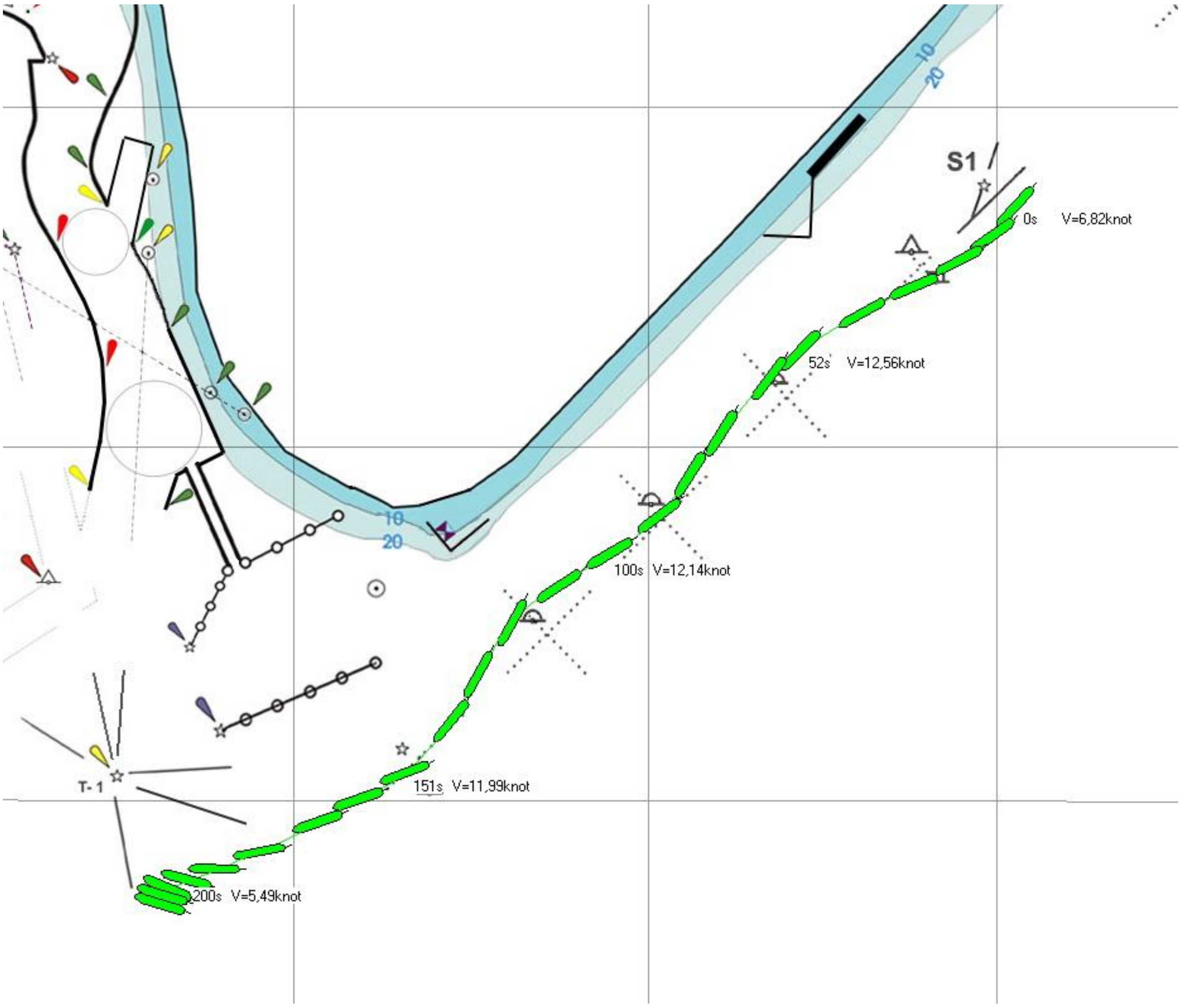


Stopping 90^0 Pod turn

7.3. Zig-zag manoeuvres

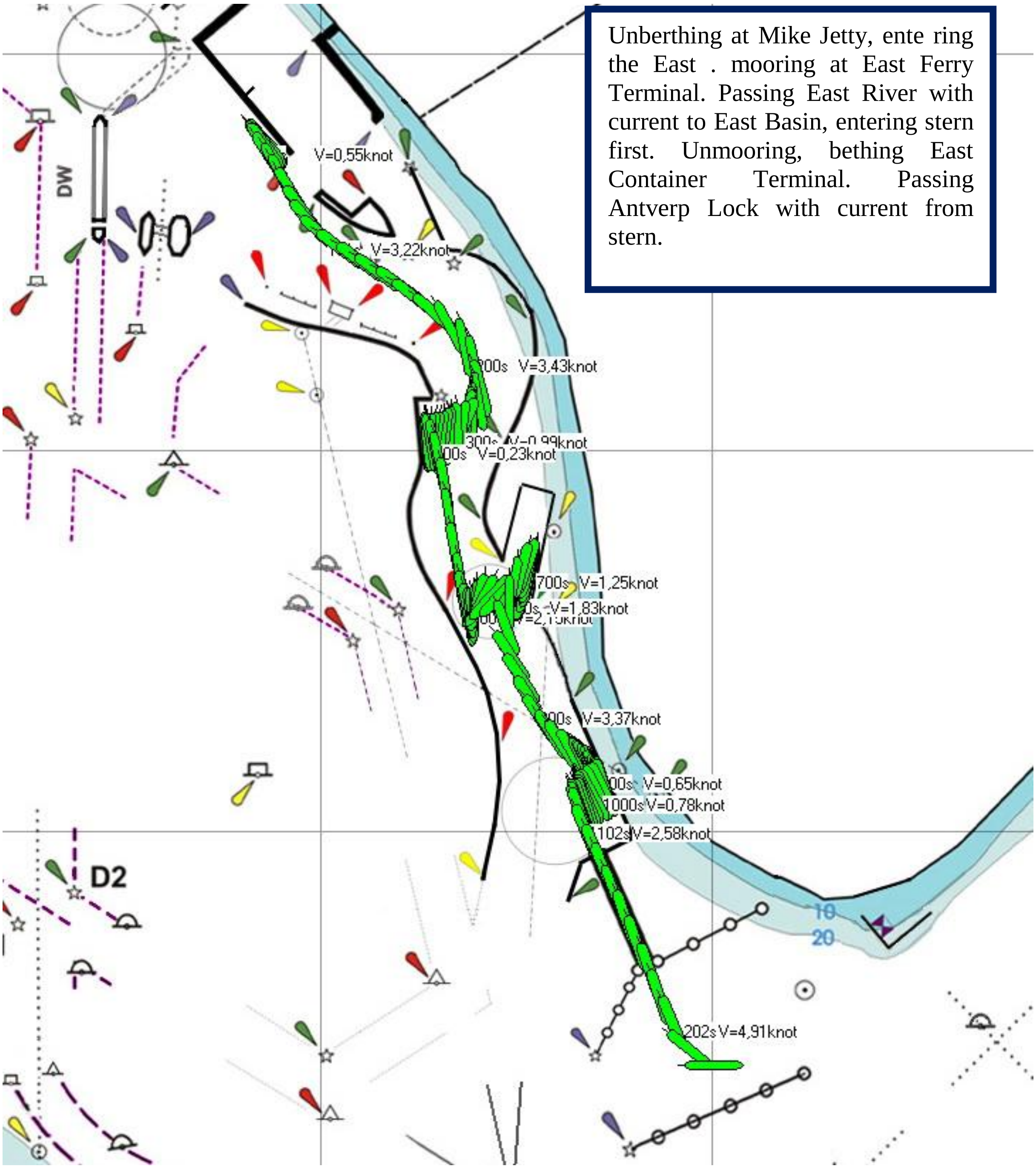




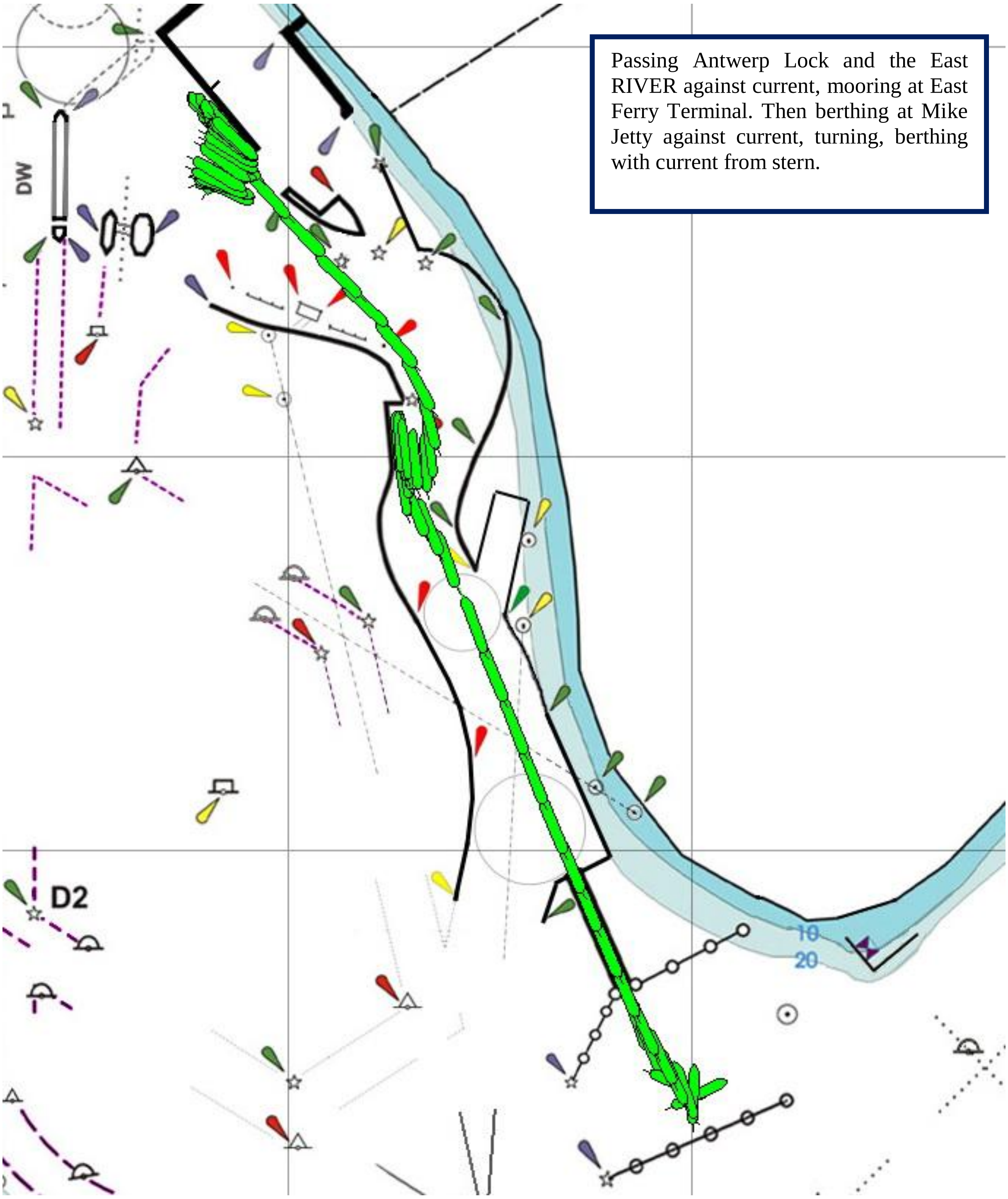


Zig-zag manoeuvre between buoys

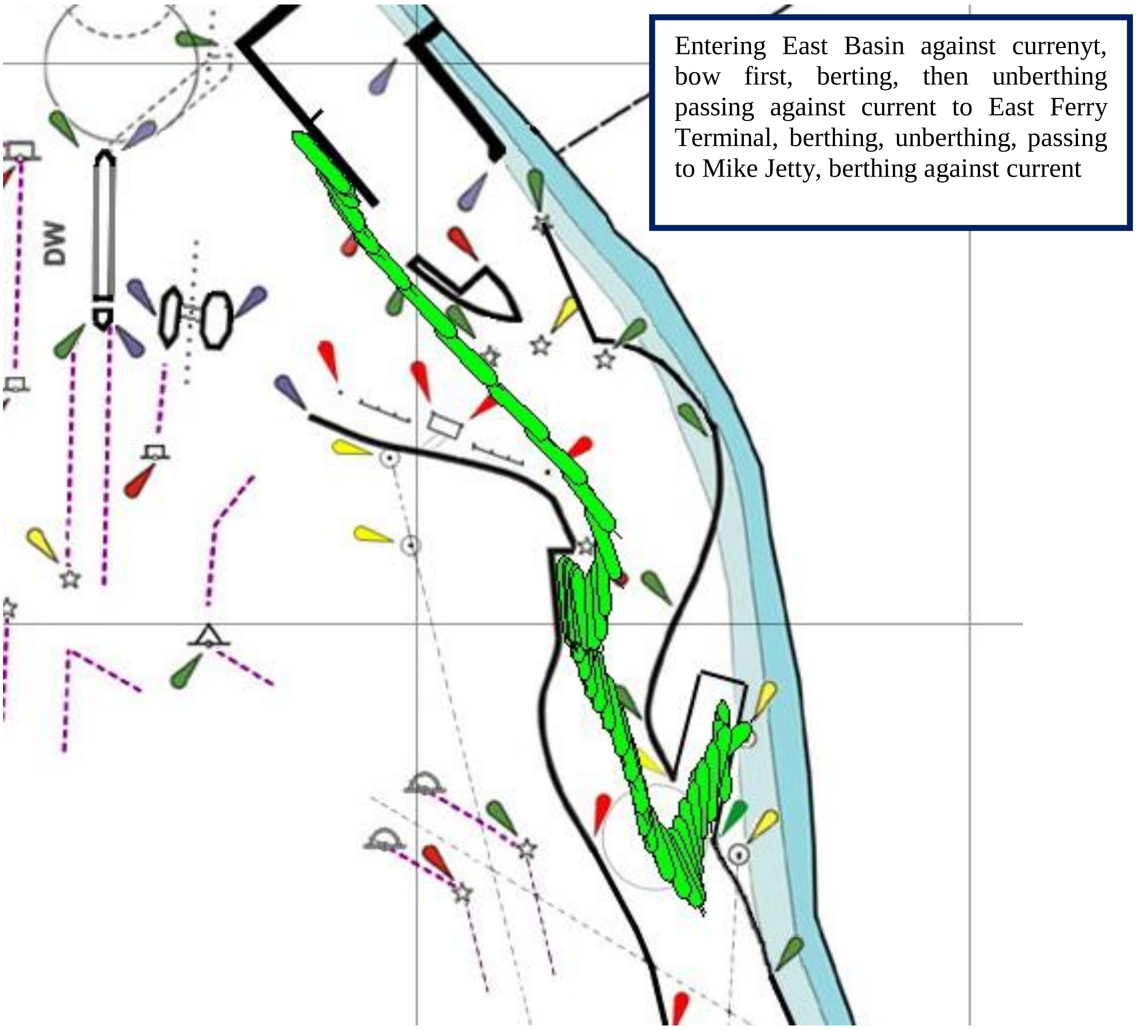
7.4. Exercises in the current in East River

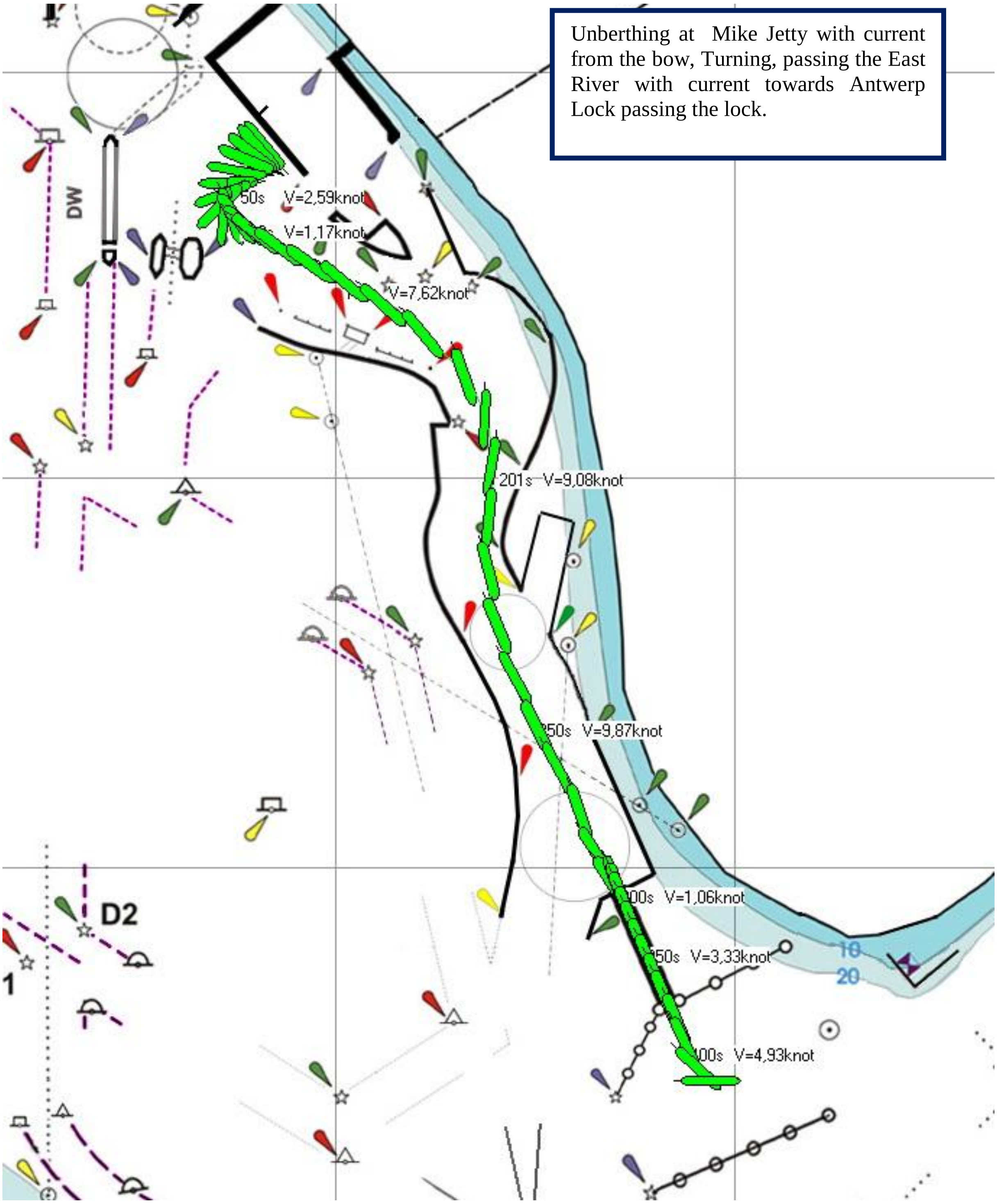


Unberthing at Mike Jetty, ente ring the East . mooring at East Ferry Terminal. Passing East River with current to East Basin, entering stern first. Unmooring, bething East Container Terminal. Passing Antverp Lock with current from stern.

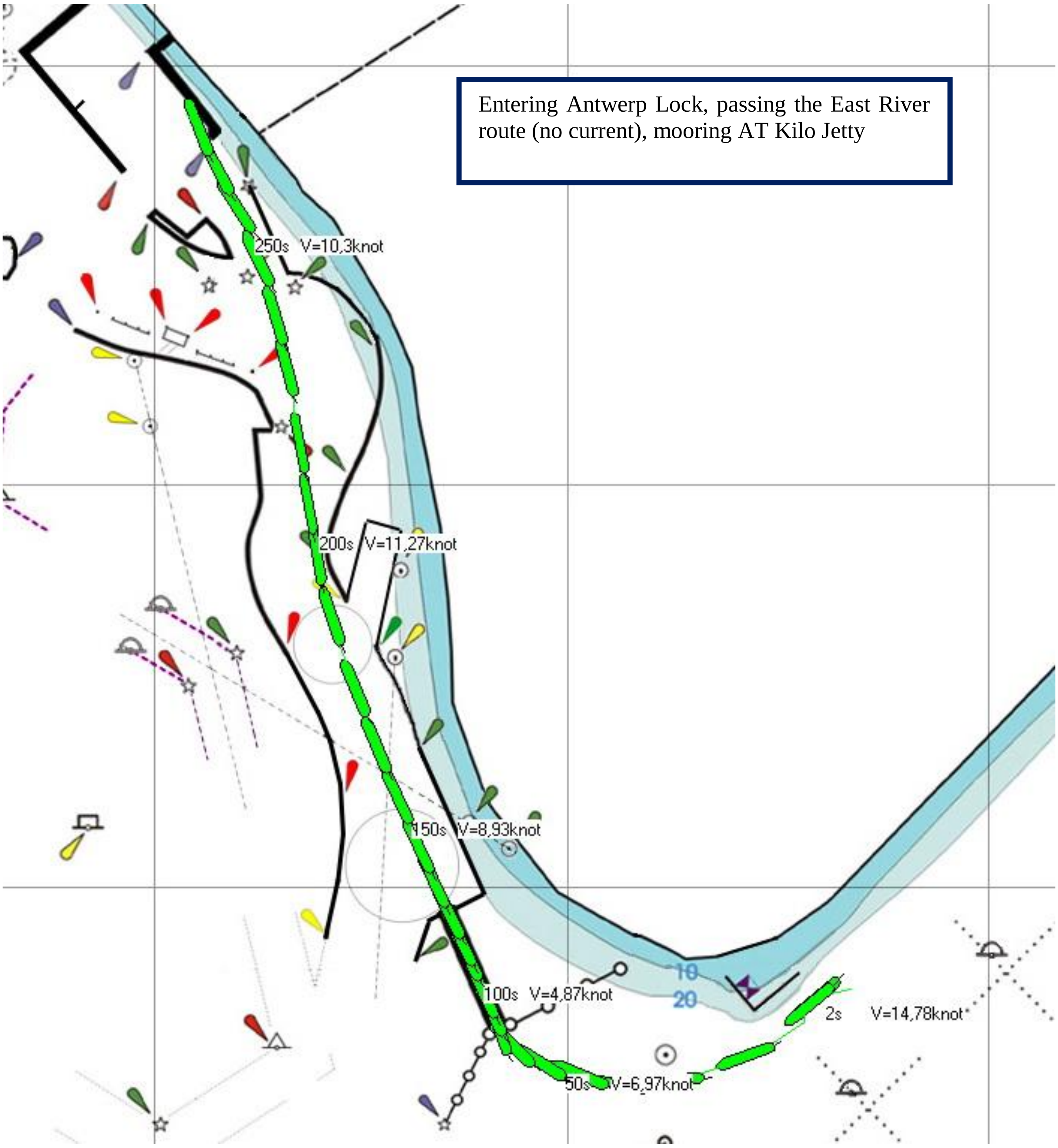


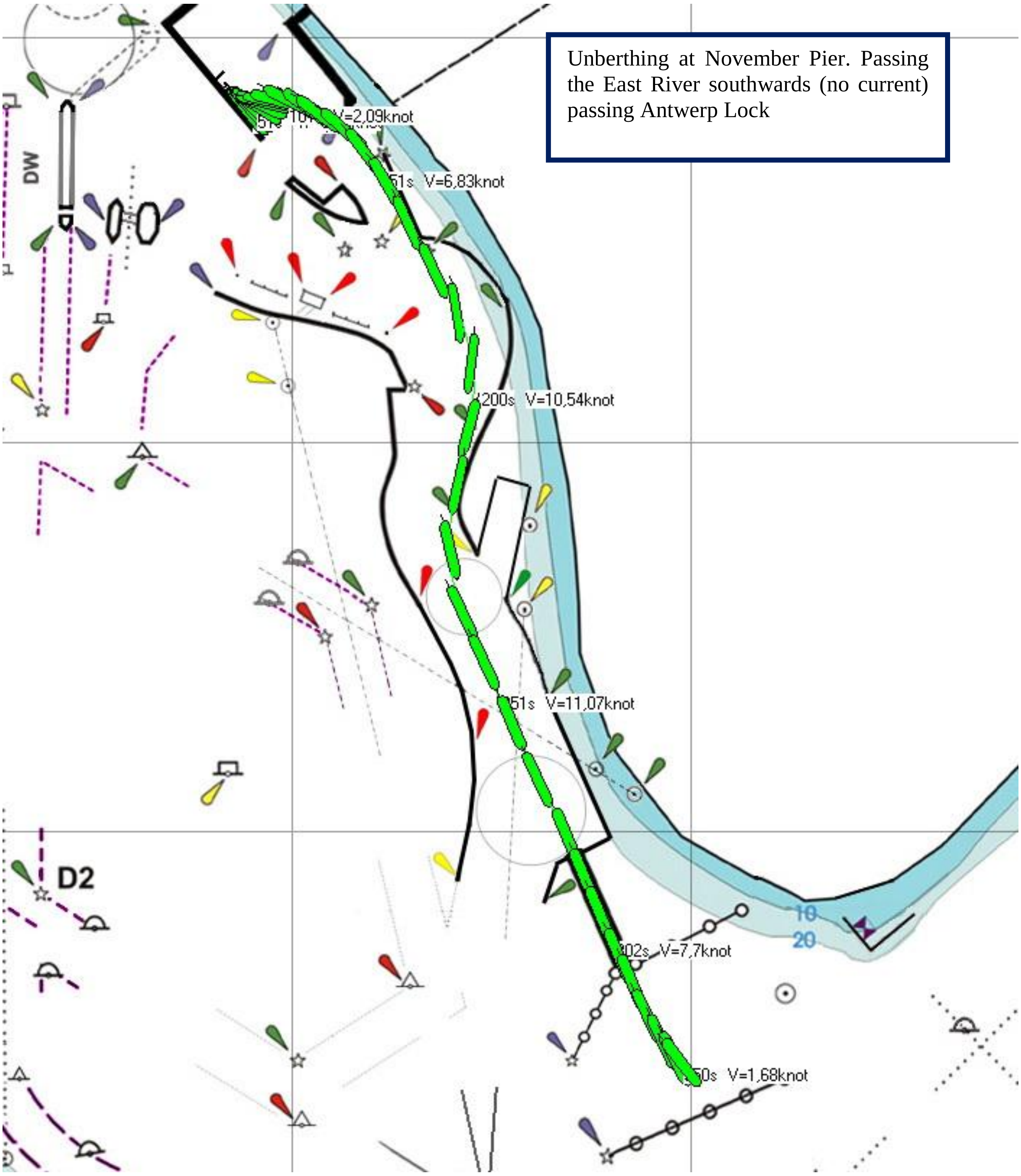
Passing Antwerp Lock and the East RIVER against current, mooring at East Ferry Terminal. Then berthing at Mike Jetty against current, turning, berthing with current from stern.

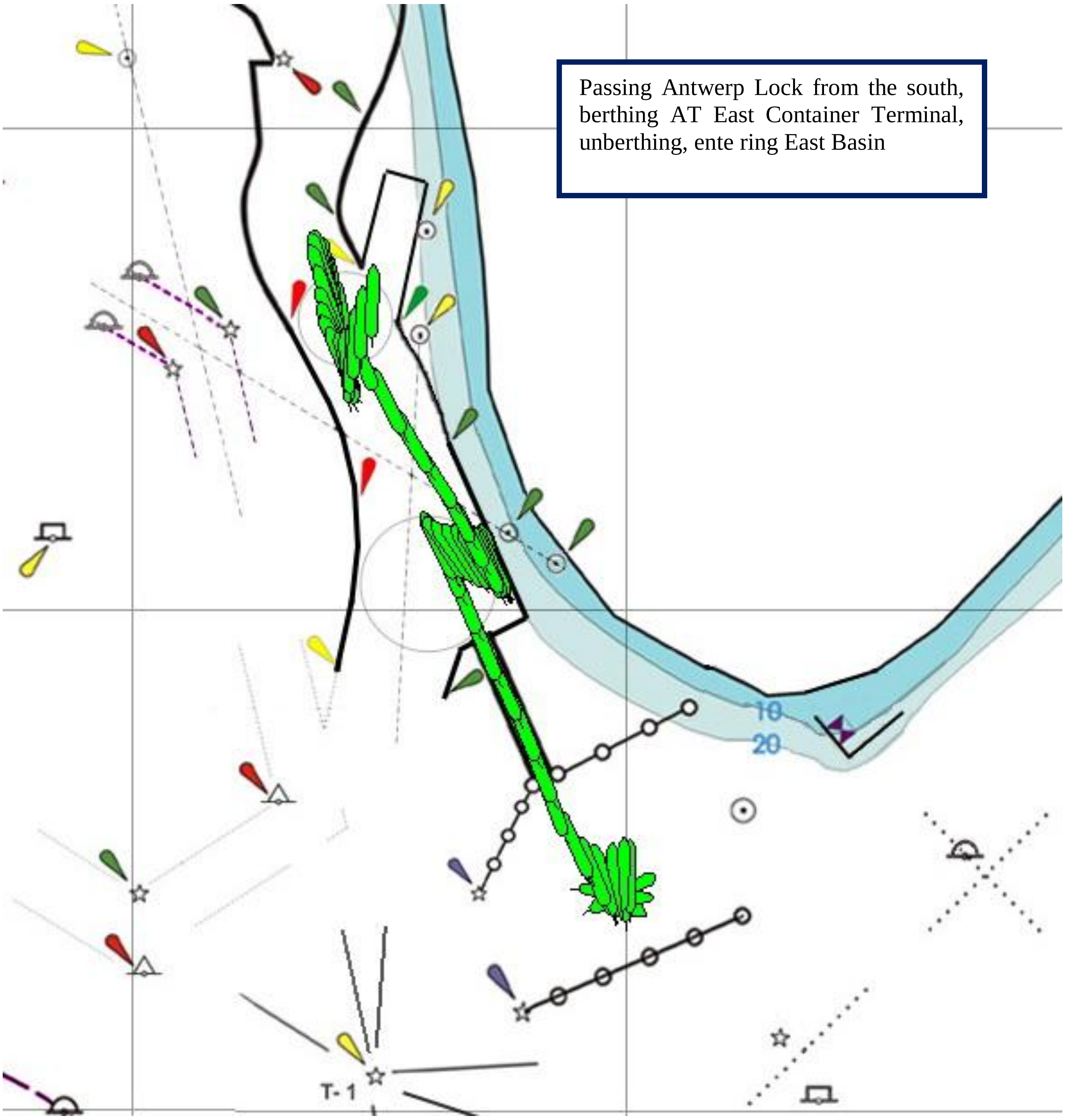

Entering East Basin against currenyt, bow first, berting, then unberthing passing against current to East Ferry Terminal, berthing, unberthing, passing to Mike Jetty, berthing against current
DW


Unberthing at Mike Jetty with current from the bow, Turning, passing the East River with current towards Antwerp Lock passing the lock.
50s V=2,59knot
V=1,17knot
V=7,62knot
201s V=9,08knot
50s V=9,87knot
00s V=1,06knot
50s V=3,33knot
00s V=4,93knot
DW
D2
10
20
1

7.5.Exercise including passage of the Antwerp lock

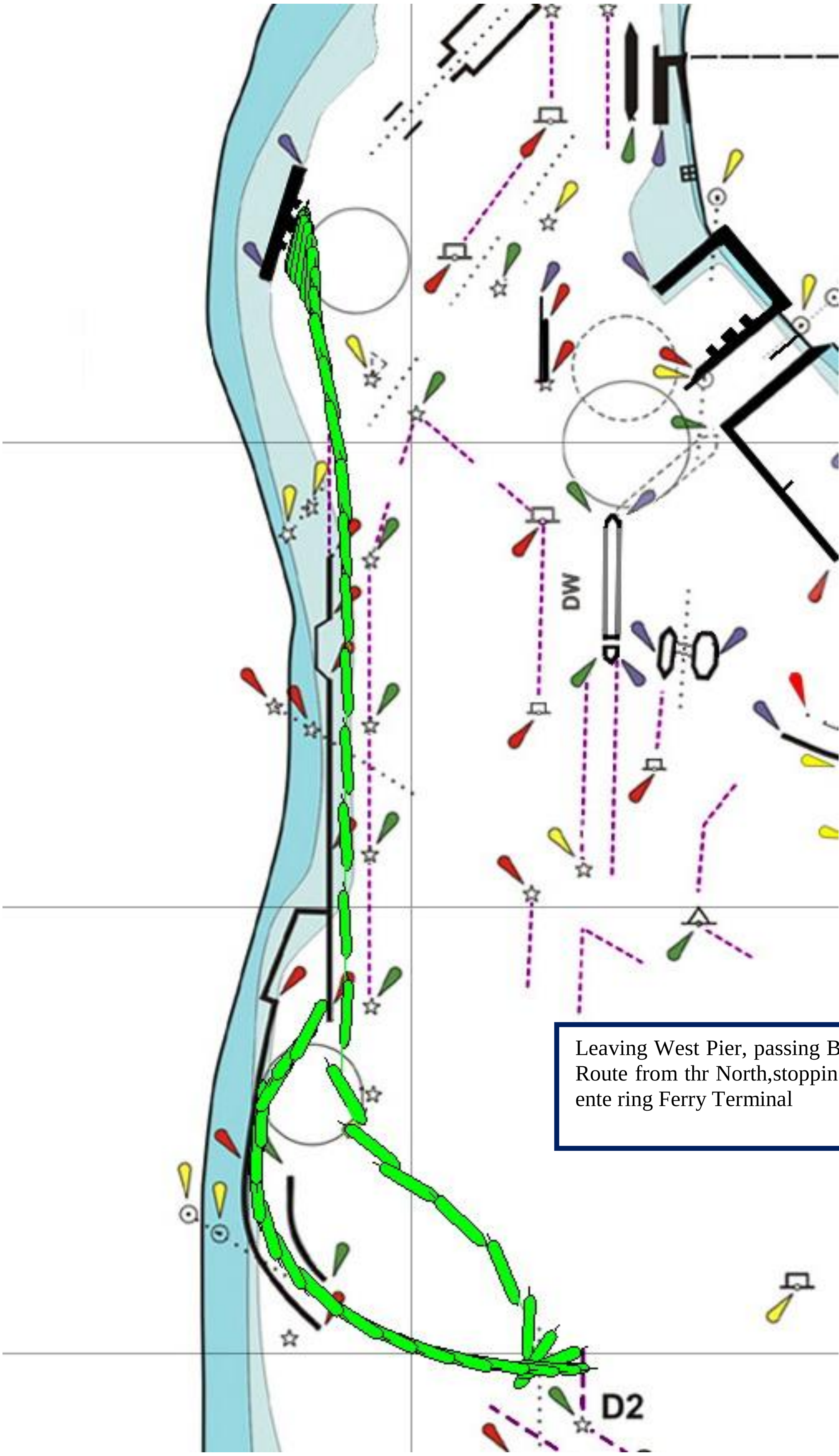



Unberthing at November Pier. Passing the East River southwards (no current) passing Antwerp Lock
V=2,09knot
V=6,83knot
200s V=10,54knot
51s V=11,07knot
V=7,7knot
V=1,68knot
DW
D2
10
20


Passing Antwerp Lock from the south, berthing AT East Container Terminal, unberthing, ente ring East Basin
10
20
T- 1

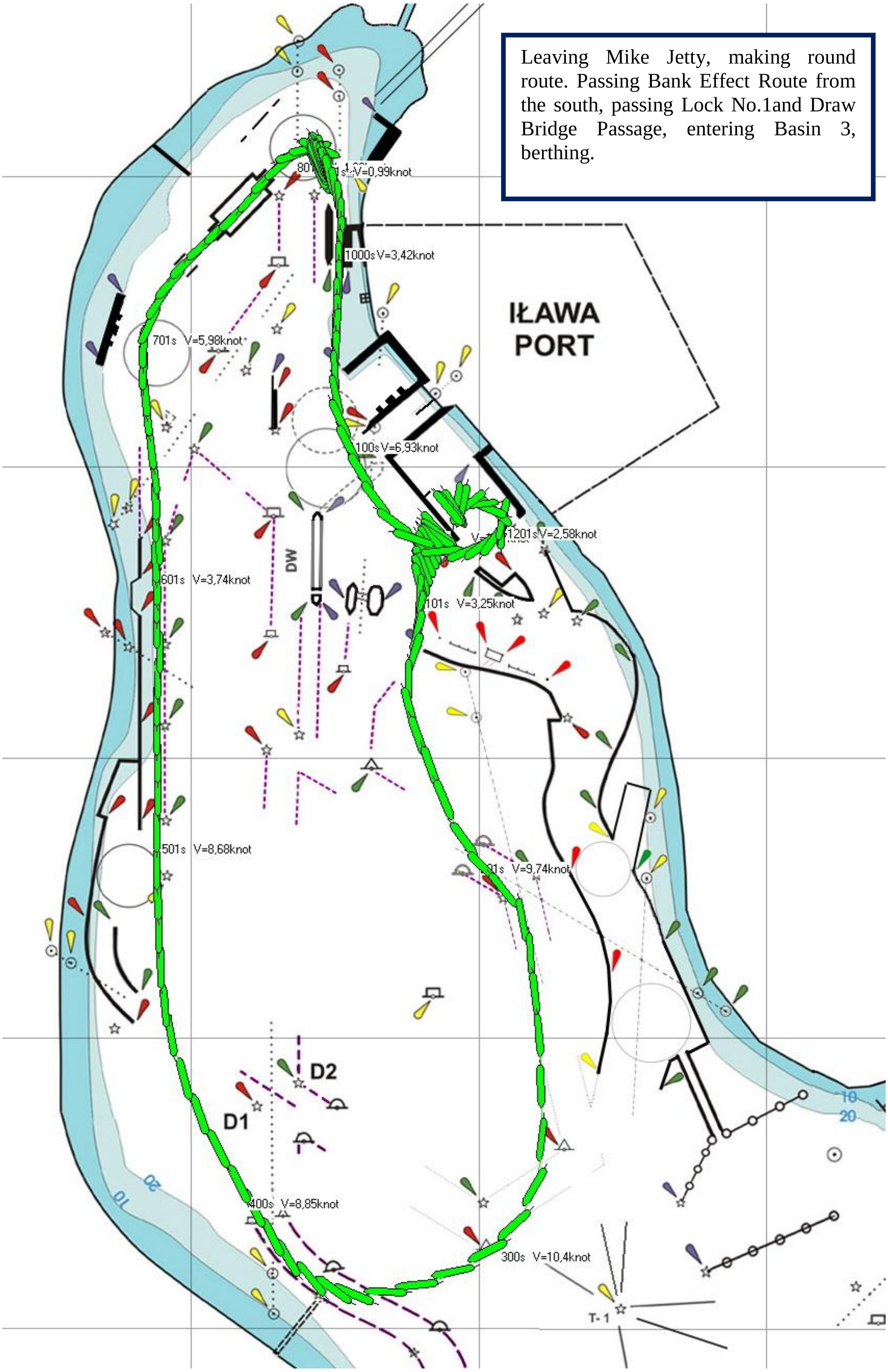
7.6.Exercises comprising negotiating different routes, including bank effect route

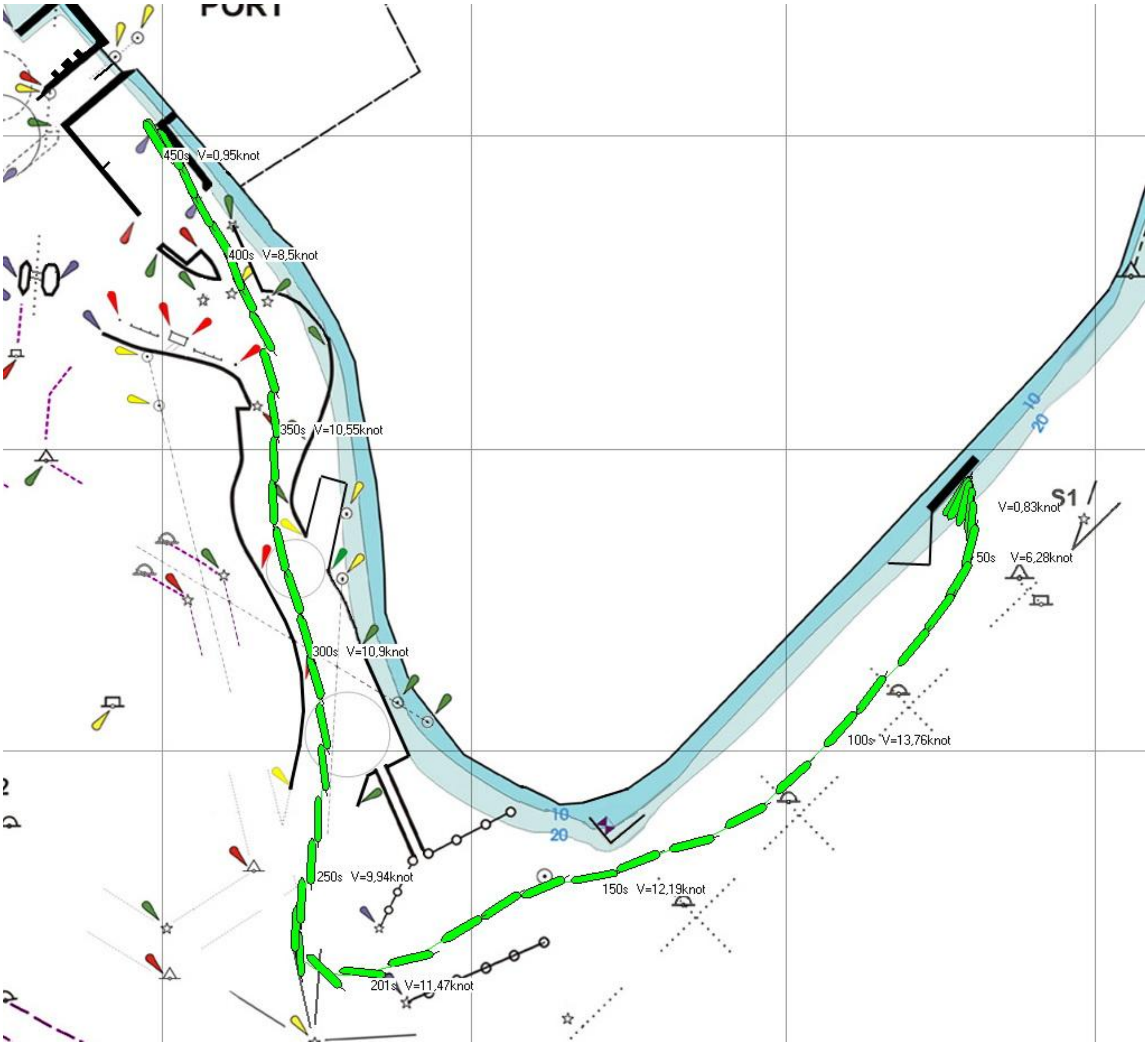
Leaving West Pier, passing Bank Effect Route, turning passing Deep Water Route



Leaving West Pier, passing Bank Effect Route from thr North,stopping, Turing, ente ring Ferry Terminal

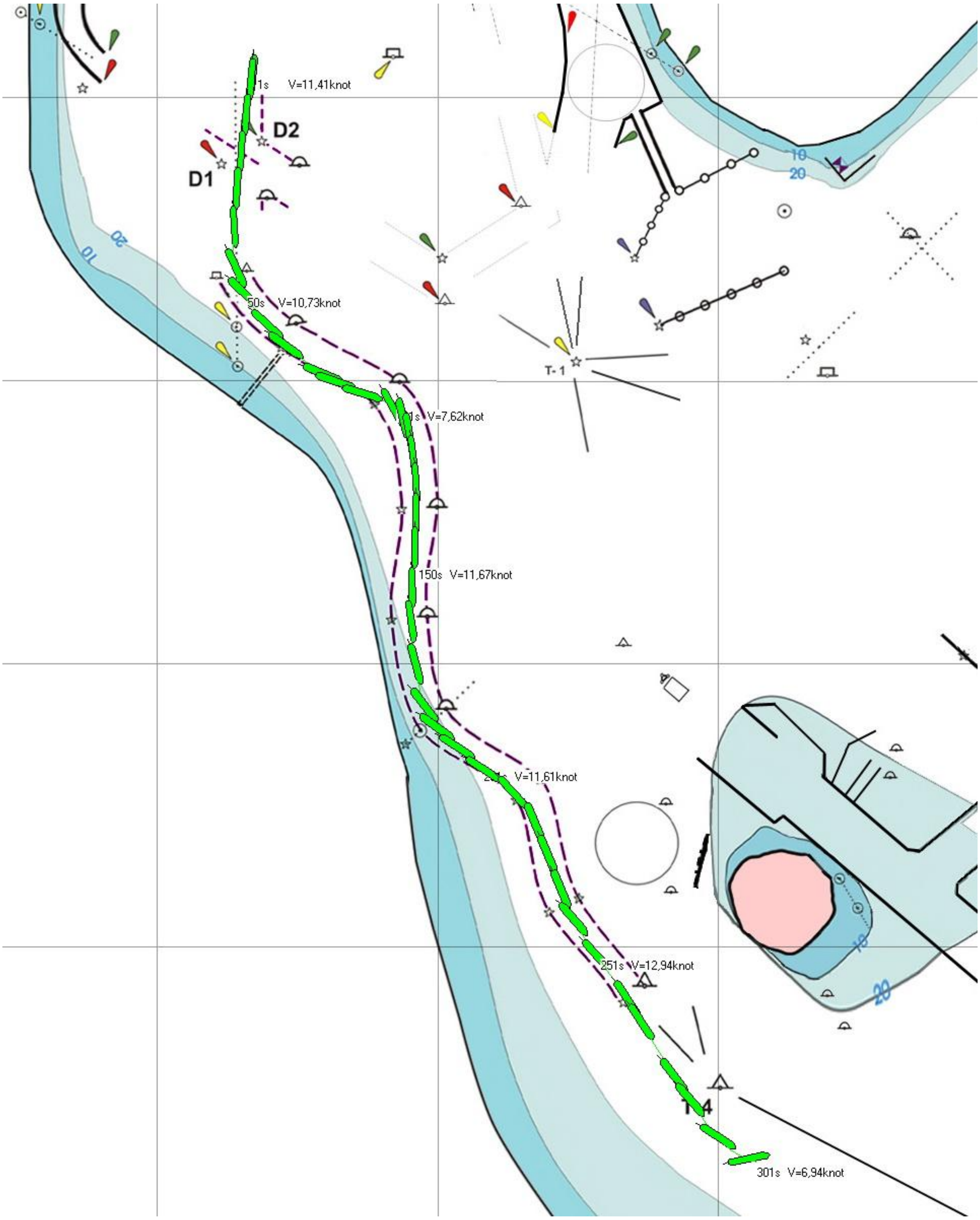
Leaving Mike Jetty, making round route. Passing Bank Effect Route from the south, passing Lock No.1and Draw Bridge Passage, entering Basin 3, berthing.



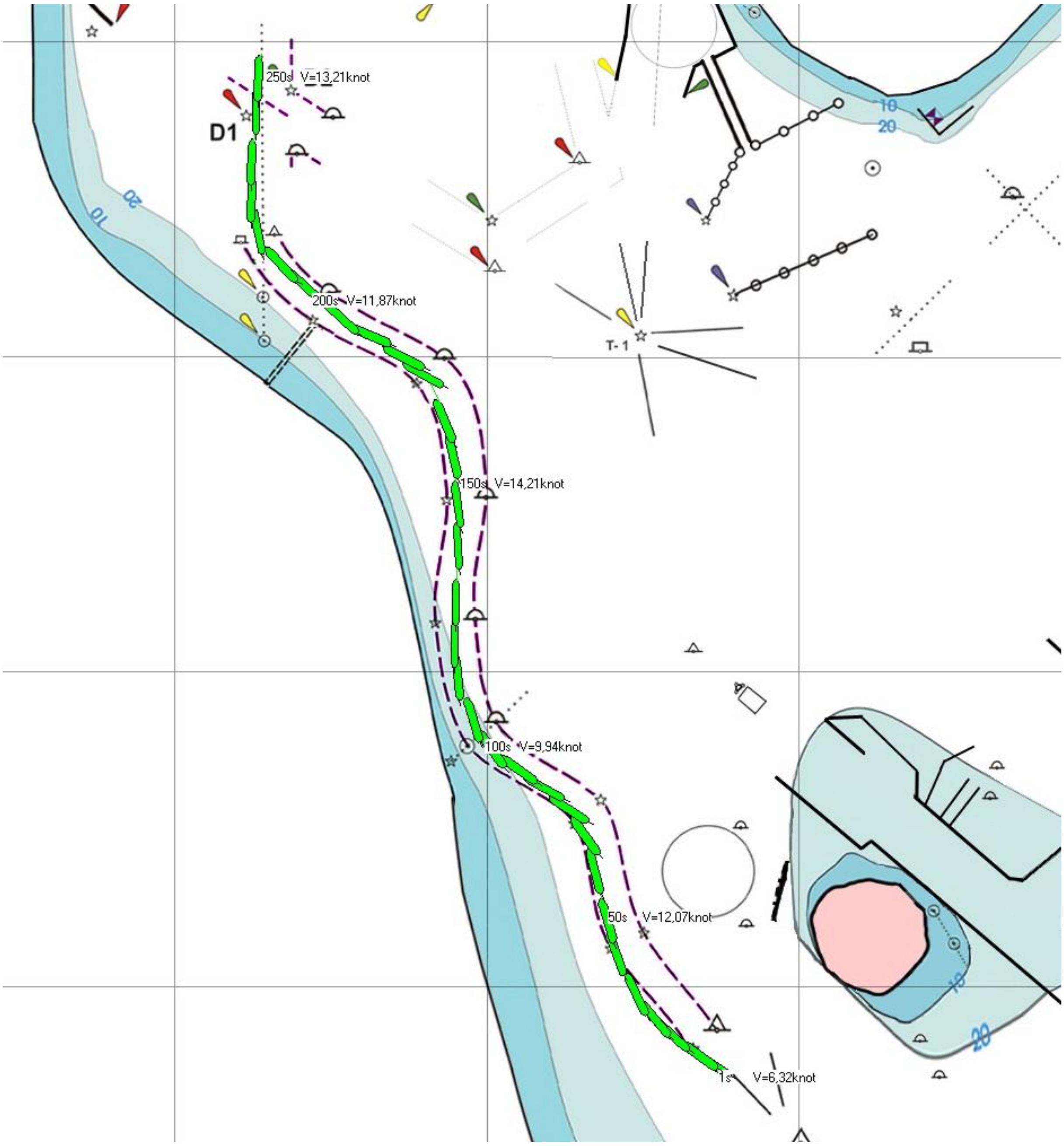


Passage the East River upstream (no current

7.7. Exercises including passing narrow curvilinear rote (Captains Canal)

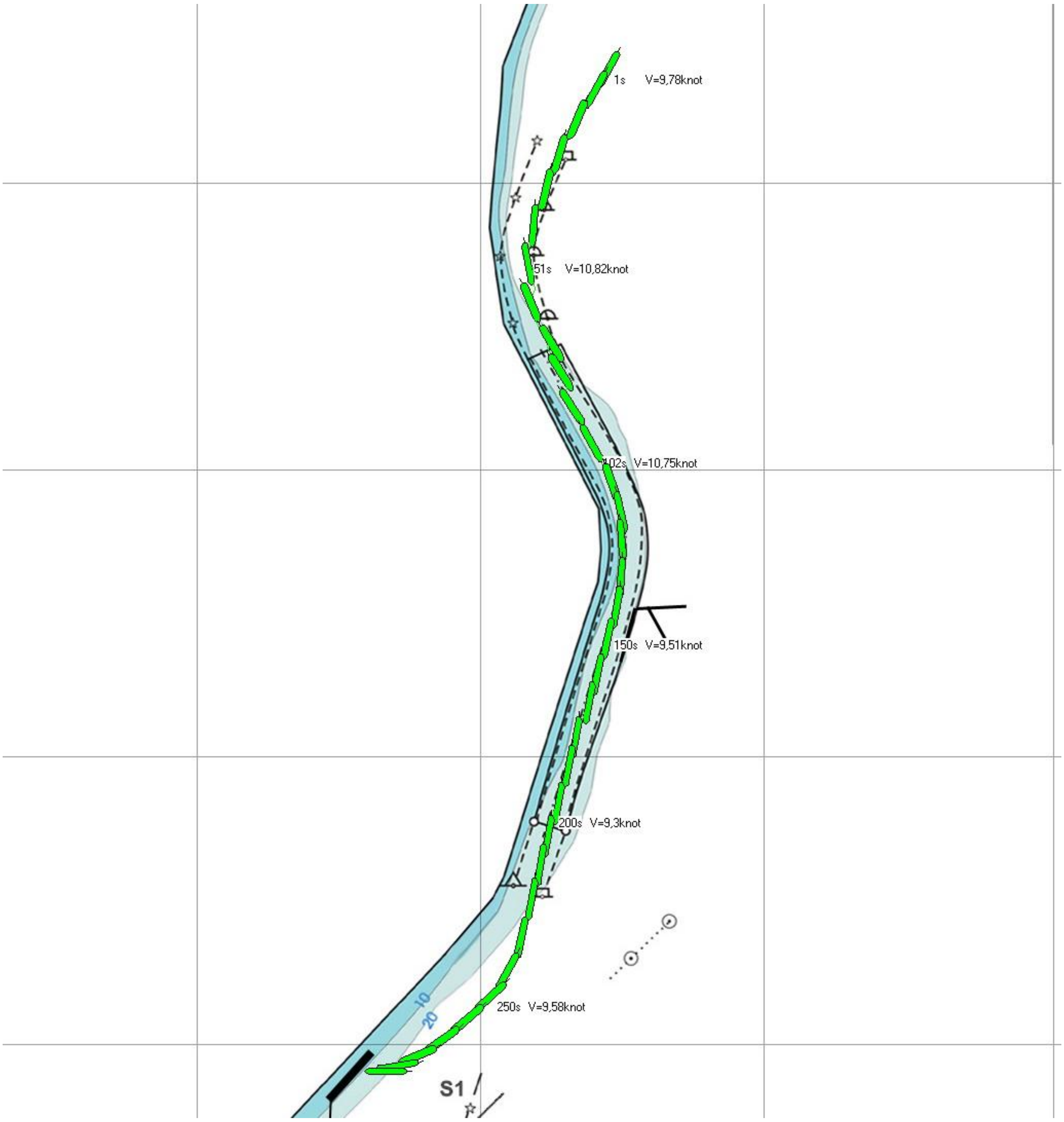


Passing Captain's Canal Route from the north



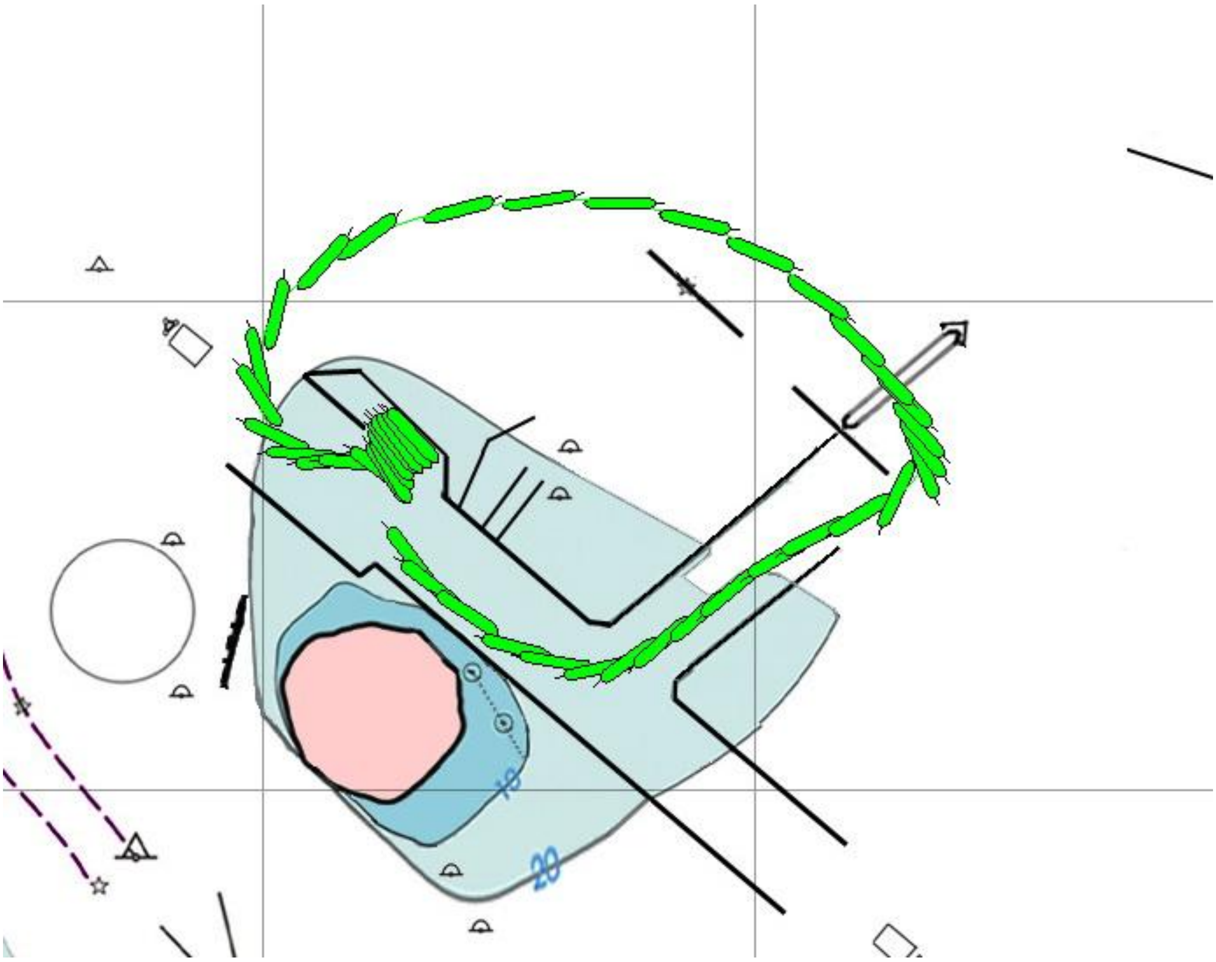
Passing Captain's Canal Route from the south

7.8. Exercise comprising passing a narrow canal with restricted cross-section (Pilots Canal)



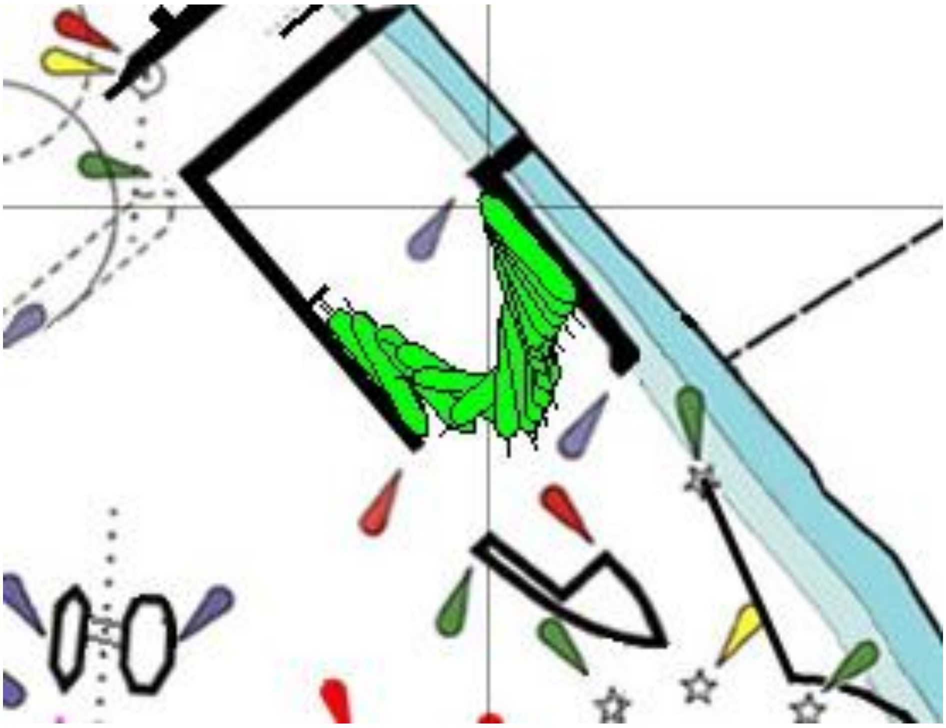
Passing the Pilots Canal Route (restricted cross-section), berthing at Oil Terminal

7.9. Exercise comprising feeling the effect of shallow water (Chiefs Canal)

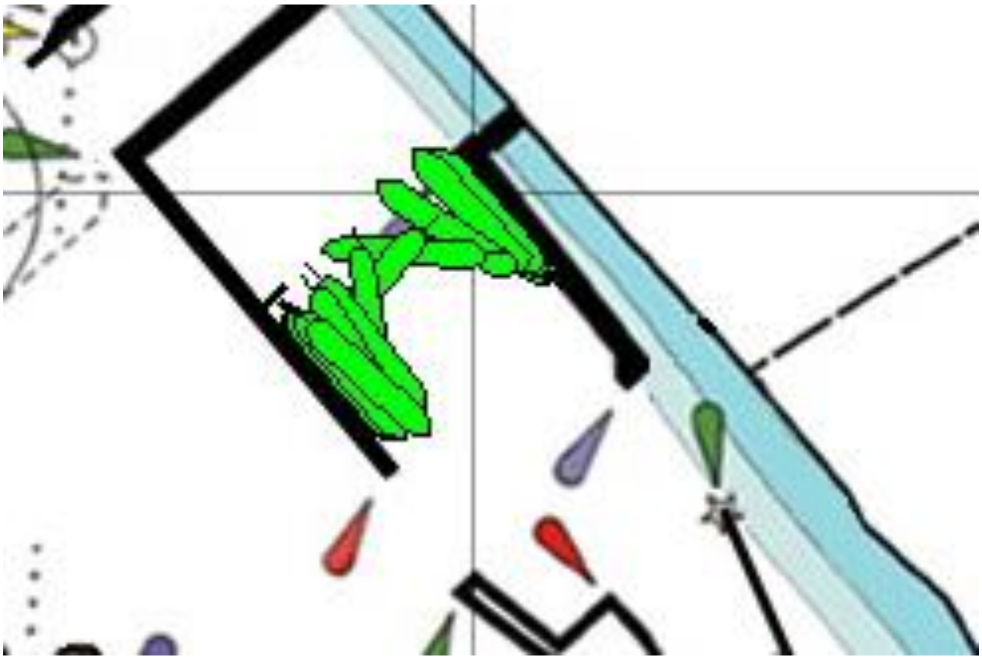


Passing Chiefs Canal (shallow water area. Making round trip, entering shallow water dock, berthing. Current created by movable current generator from astern.

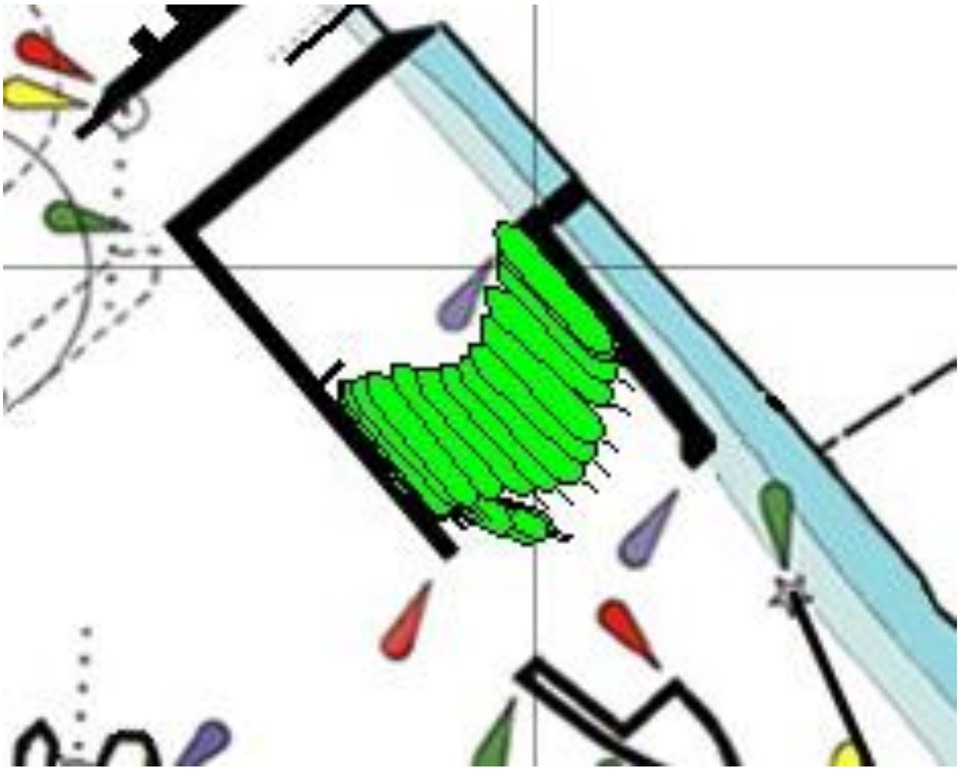
7.10. Exercises intended to learn manoeuvring the ship in harbour basin (Basin No.3)



Unberthing November Jetty, Turing inside Basin 3, berthing Kilo jetty

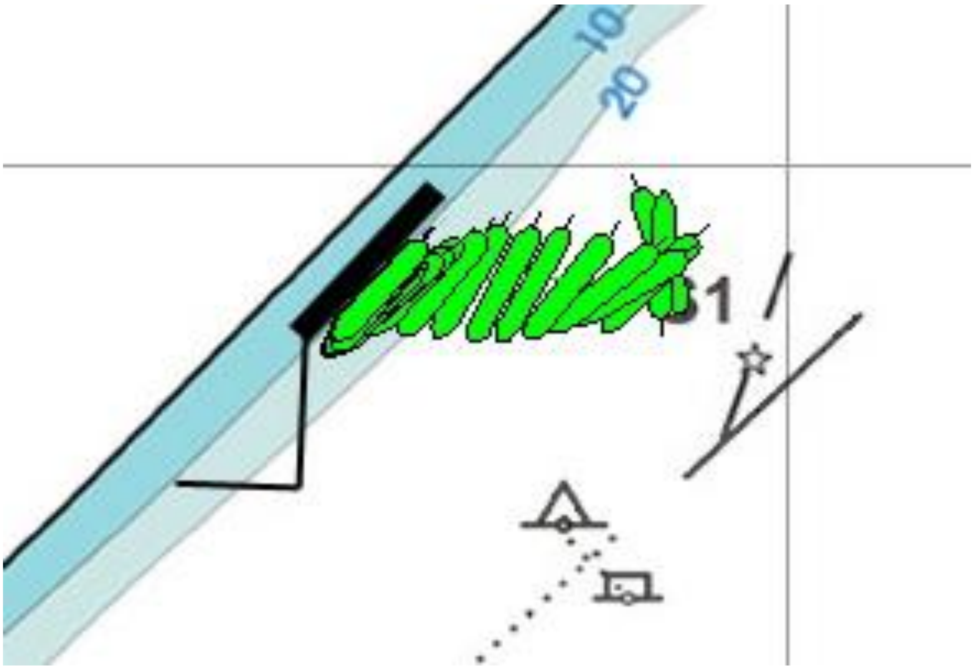


Unberthing November Jetty, Turing inside Basin 3, berthing Kilo jetty

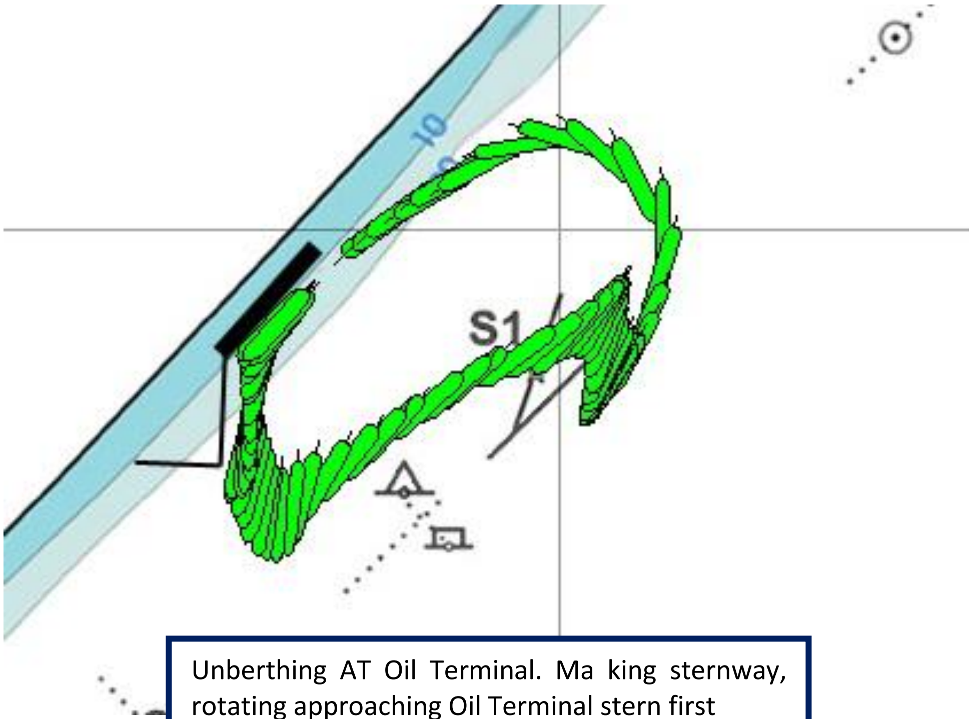


Unberthing November Jetty, berthing Kilo jetty, no rotation.

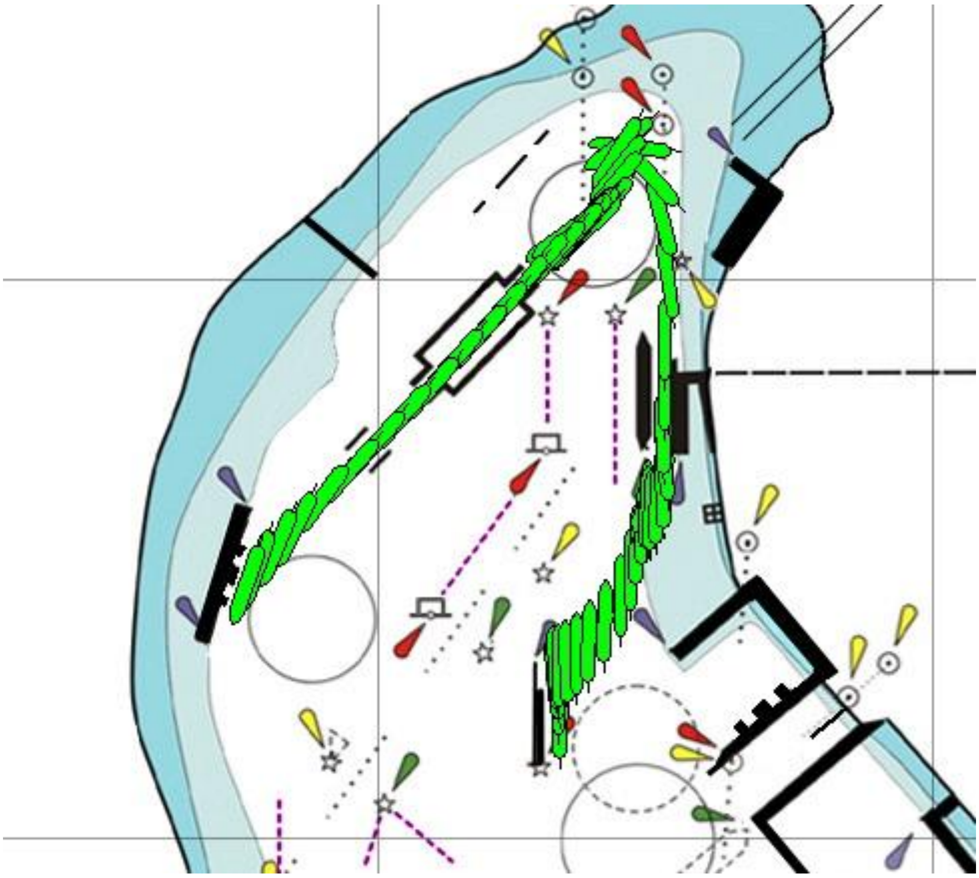
7.11. Exercises intended to learn about berthing, unberthing and passing narrow passages (Oil Terminal, Lock No.1 and Draw Bridge Passage)



Berthing at Oil Terminal



Unberthing AT Oil Terminal. Ma king sternway, rotating approaching Oil Terminal stern first



Unberthing Isle Terminal, passing Draw Bridge Passage, turning, passing the Lock 1. Berthing West Pier

7.12. Sample photographs of the model taken during the course


DORCHESTER


HESTER LADY

APPENDIX

TEXT OF THE SPECIALIZED LECTURE ON THE CHARACTERISTICS AND OPERATION OF SHIPS EQUIPPED WITH AZIMUTHING PROPULSION DEVICES

CHAPTER S.1 SHIPS EQUIPPED WITH AZIMUTHING PROPULSION DEVICES -

1. GENERAL DESCRIPTION OF PODDED PROPULSION DEVICES

Azimuthing propulsion devices are known for quite a long time. The most popular azimuthing propulsion device is outboard motor used for many years for driving small boats and yachts acting at the same time as propulsion as well as steering device. This idea was later followed by installing propulsion motor inside the hull with Z-form transmission where the propeller could be rotated around vertical axis. This solution allowed to install motors of higher power than outboard motors. Later-on this type of propulsion device delveloped into Schottel propeller allowing to install even higher power (Fig.1.)

Fig. 1. Schottel propeller

In the early thirties of the last century cycloidal propellers were invented and manufactures, the main representative of which was Voith-Schneider propeller (Fig.2). rotating around vertical axis and with several vertical blades the angle of attack of which is controlled by special mechanism. This type of propulsion device act at the same time as steering device because thrust of the propeller could be created to any direction.

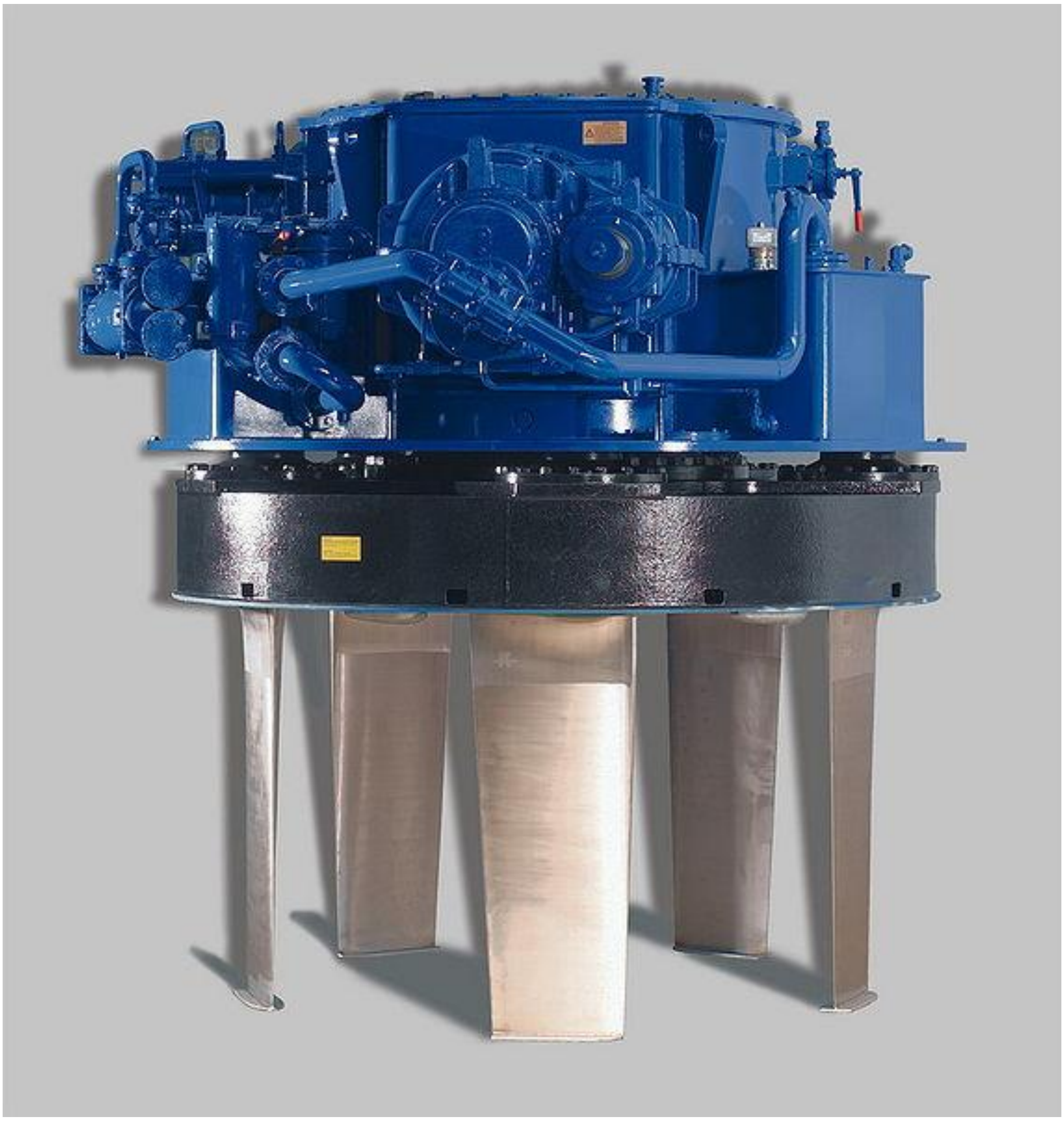


Fig.2. Voith-Schneider propeller

However all the mentioned azimuthing propulsion devices were installed in rather small ships, because power available was always limited. The real revolution in azimuthing propulsion devices took place in the last decade of the twentieth century when azimuthing podded propulsors with a power up to 25MW per unit have been developed and put into service.

Podded propulsors are characterized by two main qualities:

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

The pod propulsion consist of central pod with electric motor inside of it, driving one or more propellers of the pushing or pulling type or both (Fig.3). The pod could be rotated 360^0

around the vertical axis, therefore full propeller thrust could be used in any direction providing large turning force without necessity of installation of any rudder.

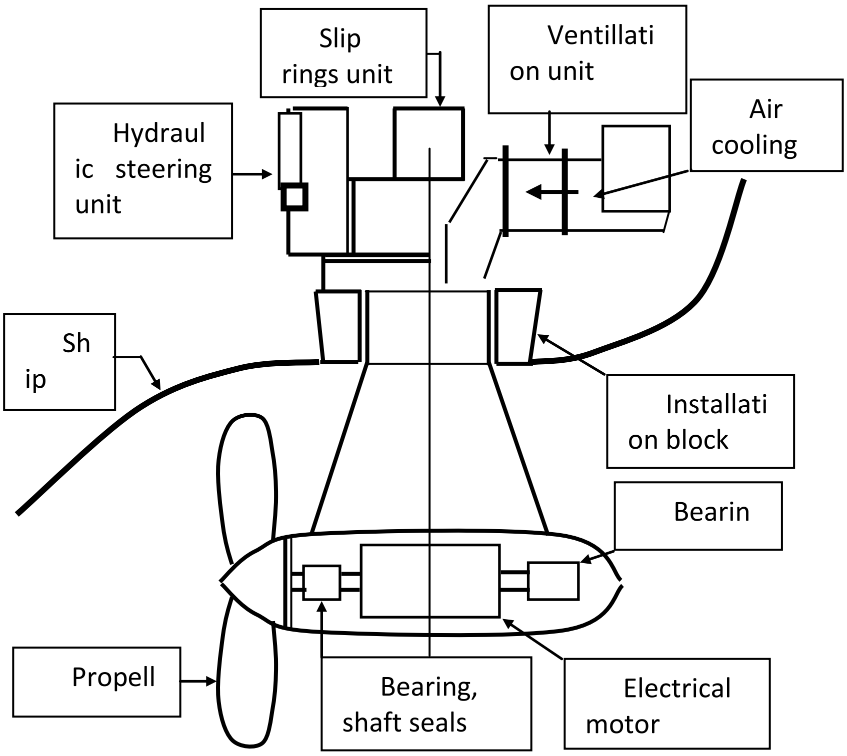


Fig.3. Scheme of the pod drive

As mentioned, the principle of pod drive is known for many years, but until quite recently, this type of propulsion was constructed using mechanical gear and the power of such drives was limited. The advent of high powered fully submerged electric motors that could be installed inside of the nacelle made this revolutionary construction possible.

Finland ABB industry and Kverner Masa Yards, Rolls-Royce–Kamewa and Siemens-Schottel are pioniering companies proliferating development and application of podded propulsion and currently vessels fitted with azimuting propulsion constitute 6.9% of all vessels, the largest groups being tugs, off-shore vessels and cruise liners. Also some icebreakers were equipped with azimuting propulsion devices.

The newest and largest cruise liner Queen Mary 2 is fitted with four pods of 21.5 MW each. Two of them are fixed and two rotatable. Most ships, however, are fitted with two rotatable pods build by one of three companies that are currently manufacturing pods of the power up to 30 MW: The construction of pods manufactured by the above companies differs slightly but the principle is always the same; it is schematically shown in fig 3. Single pods are installed in double-ended ferries or double-acting tankers.

Fig.4 shows classical podded propulsor as defined above. However, there are known many variations of this type propulsors with pushing or pulling propellers, tandem or contra-rotating propellers. Some examples of such propulsion devices are shown in figs 5 and 6.

Fig. 4. Typical twin podded propulsor with pulling propellers

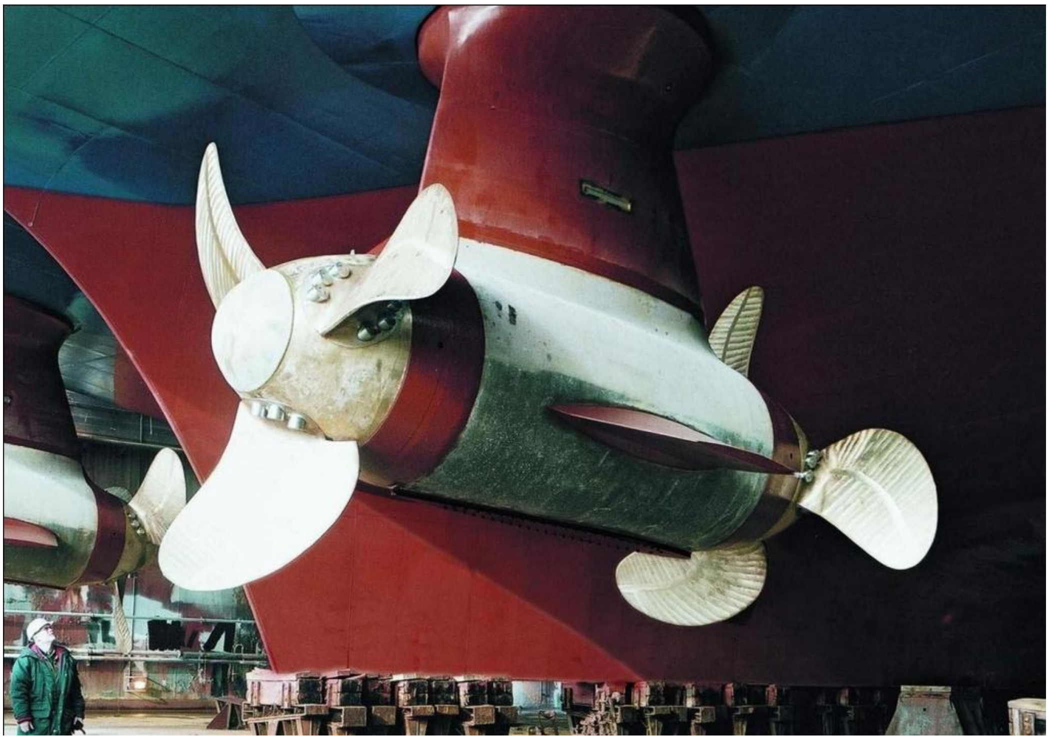


Fig. 5. Twin pod propulsion with contra-rotwting propellers

Fig. 6.Podded drive with tandem propellers

Podded propellers are are as a rule installed in pairs because if single unit is installed the ship is usually dynamically unstable and difficult to control. Sometimes, however three or four pods are installed, and example of such construction is shown in fig. 6A.

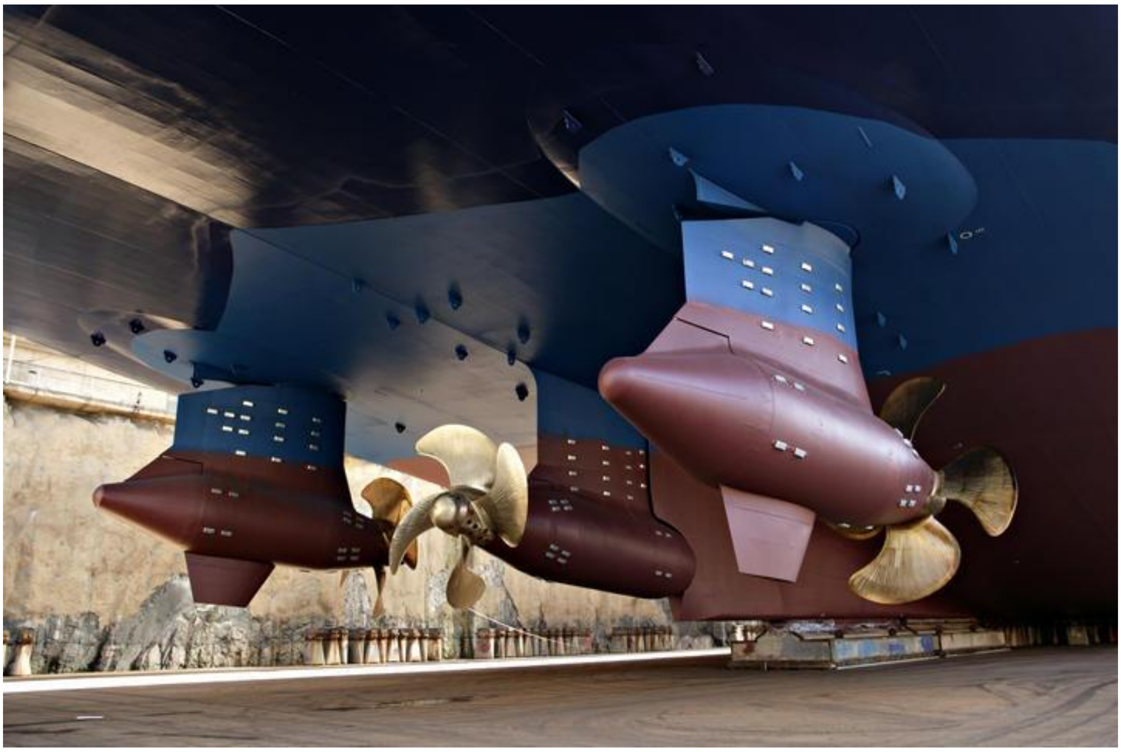


Fig.6A. Three pod propulsion system one central pod fixed, two pods rotatable

Example of hybrid construction where poddeed propeller is combined with fixed propellers is shown in fig. 7

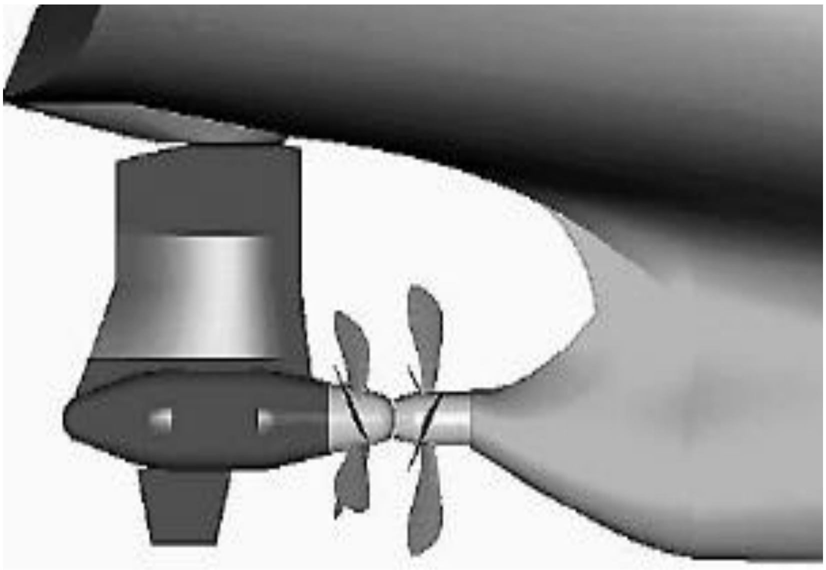


Fig. 7 Hybrid construction of podded drive.

2. ADVANTAGES , DISADVANTAGES OF PODDED PROPULSORS AND DESIGN CONSEQUENCES

The advantages of pod drives in comparison with traditional diesel propelled vesel with fixed propellers are:

1. Elimination of shaft line, steering gear, rudder and stern thrusters a
2. More cargo space because of possible re-arrangement of machinery space and utilization this space for other purposes
3. Better manoeuvrability because thrust of pod could be delivered to any direction
4. Better reversing capability and low speed and astern performance
5. Lower noise level and less vibrations
6. Smaller power required in twin pod driven ships

The disadvantages are:

1. Higher capital cost
2. Generally slightly lower propulsion efficiency and loss of power because of diesel electric propulsion
3. Stern part of ship must be re-designed in order to accommodate pods
4. Limitation of power available for single pod (up to about 25 MW at present)

Installation of podded propulsion has important impact on the design features of the ship. In particular as diesel-electric propulsion system is required, internal space of the ship may be arranged differently as in conventional diesel single or twin screw propulsion, in general more convenient and saving in space (see fig. 8).

The other consequence is the form of the stern part of the hull that with the podded propulsion units installed must be flattened in order to accommodate pods and fitted with skegs or fins (fig. 9) in order to assure sufficient course-keeping ability (see paragraph 3).

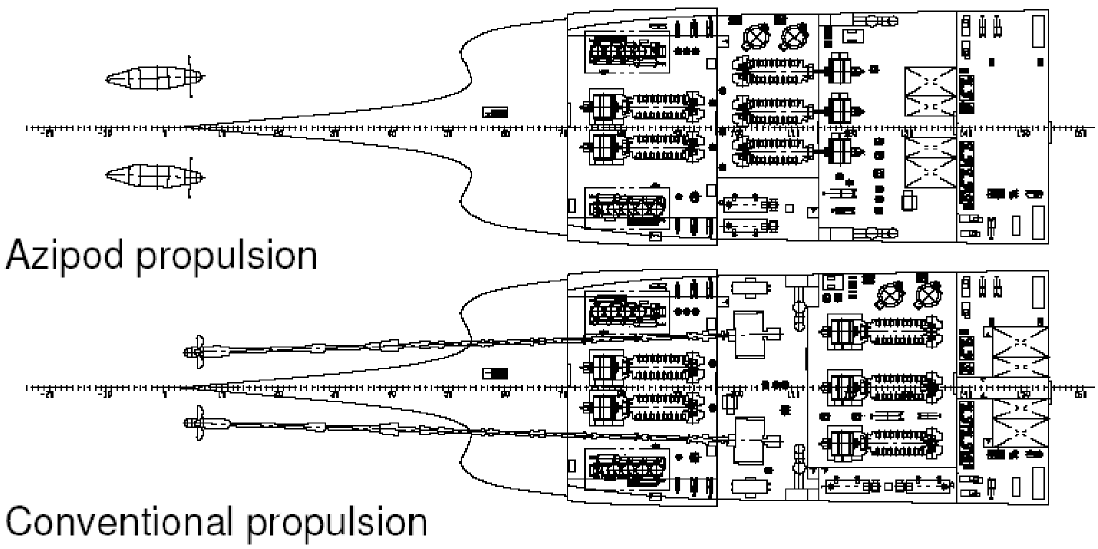


Fig.8 Comparison of internal arrangement a ship equipped with podded propulsion units and with conventional propulsion.

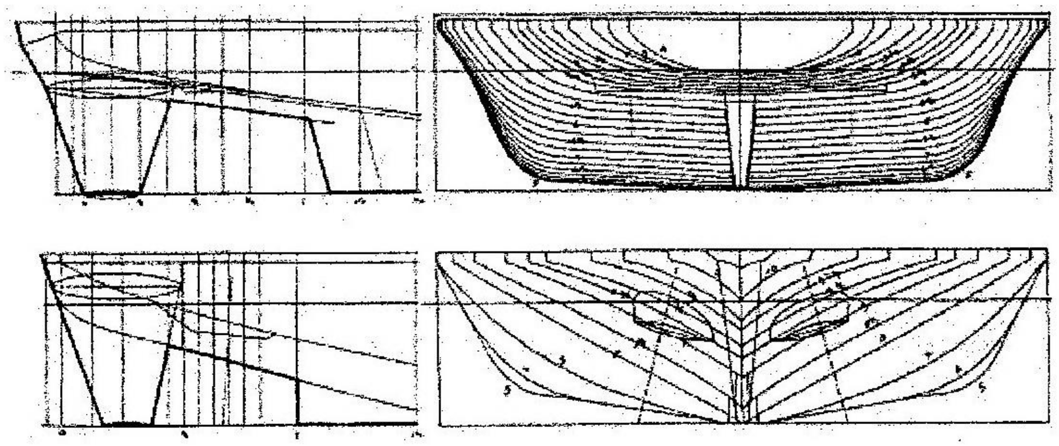


Fig.9. Recommended form of stern part of ships suitable for accommodation of pods

Podded propulsors are well suited for (Mewis 2001):

- Cruise liners
- Ro-Ro passenger ferries
- Icebreakers
- Off-shore supply vessels
- Tugs

Not well suited for:

- Container vessels
- Bulk carriers
- Tankers

3. HYDRODYNAMIC CHARACTERISTICS OF PODDED DRIVES

The propulsion efficiency of pod drives does not appear to be a very important factor in the selection of podded drive as a main propulsion device. Other considerations, and in particular manoeuvring characteristics of pod drived may play decisive role.

Comparison of efficiency of single pod drive with traditional single screw propulsion shows that the efficiency of pod drive is little lower. Measurements performed in HSVA (Mewis 2001) show that this difference maybe about 5% (fig. 10).

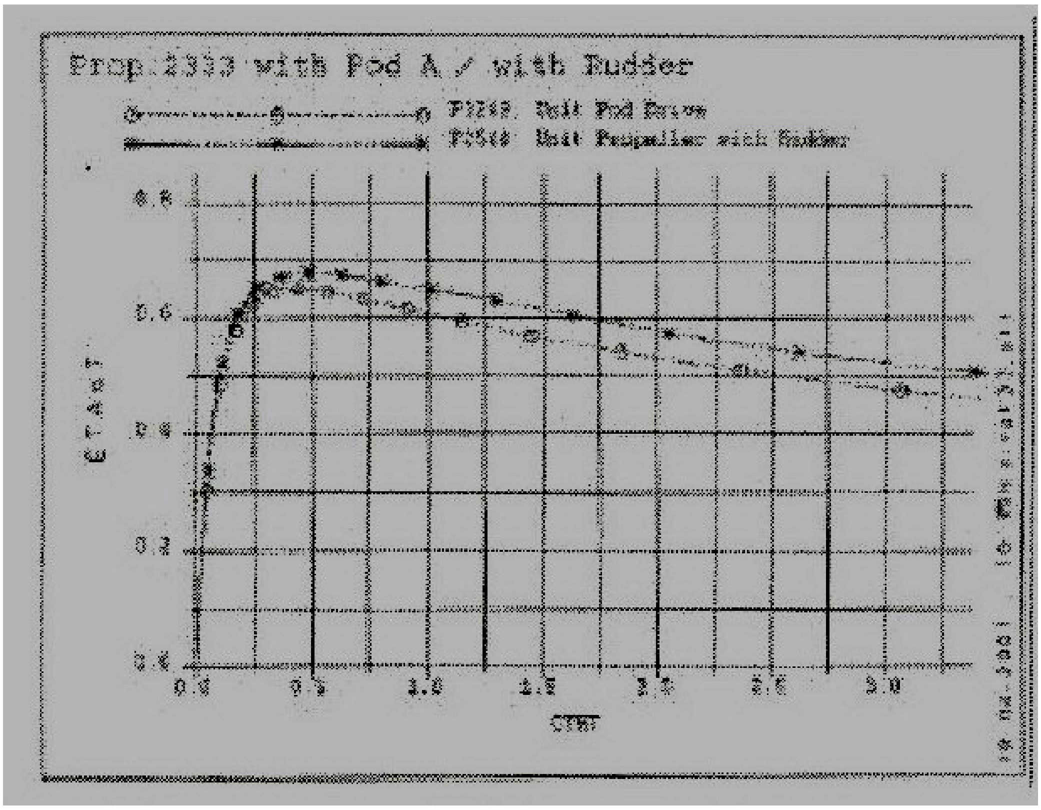


Fig. 10. Comparison of propulsive efficiency of single pod drive (open water condition) fixed propeller with rudder.

In general pod driven single screw ship would have lower propulsion efficiency than conventional single screw ship. By optimizing ship form this loss may be , however, reduced. Twin pod driven ships generally would have also little smaller propulsive efficiency in comparison with conventional twin screw ships, but additional resistance of appendages in conventional twin screw ships may cause that the total power requirement in pod driven ship may be almost the same or only slightly smaller.

As pod propulsors may by rotated, in certain positions of pod propulsor propeller axis is at certain angle to the incoming flow (Fig.11). The effect of the angle of water inflow to the POD is shown in fig.12. The data were obtained from the tests of ROPAX model fitted with PODs on PMM facility (Kanar et al 2002). Fig 12 shows that this angle depends on drift angle and on the position of the POD whether it is on leeward side or on the starboard side.

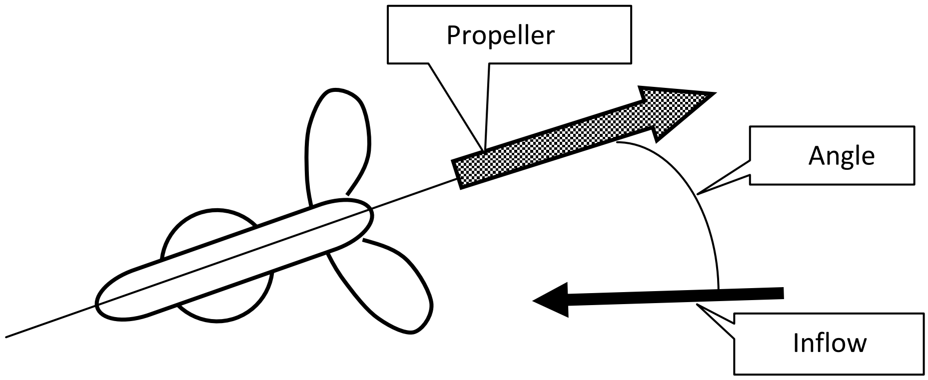


Fig. 11. Pod in oblique flow

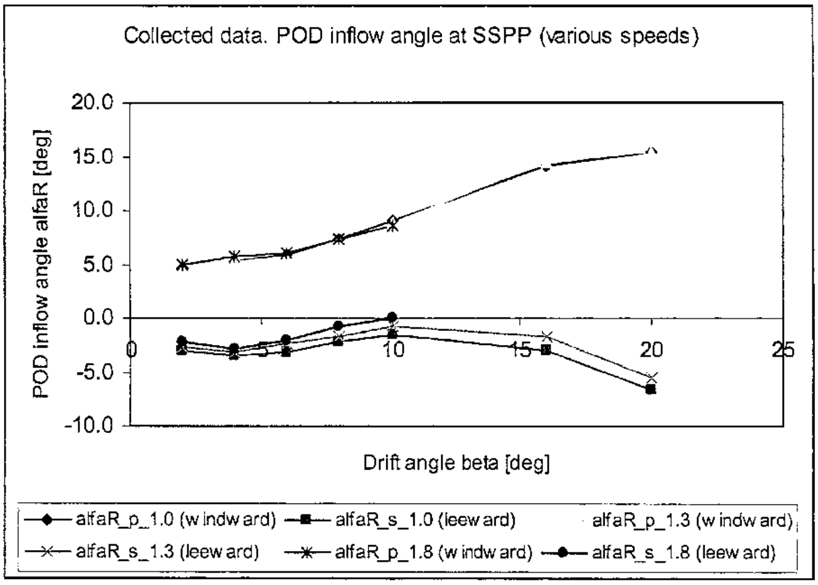


Fig.12. The effect of angle of water inflow to POD. (Kanar et al 2002)

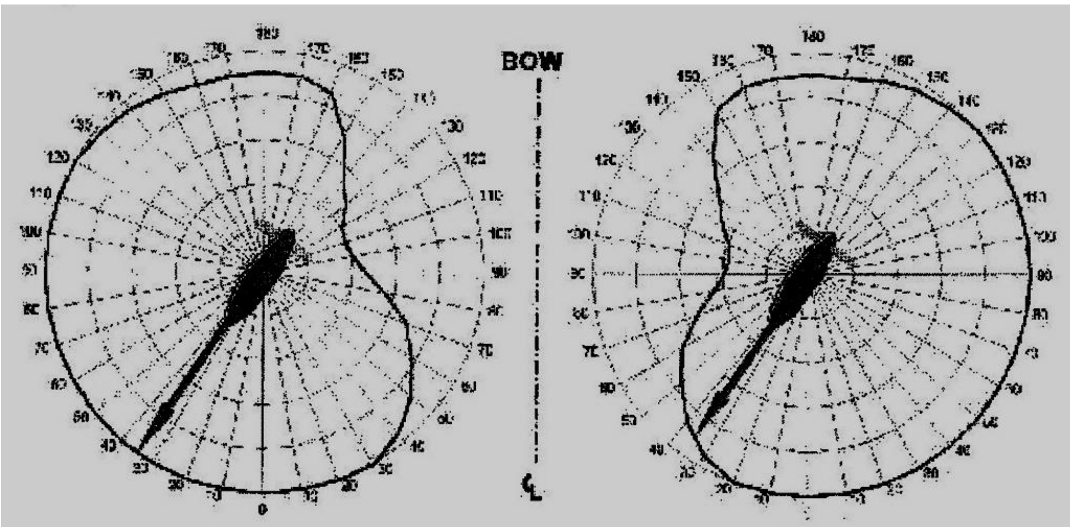


Fig. 13. Relation between pod's propeller thrust and angle of pod deflection

The relation between pod's propeller thrust and the angle of pod deflection in twin pods propulsion is shown in fig.13. It is seen that in certain position of the pod thrust of the propeller is substantially reduced because the propeller race is then directed against the hull or against the skeg or fin, as shown in fig 14. This is different for port side and starboard side because of the direction of rotation of the propeller that might be right handed or left handed. (de Mello Petey 2008).

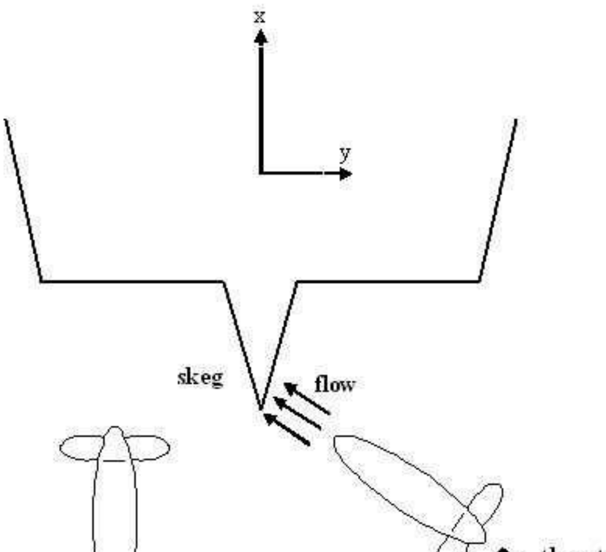


Fig.14. Pod working in the position where propeller race is against skeg

In this position ship is supposed to turn to port but pod propeller race is directed against skeg generating force opposing the propeller thrust. In some cases this effect might reduce pod thrust to zero, so that the ship is not turning at all.

Strong interaction may be expected when one POD is working in the propeller slipstream of the other one and this is affecting considerably thrust and torque. This may happen when PODs are deflected to angles between about 60 to 120 degrees both sides (Fig.15).This may be the case with PODs fitted with pulling propellers as well as fitted with pushing propellers. The interaction effect may be different if at the stern of the ship one long skeg or fin is fitted that may distort propeller slipstream.

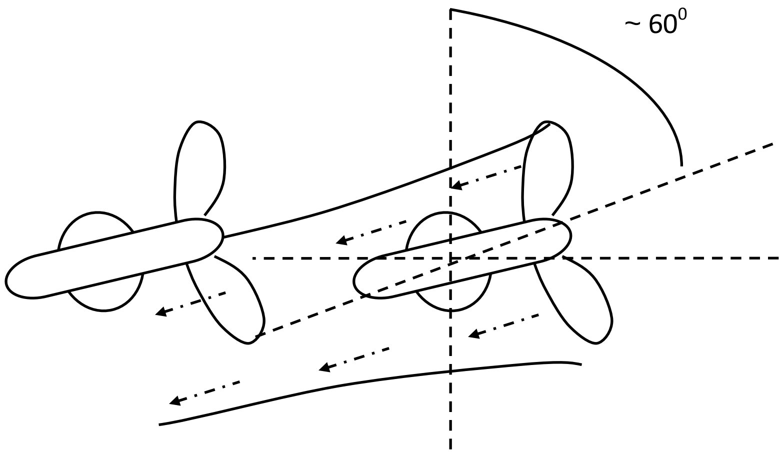


Fig 15. Wash-out of one pod is affecting the other

Strong interaction between pods is expected also in the position when the starboard POD is turned to 90^0 whether the port one is at rest (T position) (fig.16). In this position the propeller race of the starboard POD is against the port POD creating the force reducing the starboard thrust.

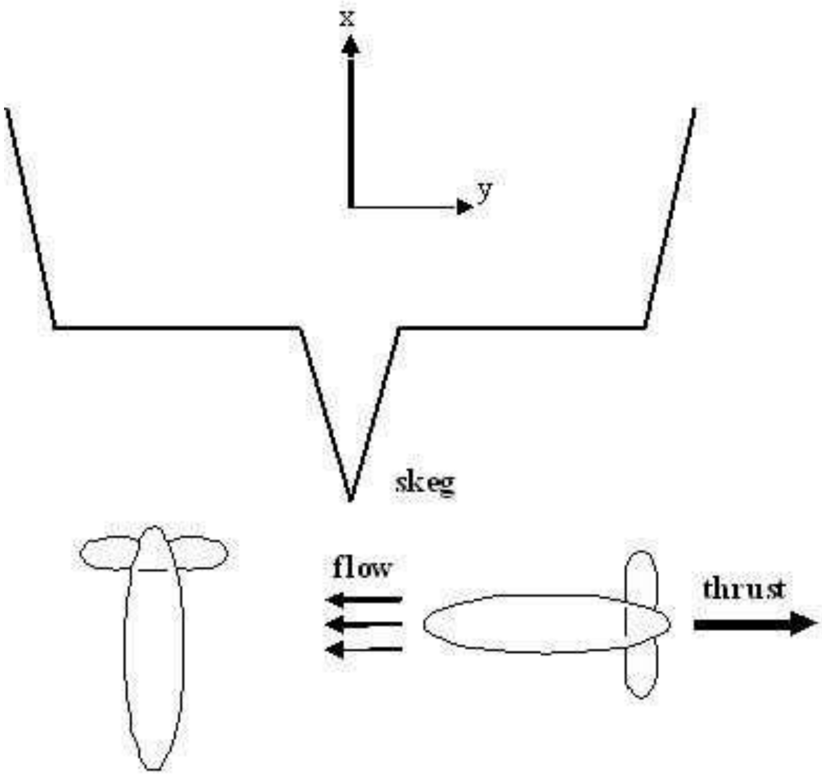
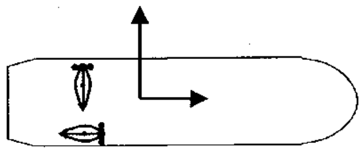
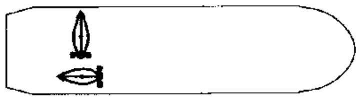


Fig.16. Pod-pod interaction effect

Ankudinov (2010) provided three diagrams showing effectiveness of azipod propulsors illustrating pod efficiency for lateral movement with different T-positions of pods. Those diagrams are reproduced in figs. 17, 18 and 19.

Pod–pod interaction was considered also by de Mello Petey (2008). In the situation where the starboard pod is turned to 90^0 (thrust to starboard) whether the port one is at zero angle (fig.16), the propeller race of the starboard pod is against the port pod creating additional drag to starboard reducing the turning moment. Such situation should be avoided when manoeuvring.

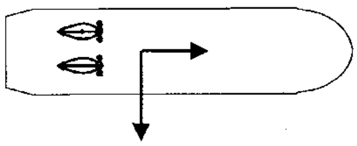
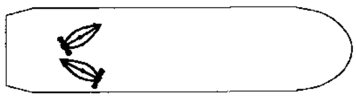
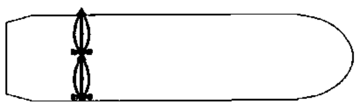
The following tables illustrate **approximate** pod efficiency values for lateral movement with one pod perpendicular to the vessel's centerline. These values are for a typical large cruise vessel whose initial speed is 0. Fx is fore and aft movement, Fy is lateral movement. The vessel's stern is moving to port.

Pod Position	Port	Stbd	Fx	Fy
	-90	0	100%	80%
	+90	0	100%	50%
	0	-90	100%	100%
	0	+90	100%	80%

Azimuth Pod Propulsion and Ship Maneuvering Simulations

Fig. 17.

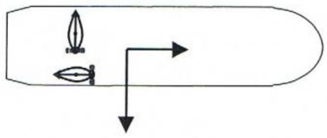
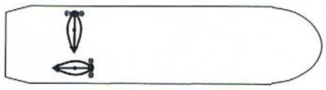
The following tables illustrate **approximate** pod efficiency values for lateral movement using a combination of azimuth angle and RPM to produce lateral movement. These values are for a typical large cruise vessel whose initial speed is 0. Fx is fore and aft movement, Fy is lateral movement. The vessel's stern is moving to starboard.

Pod Position	Port	Stbd	Fx	Fy
	0	0	200%	0
	+135	+45	0%	140%
	-45	+45	20%	120%
	+90	+90	0	150%

Azimuth Pod Propulsion and Ship Manœuvering Simulations

Fig. 18.

The following tables illustrate **approximate** pod efficiency values for lateral movement with one pod perpendicular to the vessel's centerline. These values are for a typical large cruise vessel whose initial speed is 0. Fx is fore and aft movement, Fy is lateral movement. The vessel's stern is moving to starboard.

Pod Position	Port	Stbd	Fx	Fy
	+90	0	100%	100%
	-90	0	100%	80%
	0	+90	100%	80%
	0	-90	100%	50%

Azimuth Pod Propulsion and Ship Maneuvering Simulations

Fig.19.

4. MANOEUVRING CHARACTERISTICS OF AZIMUTHING PROPELLED SHIPS

4.1.General

One of the most important advantages of podded propulsion units is that manoeuvring characteristics of pod propelled vessels are different, and in general much better than of vessels fitted with conventional propellers. Three main manoeuvring qualities that are subject of IMO recommendation are considered;

- Turning ability
- Course keeping ability
- Stopping ability

4.2. Turning ability

Turning ability of POD driven ships is much better than turning ability of conventional ships fitted with conventional rudder. This is obviously the result of high steering forces created by azipod rotated to certain angle and also the result of the possibility to rotate azipod around vertical axis by 360 deg.

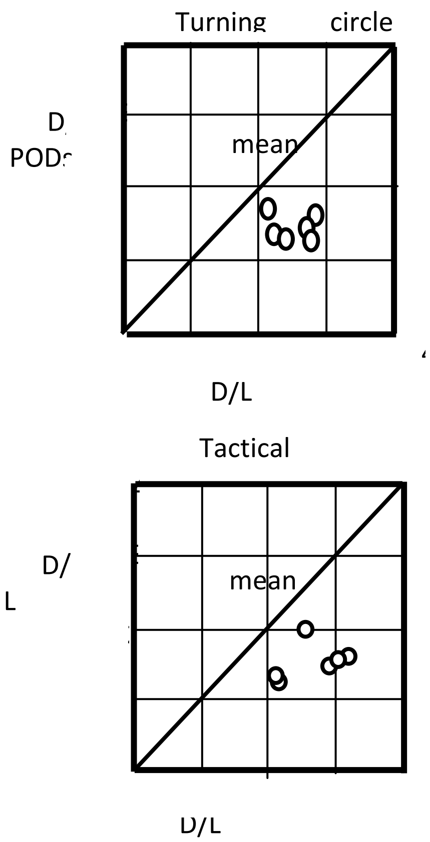


Fig.20. Comparison of turning characteristics for podded and conventional propulsion units

Fig 20 (from: Toxopeus & Loeff, 2002) shows comparison of two turning measures – turning circle diameter and tactical diameter for several POD driven ships versus conventional units. The mean line represents the situation when the values for both types of ships are equal. In this comparison the angle of POD or rudder was limited to 35^0, as it is normal limiting angle of rudder deflection

It clearly shows that the turning ability of vessels with podded propulsion is much better than vessels with the conventional propellers and rudder. Moreover, PODs could be rotated to higher angles with the result that the ship may turn even around of its own centre of gravity. Clarification of this behaviour can be ascribed to large steering force generated by POD, where full thrust of the propeller can be created to all directions.

Excellent manoeuvring characteristics of pod driven ships were confirmed by tests of the model of a gas carrier with single and two podded propellers conducted at Ilawa Training Centre. (Kobylinski & Nowicki 2005):

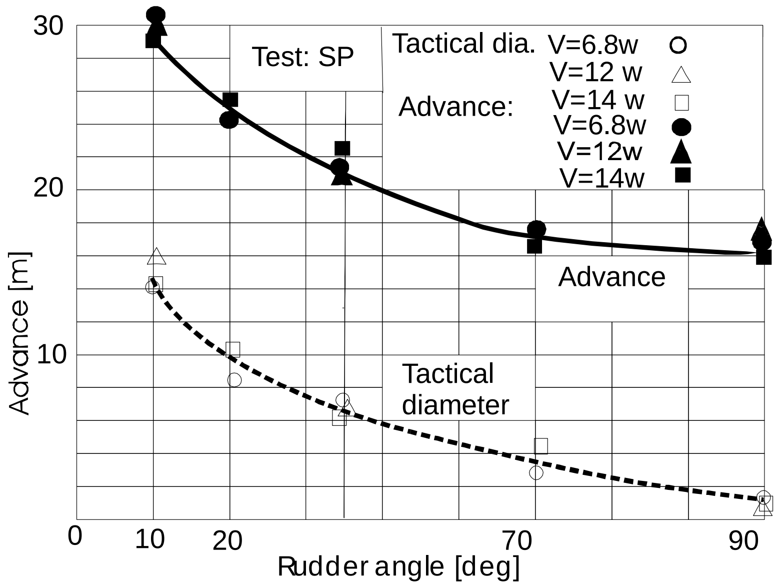


Fig.21. Tactical diameter and advance for single pod configuration

Fig.21 shows results of the turning circle experiments of the model fitted with single pod propeller where advance and turning diameters are shown over the range of rudder (azipod) angles up o 90 degrees. The figure shows that at azipod angles closing to 90 deg. the model turns at the spot (tactical diameter is almost zero and advance is equal to about 1.5 model length).

Tests with twin azipod propulsion were conducted with the same model fitted with several different configuration of skegs and fins that were installed in order to achieve satisfactory course keeping ability (see below). Even with the installation of skegs and fins large enough to achieve satisfactory course keeping ability advance and tactical diameter at high rudder angle were very small (Fig.22).

Data on turning characteristics for two cruise liners, one equipped with azimuthing propulsion units (Elation) and the other with conventional propulsion (Fantasy) were provided by Woodward (2009). They are shown in the table 1.

The table shows advance, transfer, tactival diameter, steady diameter and speed loss measured at sea trial and for one ship (Elation) also model test results were available. For comarison data taken from ship trials of the ship Fantasy (conventional propulsiion) are also shown. The data show clearly that turning characteristics of azimuthing propelled ship were excellent and better than comparable ship equipped with conventional propulsion.

Table 1. Tuning circle data for M/S Elation and M/S Fantasy

	Fantasy (sea trial)		**Elation (model)**	**Elation (sea-trials)**	
Initial speed	10.2 kn	Full speed	19.5kn	11.2 kn	Full speed
Helm angle	40^0	40^0	35^0	35^0	35^0
Advance	2.73	3.11	2.99	2.01	2.35
Transfer	1.67	1.55	1.00	0.73	0.71
Tactical Diameter	3.14	3.05	3.14	1.94	1.89
Steady diameter	3.28	3.15	3.07	1.81	1.77
Speed loss %	31	51	42	60	>70

- **Course keeping ability**

The course keeping ability for pod driven ships is known to be worse than for conventional vessels. The reason of this effect may be attributed to the different form of the stern that is flat in order to accommodate PODs. For sufficient directional stability a suitable arrangements of skegs and fins, either central or in front of each POD is necessary.

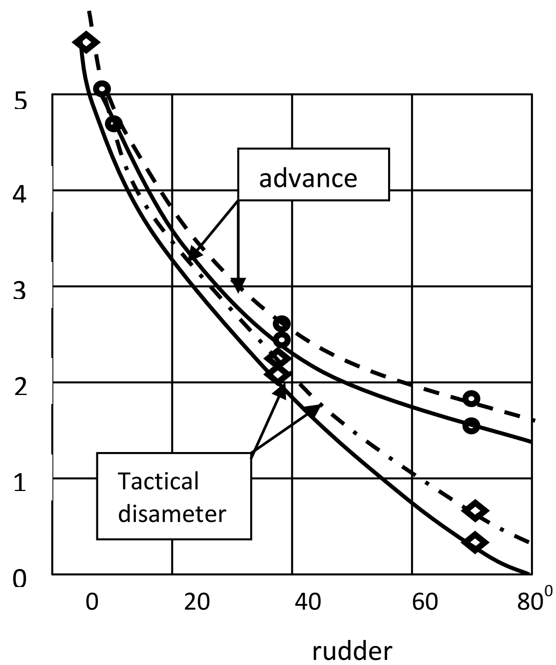


Fig. 22. Tactical diameter and advance for twin pods configuration. (solid lined – approach speed 6 knots, dotted lines – approach speed 14 knots)

The course keeping ability is assessed by the amount of overshoot angle measured during the yaw checking or zig-zag test. The same source (Toxopeus & Loeff, 2002) shows that overshoot angles obtained are in average larger for POD propulsion than for conventional propulsion, but still seem to satisfy manoeuvring standards adopted by the IMO Resolution MSC.137(76) (IMO 2002). (Fig.23). The results shown, however, are applicable to fast ships having rather low block coefficient and which usually are inherently dynamically stable on straight course.

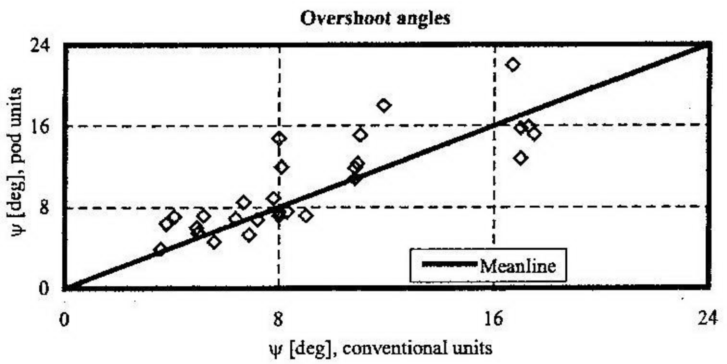


Fig. 23. Overshoot angles of ships equipped with podded or conventional propulsion units

Course-keeping characteristics of pod driven full bodied ships was subject of special investigation by SHRTC in years 2003-2005. (Kobylinski&Nowicki 2005). The results of this investigation and extensive model tests with large manned model in different configuration of fins and skegs (Fig. 24.) showed that:

- Model driven by single POD was dynamically unstable to high degree and very difficult to control.
- Model driven by twin PODs arrangement without skeg(s) or with small skegs was also dynamically unstable, although to the lesser degree as with single pod propulsion.
- Model with large skegs was still dynamically unstable, but with small amount instability. Model revealed satisfactory course-keeping characteristics.

This last variation was tested by several pilots who handled it in different situations. Their judgement with respect of single POD propulsion was negative. They had also some difficulties piloting model with twin PODs fitted with single skeg, large or small, because insufficient course keeping ability, but were fully satisfied with the final version fitted with two skegs and rudder fin.

The model was handled easily, all manoeuvres including slowing down and stopping in the narrow fairway, negotiating narrow passages and tight bends, entering locks and harbour basin, mooring and unmooring could be performed successfully in calm weather and under influence of wind and in the current. This was in spite of the fact, that no thruster was fitted in the model. The usual practice is to install bow thrusters in such ships, which considerably improves handling capability in confined areas.

It appears that in order to achieve satisfactory course-keeping ability of pod driven ships the most important is the shape and arrangement of appendages, first of all fins or skegs of different arrangement and proportions.

With single POD propulsion during standard 10/10 deg tests because of a very high degree of dynamic instability model did not respond to counter rudder. In standard 20/20 deg tests the first overshoot angles were extremely high, exceeding 120^0, the second were kept within limits of about 30^0. Additional 20/10 deg tests revealed similar behaviour. Handling exercises where the model was sailing within limits of a narrow fairway making a loop confirmed the above conclusions.

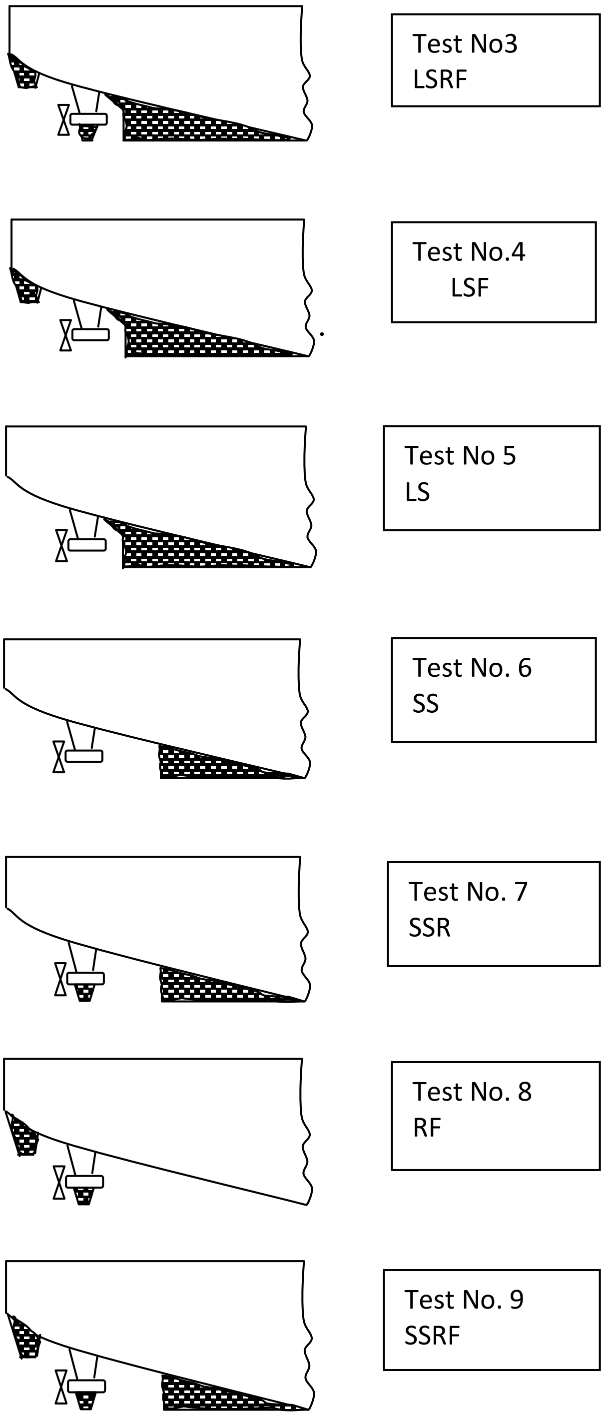


Fig. 24 Versions of the model with two POD's and two skegs

Steering of the model and keeping it within the limits of the fairway was very difficult, sometimes really impossible. Control of yawing was difficult and in order to counter turning large rudder angles were necessary. Clear passing a very narrow passage under the bridge was impossible in spite of very skilled pilot at helm. The judgement of pilots with respect of single POD propulsion was negative. It was concluded that single POD propulsion is not suitable and further tests of this version were cancelled.

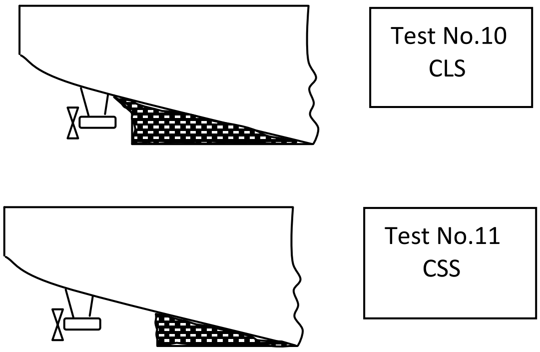


Fig.24A. Versions of the model with single central skeg

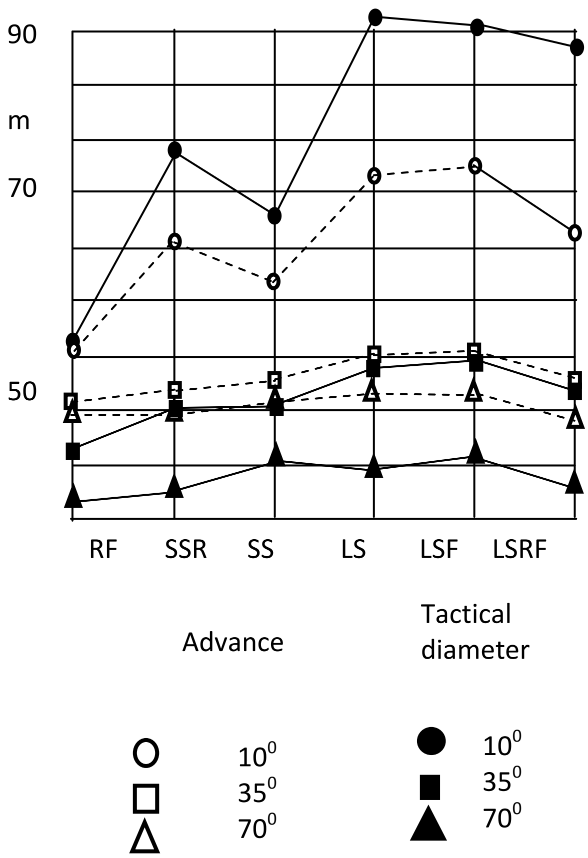


Fig. 25. Tactical diameters and advances at approach speed 14 knots

The behaviour of the model fitted with twin PODs without fin, or with small central fin (e.g tests 10 and 11 - see fig.24A) was similar to the behaviour of the model with single POD, although dynamic stability in this condition was slightly better and in some 10/10 deg tests model responded to counter rudder. With large central fin installed overshoot angles in 10/10 deg tests were considerably smaller, although in most cases still much larger as required by IMO standard.

As it was expected, installation of fin caused increase of both tactical diameter and advance, but still turning ability was excellent.

Installation of two skegs, each in front of the POD and in addition a combination of fins at stern and at PODs revealed important effect on manoeuvring characteristics of the model. Several variants were tested as shown in fig.24 and 24A The behaviour of the model improved considerably.

Turning ability characteristics for the model fitted with two PODs and different combinations of skegs and fins are shown in fig. 25.

The example results of zig-zag tests for the model fitted with two PODs and different combinations of skegs and fins are shown in fig. 26.

From fig.25 may be seen that tactical diameter and advance for 35^0 rudder never exceeds 30m (2.6 L) and for 70^0 rudder are less than 2.0 L. Fig 25 shows that for all versions tested except version where no skegs were installed first overshoot angles in 10/10 deg test are within IMO limit.

Handling of the model in the narrow fairway, negotiating the bends, entering the locks and harbour basins was easy and the model responded properly to counter rudder.

As expected, reduction of the area of skegs resulted in improving of the turning characteristics at the same time making course keeping characteristics worse, although still within IMO limits.

Reducing the size of skeg caused, for example, at 35^0 rudder and approach speed v = 14 knots reduction of tactical diameter from 37.9m to 20.1m (3.27L to 1.74L) with corresponding reduction of advance. At the same time 1st overshoot angle in 10/10 zig-zag test increased from 14.3 to 17.6 deg.

Installation of small fin in the lower part of the POD propeller resulted in improving turning characteristics as well as course keeping characteristics. The tactical diameter and advance at 35^0 rudder were almost the same, but overshoot angles were much smaller (1st overshoot angle at 14 knots approach speed in 10/10 zig-zag test drops from 17.6 to 14.3 deg).

It may be expected that installation of a small fin at stern may improve course keeping ability considerably. In fact, it had little effect With slightly worse turning ability the course keeping ability, measured by overshoot angles remained almost the same.

It may be concluded that with two PODs installed course keeping ability is much better, but still in order to achieve satisfactory results it would be necessary to fit a combination of skegs and fins. A proper design allows to achieve good course keeping and excellent turning characteristics of the vessel.

The measurements taken of the tactical diameter, advance and overshoot angles provide good material for assessment of manoeuvring characteristics and in particular they enable checking whether the design satisfies criteria set up by IMO (IMO 2002). However, the results of measurements are not sufficient for judging handling possibilities of the ship in various external conditions and in different actual situations.

Table 2 (Woodward 2009) shows the results of zig-zag tests (overshoot angles) for the M/S Elation (equipped with azimuthing devices)). The table compares the sea-trials results with predicted values obtained from simulation using derivatives from model PMM tests.

As it is seen the ship not only meets the IMO criteria but also reveals very good course-keeping characteristics.

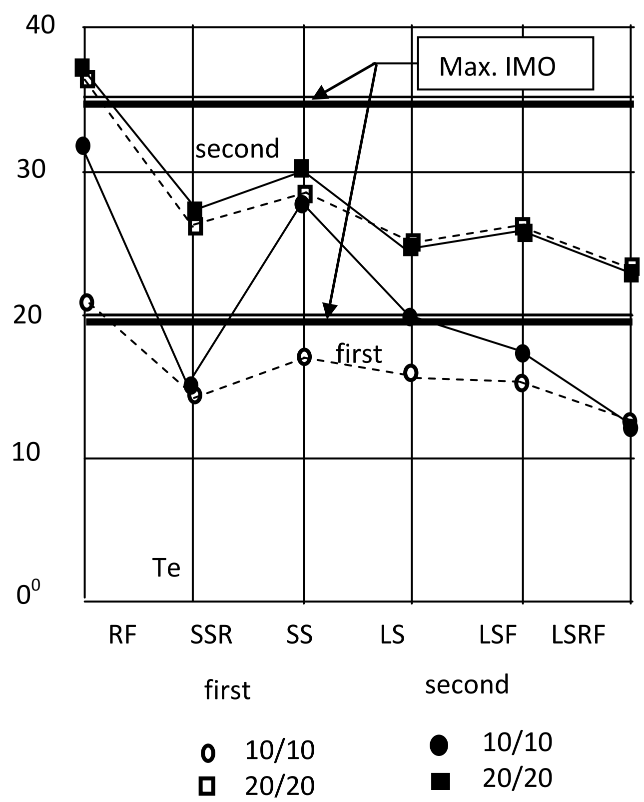


Fig. 26. Overshoot angles in zig-zag tests for approach speed 14 knots

Table 2 –Zig-zag test data for M/S Elation

	M/S Elation (model tests and simulation)		M/S Elation (sea trials)		
Approach speed	19.5 kn		19 kn	22 kn	
Test	10/10	20/20	10/10	10/10	20/20
1st oversoot	5.8	12.1	7	5	11
2nd overshoot	9.7	14.7	9	8	15

The effect of centre skeg was tested by Haraguchi (2003). In general effect of the centre skeg was reducing the width of loop in spiral tests and therefore improving course-keeping ability. This confirms conclusions drawn from the tests discussed above.

4.3. Stopping ability

Stopping ability is an important element of manoeuvring characteristics of the ship and stopping distance according to IMO criterion should be not more than 15 ship lengths when crash stop test is performed.

With pod driven ships there are several possible modes of stopping the ship:

- Conventional stopping manoeuvre when engines are ordered full astern –(CSM)
- Slew 180^0 stopping manoeuvre when ordering PODs turning 180^0 outwards in opposite directions while maintaining constant shaft torque (SSM1)
- Slew 180^0 stopping manoeuvre when ordering to rotate PODs 180^0 in opposite directions while simultaneously reducing 40% in delivered shaft torque (SSM2)
- Indirect stopping manoeuvre where ordering PODs to rotate by 60^0 outwards in opposite directions while simultaneously ordering full astern – when the ship speed has reduced by 80% ordering PODs back to 0^0.(ISM).

On top of these four modes that were studied by Woodword et al (2004) it is possible to stop effectively the POD driven ship by hard turn. There are several possibilities to perform hard turn without causing overloading the propeller and the struts.

Table 3. Comparison of four stopping modes

Manoeuvre performed	Stopping distance (Ship/lengths)	Stopping time (s)
CSM	**11.97**	**303**
SSN1	**6.66**	**201**
SSM2	**9.05**	**299**
ISM	**5.81**	**182**

Comparison of simulation of the above four modes of stopping is shown in Table 3 (Woodword et al 2004). Simulated ship was OPTIPOD Ropax of the length 172.2m tested under European Commission RTD FP5 project.

CHAPTER S.2 OPERATION OF SHIPS EQUIPPED WITH PODDED PROPULSION DEVICES

1. NEED FOR SPECIAL TRAINING ON AZIMUTHING PROPELLED SHIPS

Fast development of azimuthuing prpulsion devices that offer several advantages caused that ship masters and pilots more often have to handle ships equipped with these devices. The manoeuvring characteristics of pod driven ships differ substantially from those of conventional ships and pods control became very complicated and quite counterintuitive. Because of that helmsman at the controls may not intuitively handle motions of the ship without previous training and experience and he may be not fully aware of the results of ordered settings of the pods. In particular handling two pods independently may be confusing as to the effect of settings on ship movements. Controls on pod propelled vessels are generally quite different from controls in conventional vessel and they are not intuitive.

The main difference between steering of a ship with conventional propulsion and a ship equipped with azimuthing propulsion device that may be confusing is that starboard rudder causes the ship turn to starboard whether starboard directed pod causes the ship turn to port (fig.1).

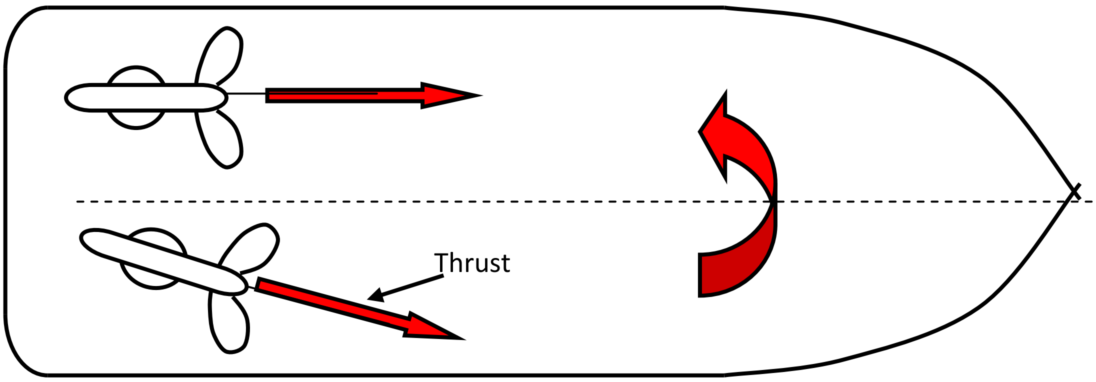


Fig.1. Direction of thrust and turning

Even the more confusing situation may occur when both pods (in twin pods propulsion) are used at the same time separately. Without previous training the result of particular setting of pods may be difficult to predict. Moreover, possibility to rotate pods by 360^0 and also the possibility to reverse direction of rotation of propellers causes that many different manoeuvres may be performed others than with conventional propelled vessels.

In emergency situation in a ship with single screw conventional propulsion bridge personnel have only finite number of options, whether in a ship equipped with azimuthing propulsion devices the number of options is quite large and the decision which option to use is not clear and is not intuitive.

Taking into account all these factors it is obvious that there is the need for special training on ships equipped with azimuthing propulsion devices for pilots and for prospective masters of such ships.

According to Rees (2010) 8044 pilots were questioned on the matter of the need for training on azimuthing propelled ships, of which 2334 responded, and of these 96% had to pilot pod driven ships and expressed the need for special training. From this number 736 pilots (32%) received some kind of training on pods propelled vessels and few others received some instruction from manufacturers. The others did not receive any training on azimuthing propelled ships at all.

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

Recently in many districts escorting of large vessels carrying dangerous goods - oil tankers, gas carriers and similar-is required. Escort tugs are almost always fitted with azimuthing propellers and escorting operations in case of emergency require greater skill from the tug masters and ship masters. Training in escorting operations is another fast developing area where azimuthing propelled vessels are involved and where special training is required.

2. BASIC CONTROL MODES WITH TWIN AZIPOD CONFIGURATION

Three basic control modes for ships fitted with two azimuting propulsors (PODs) are as follows (The Naval Architect 1996):

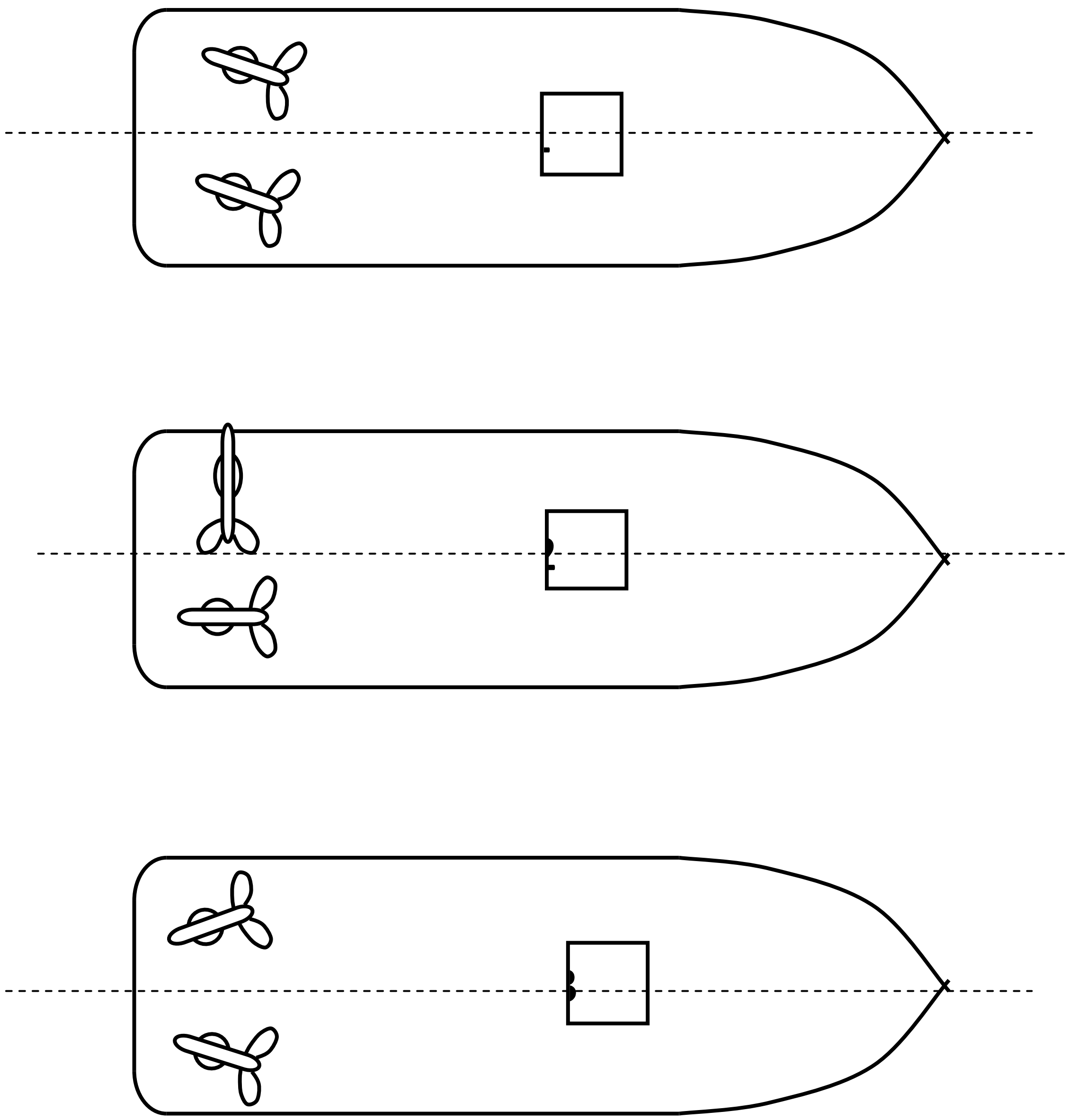


Fig.2. Basic operation modes for pod s equipped ships

1. CRUISE MODE, (or open sea mode) where pods are synchronized. Both PODs deflected to the same angle, in a similar way as it is usually done with two coupled rudders in twin-screw ships fitted with conventional propellers and rudders. Power avalable is unlimited, but turning angles of pods are greatly restricted (not more than 35^0)

2. MANOEUVRING MODE - SOFT when pods are not synchronized and operated independently. In this mode often one POD (left or right, depending on the direction of turn) is used to perform maneuvers. Power available is limited to about 50-60% of the total, and the turning angles of pods are also limited to 35^0.

3. MANOEUVRING MODE - STRONG (AZIMAN) when pods are not synchronized and operated independently. In this mode both PODs are used to perform manoeuvers (for example docking operations) and the system will automatically reduce power to about 50-60% (If such control is provided in the ship). Turning by 360^0 is allowed.

All three control modes are illustrated in fig. 2

Rees (2010) sumarised basic features of the three modes. (Table 1)

Table 1. Modes of operation as shown by Rees (2010)

MODES OF OPERATION

AZIPILOT

Mode	Power	Rotation	Syncronised
Open Sea Cruise	Full power i.e. 17 mgw	≤ 10° But may be 35°	pods and rpm
Manoeuvre Manoeuver direct	Reduced power i.e. 12/13 mgw	≤ 35°	pods and rpm
Fast Mode Aziman Azimuth mode	Reduced power i.e. 10mgw	360°	pods and rpm independent

SEVENTH FRAMEWORK PROGRAMME

In operation of pod propelled vessel it is very important for bridge team and pilot to be aware at which mode currently ship is operating and what are limitations imposed within this mode. Different manufacturers have different terminology for what is essentially the same mode. This may be confusing. Operators coming onboard various vessels with different terminology need to know what each different term is equivalent to. Therefore the current operating mode should be clearly detected. This is required actually by the Safety of Navigation Circular 265 (see paragraph 6).

3. OPERATIONAL RECOMMENDATIONS AND LIMITATIONS

Azimuthing propellers of the type Voith-Schneider propellers, Schottel propellers or conventional outboard motors having limited power (usually not more than 1MW) are known and operated for many years and their operational limitations are well known. It is different for innovative azipod propulsion units, where electric motor is situated in the underwater housing and the power may be as high as 25MW. Main suppliers are Rolls Royce Kamewa/Alstrom, Finland ABB Industry, Siemens-Schottel, and STN Atlas Marine/ John Crane-Lips.

Experience with operation of these high power azipod units, mainly in cruise liners, did reveal some difficulties from the structural point of view, the critical issues being seals and bearings, the result might be leakage, insufficient lubrication etc. This is the result of very high forces created at azipod housing when the unit is rotated to large angles at high speed. Those forces may be to large the housing could withstand. Because of this and bearing in mind several accidents where some damage to the azipods happened, manufacturers imposed some limitations with regard to the operation of azipod driven ships. Those recommendations may be different for different types of podded drives, but some general instructions are repeated below.

When the pod unit is turned rapidly to large angle at high speed, very high transverse force would be created that may cause large heel angle of the ship and very high loads on pod construction that may cause serious damage to the pod, its bearings, transmission and shaft. This is prohibited and usually the system will not allow to do so in cruise mode, Therefore the main recommendation in operational practice is:

- <u>**Operate pods as gently as possible and maintain minimum revolutions**</u>

That is because with azimuthing propulsion devices it is possible to accelerate the vessel quickly to any direction and this usually leads to necessary use of high power levels to stop motion. High power at low speed usually leads to harmful heavy vibrations that may reduce life time of mechanical components. Other recommendations and limitations in operating azimuthing propulsion devices are:

- **In open sea avoid reverse power (reverse RPM) and try to maintain positive RPM.** The recommendation for use of negative RPM during ship operations are given in the table 2
- **Crash stop to be avoided. (**For recommendations regarding stopping manoeuvres see paragraph 5)
- **Avoid wash onto another pod, especially over unpowered pod** (see fig.3)
- **Avoid flow from a pod directly entering the propeller of the other pod** (se fig.3)
- **Avoid applying large angles of rotation at high speed. This may lead to large angles of heel and high forces acting on the unit**
- **Avoid large differences between RPM and ship speed**
- **Avoid unpowered rotation at low speed**
- **Avoid powered rotation below 25 RPM and preferably 30 RPM.** To avoid unnecessary wear on shaft bearings due to lack of oil film between the rollers and the raceways avoid long time operation close to zero RPM. In some vessels this RPM is blocked in manoeuvring mode according to fig. 4. The blocked range is about 15 RPM,
- **Avoid cycling between zero 25 to 39 RPM**
- **Avoid cycling between forward and reverse RPM**

- **When turning the unit quickly in one move avoid applying large angles (about 80^0),** because unit turns the shortest way from its current position and it may therefore lead to a situation where the units turns the opposite way from what is intended

Those are general recommendations by the manufacturers. Further recommendations regarding operation of pods may be found in detailed operating instructions provided by the manufacturers of particular product.

Table 2 Recommendation for use of negative RPM

Manoeuvring with low speed -2 to 4 knots (docking and undocking	Position keeping (anchoring, DP)	Channel keeping or approach to pilot station	Normal service speed
Negative RPM allowed	Negative RPM allowed	Negative RPM occasionally allowed	Negative RPM **NOT** recommended

As it is seen from the list, operation of pod driven ships is not easy and shipmasters and pilots must be fully aware of all the limitations otherwise they may cause damage to the pod.

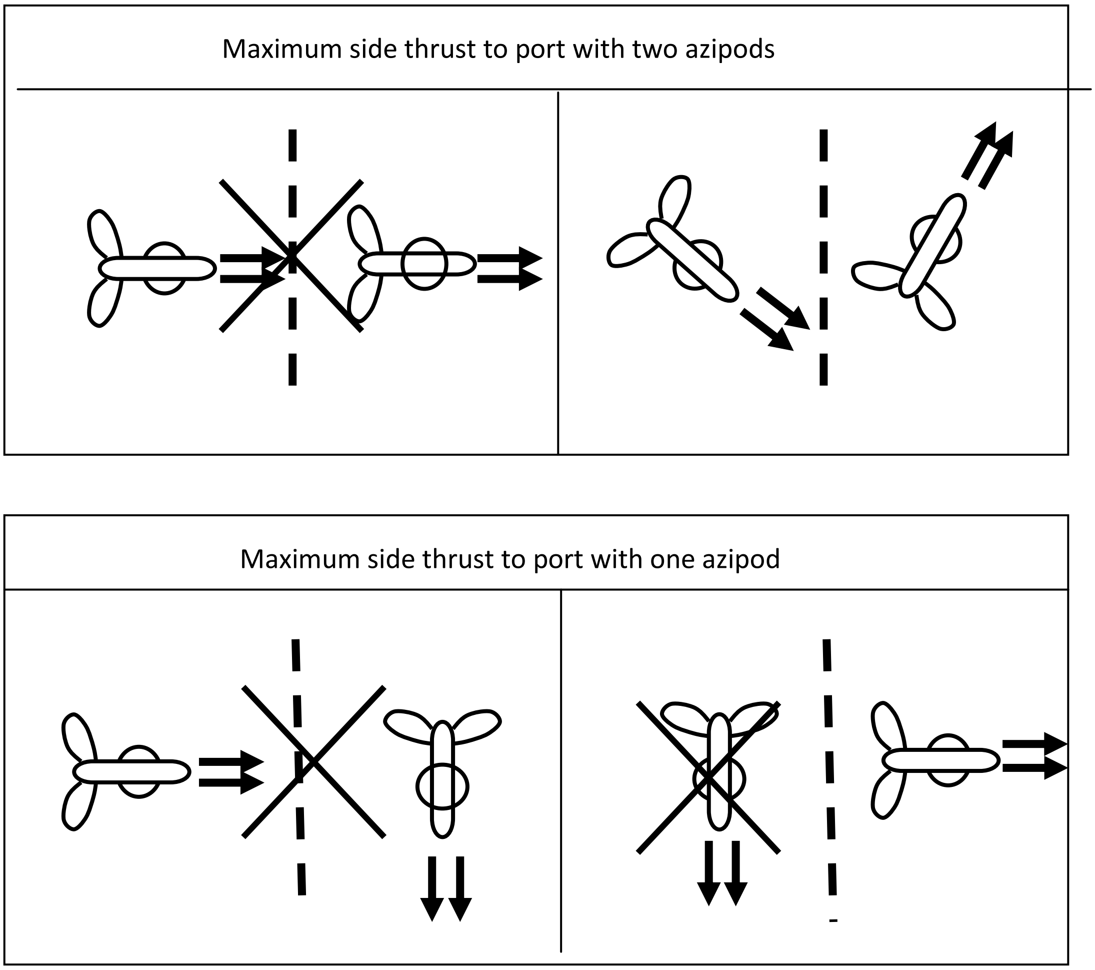


Fig.3. Situations to be avoided according to ABB instruction. (X –mark, to be avoided)

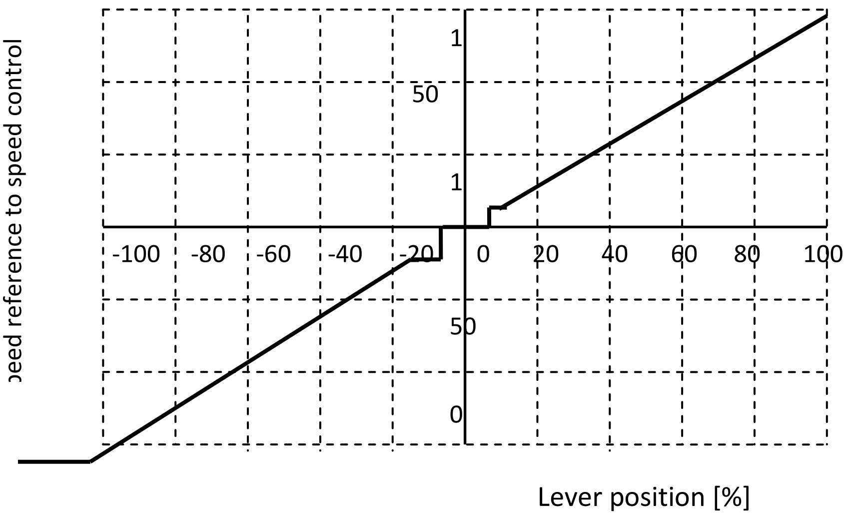


Fig.4. Example of software controlled speed ramps close to zero speed

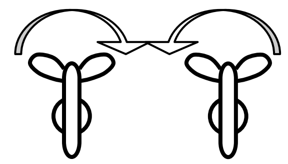
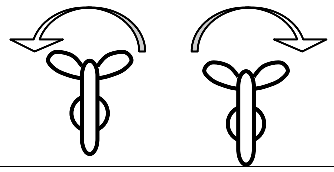
Vessel speed (knots)	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**
Both azipods turning inwards 													
Both azipods turning outwards 													
Ship slowing (start speed) by rotating both azipods 35 to 90^0 outwards (windmilling propellers or low power)													
Maximum ship speed during the use of FAST Steering gear mode													
Maximum allowed ship speed during the ordinary use of NFU (Non Follow Up) steering tillers													

Fig. 5. Various manoeuvring operations depending on vessel speed green – allowed, yellow – occasionally allowed, red – may cause dangerous situations due to fatiguing and excessive wear on components or by sudden movements endangering the general ship stability.

ABB Oy Marine Azipod operating guidelines put severe restrictions on operating azipods that are reproduced below:

4. MANOEUVRES PERFORMED BY SHIPS EQUIPPED WITH AZIMUTHING PROPULSION DEVICES

Turning with headway

Turning with headway could be realized in each of the three modes. In cruise mode both pods are deflected to certain angle and stering is similar to steering using conventional rudder with the difference that directing pod to port (in this case the propeller thrust will be also directed to port) will cause turn to starboard (fig 6.). The resulting turning is moderate. If comparing with the conventional rudder deflected to the same angle (say 35^0) the turning diameter of the ship equipped with podded drive is substantially smaller (compare fig.20 of Chapter 12.1)

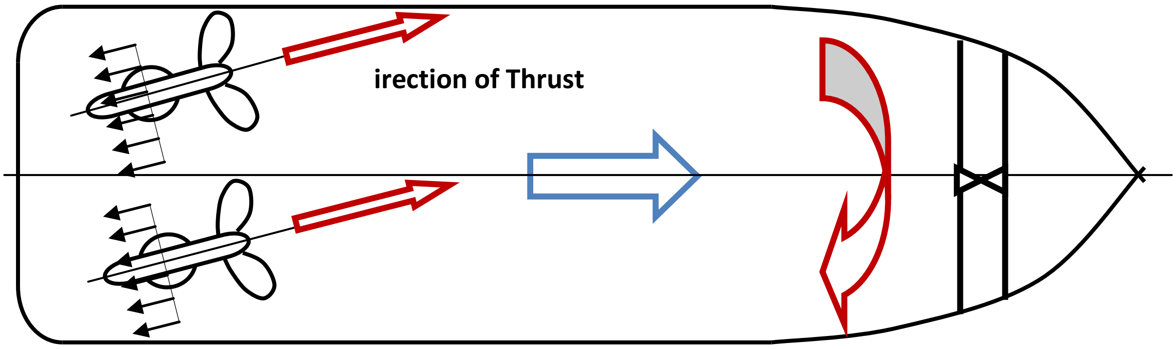


Fig.6. Moderate turn in cruise mode

Turning could be executed also in the soft mode, using only one pod as shown in fig.7.The resulting turm may be gradual and gentle. Port pod is deflected to port resulting turn to starboard.

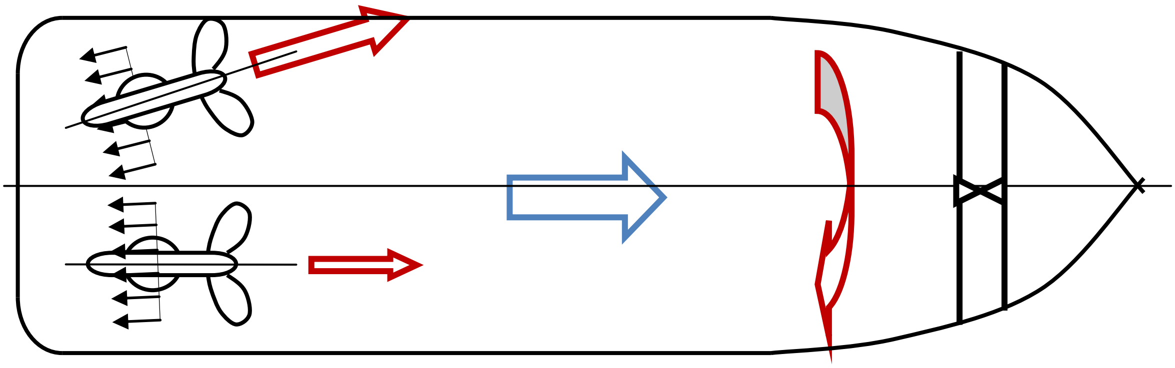


Fig.7. Gradual turn realized in the soft mode

Very hard turn may be realized in the strong mode. In this case both pods are used (STRONG or AZIMAN mode). The port one is directed to port at certain angle with higher revolutions, the starboard pod directed aft also to port but slower, creating thrust astern and to port (fig.8.). In result hard turn with very small turning circle diameter is executed. This is the case where according o ABB Guidelines thhe largest side force for the ship is reached

The range of pod angles is between 75 and 105^0. when both pods are blowing in the open the interaction between pods and the hull is avoided.

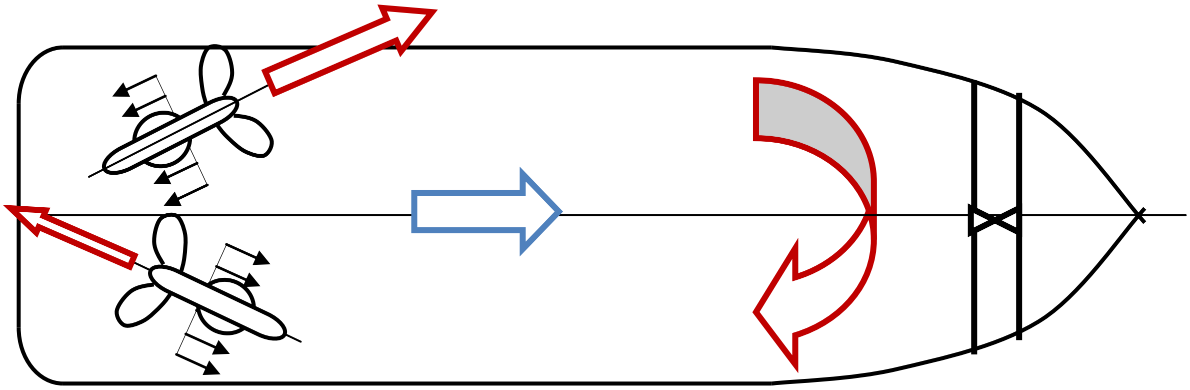
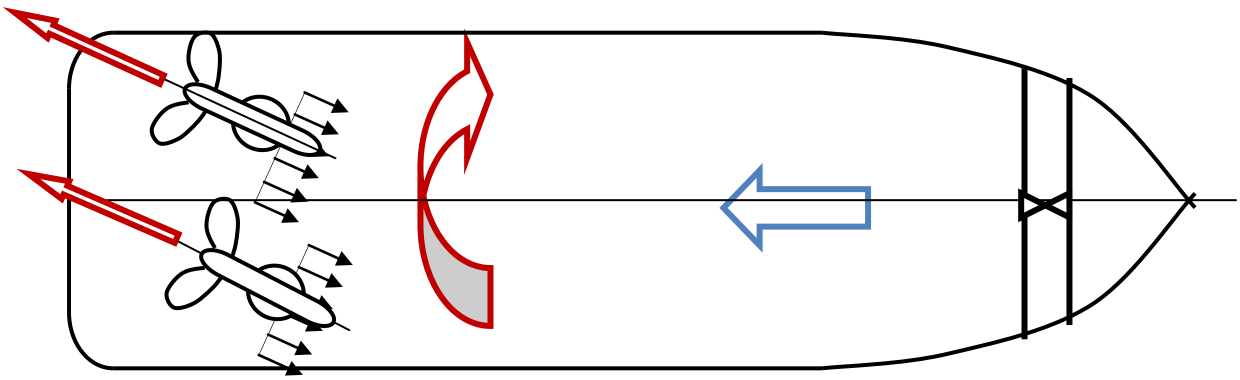


Fig. 8. Hard turn, pods in strong mode

Turning with sternway

Turning with sternway could be executed either by rotating pods or by reversing direction of rotation of propellers. The second option is not recommended by manufactureres; usually they recommend to maintain positive revolutions of the propeller as shown above.



Fig, 9. Moderate turn to starbord with sternway – pods in cruise mode

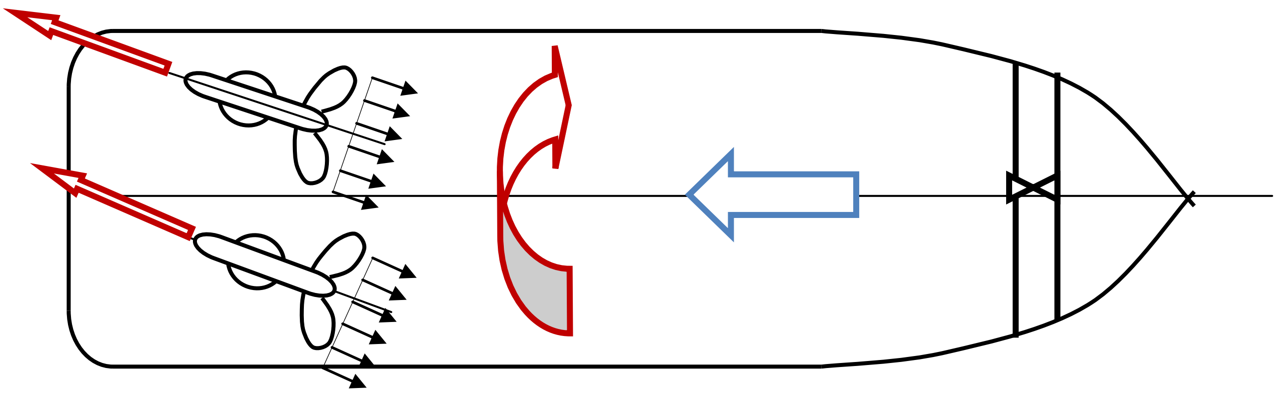


Fig. 10. Moderate turn to starboard with sternaway in cruise mode – propeller revolutions reversed (not recommended)

Gradual turn to starboard with sternway is realized using one pod only (SOFT mode). Both pods are working sternway creating thrust in the aft direction (fig.11). The starboard pod is used and directed to starboard creating thrust to port. Moderate turn to starboard is achieved.

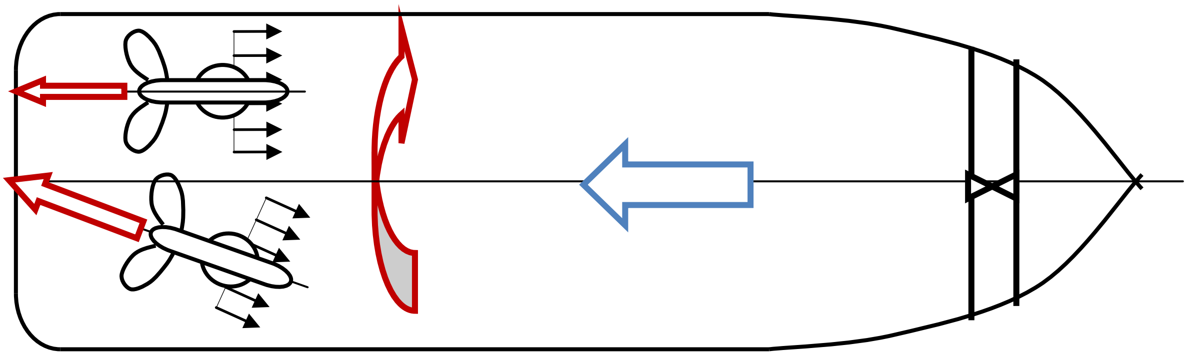


Fig. 11. Gradual turn with sternway- pods in soft mode

Hard turn with sternway is achieved if port pod is directed to port creating thrust directed ahead and to port whether the starboard pod working at higher revolutions is also directed to port creating larger thrust astern and to port. In result very hard turn with small turning diameter is achieved (fig.12).

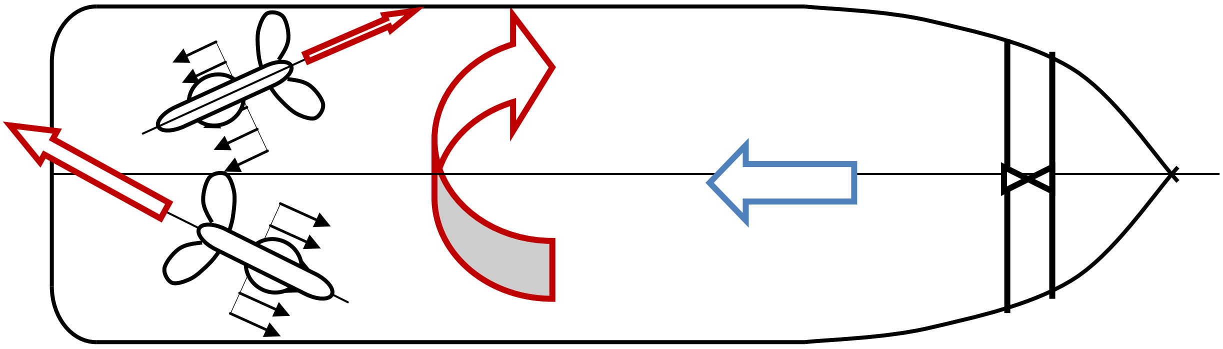


Fig.12. Hard turn with sternway –pods in strong mode

In all situations where the ship is making sternway pod revolutions could be reversed, however, as pointed out before, this is usually not recommended by the manufacturers and reverse revolutions possibly could be used only in emergency situations or at very low speed (compare Table 2). In all turning manoeuvres shown the bow thrusters is not used. With the use of bow thrusters the turn in all cases will be more tight.

Turning when stopped

When the ship is at rest it may be turned in similar way, but pods could be rotated at higher angle approaching 90^0. This is illustrated in figure 13.

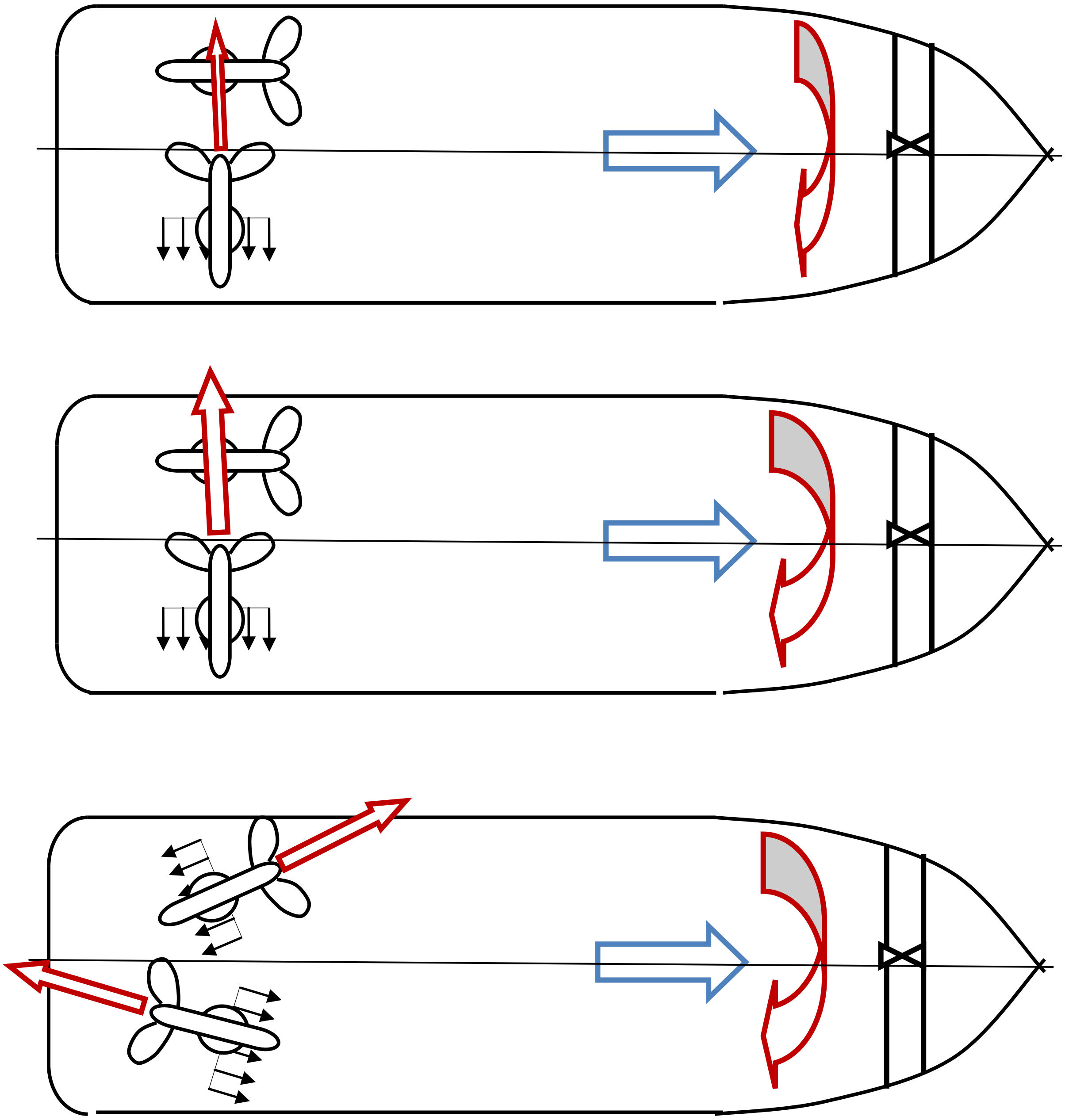


Fig.13. Turning when stopped. Top-gradual turn, middle-moderate turn, lower –hard turn

Crabbing

For crabbing manoeuvre with pod driven ship more flexibility is available in comparison with the twin screw conventional propulsion (Toxopeus&Loeff 2002). In general the angle of the pod that is close to the quay working ahead is varied, while the other pod running at the same RPM is working astern cancelling longitudinal speed. It was found that optimum results for unberthing are when quay side pod is directed with trailing edge slightly aft of the perpendicular to the quay (between 75^0 to 90^0) and the other pod directed with the trailing edge slightly forward (about 90^0 to 120^0) (Fig. 14).

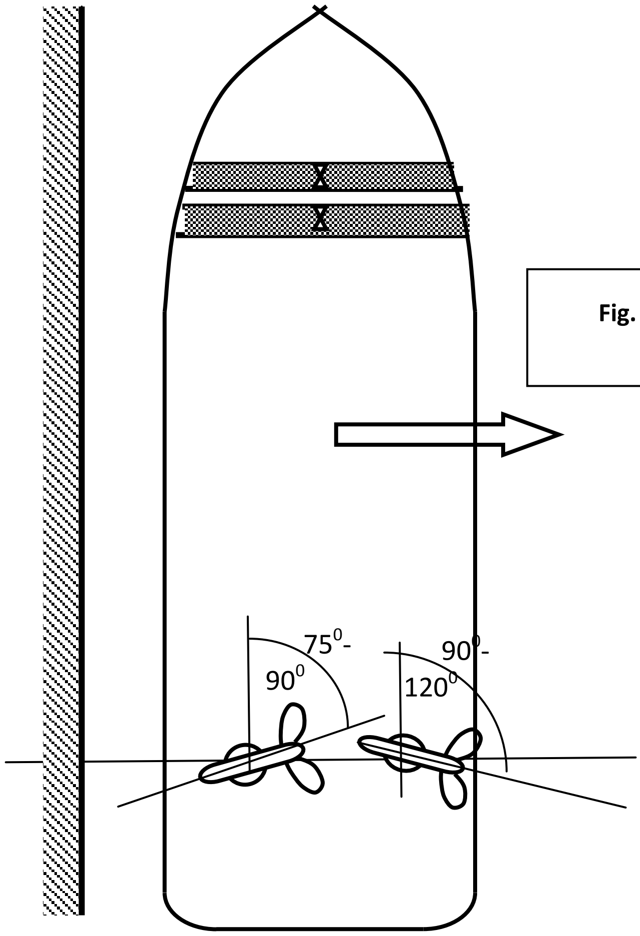


Fig. 14. Best solution for crabbing when unberthing

Low speed Manoeuvring.

The low speed manoeuvring characteristics are important for vessel' operation in restricted water areas. There are several tests manoeuvres that characterise ship manoeuvring at slow speed conditions (Hwang et al 2003). The basic test manoeuvres are:

- **Minimum effective rudder angle (MER)**
- **Crash stop from half ahead**
- **Acceleration/deceleration combination**
- **Backing/stopping combination**
- **Accelerating and coasting turns**
- **20/20^0 overshoot and coasting overshoot test**
- **Back and fill test.**

Slow speed manoeuvring characteristics of pod driven ships differ considerably from the characteristics of conventional vessels. Pod propulsion provides ample opportunities to perform slow speed manoeuvres in different way. Pods could be rotated 360^0 and also direction of rotation of the propeller may be reversed.

Low speed manoeuvres are performed usually in the STRONG (or AZIMAN) manoeuvring mode when with twin pods arrangement the RPM and rudder angle of both pods are controlled independently.

In general the ship is sailing with the pods running at the same RPM and positioned at an angle of about 45^0 with respect to the ship centreline as shown in fig. 15. The speed of the ship is controlled by maintaining RPM constant but changing the angle of pods. The heading is controlled by increasing RPM of one pod while reducing RPM of the other. With this approach the heading of the ship remained constant when controlling the speed and vice versa (Toxopeus&Loeff 2002).

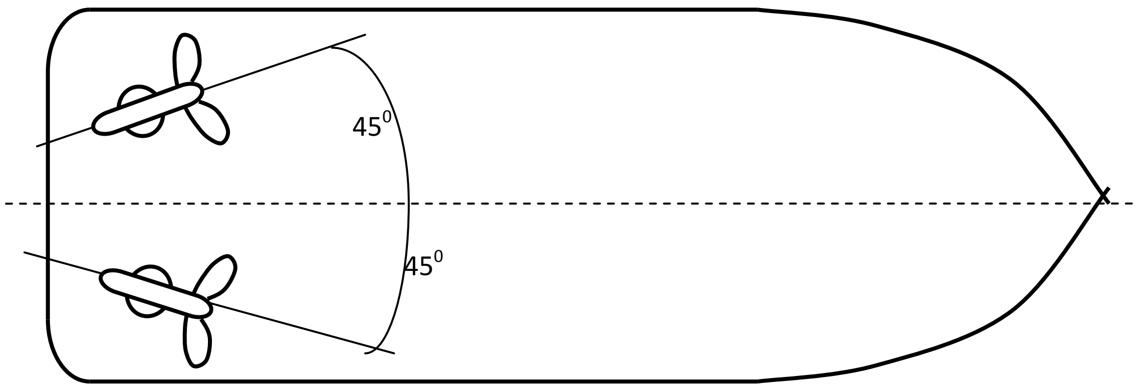


Fig.15. "Position of pods in manoeuvring mode at slow speed

5. STOPPING OF SHIPS EQUIPPED WITH AZIMUTHING PROPULSION DEVICES

Crash stop

There are several possibilities to stop ships fitted with azimuthing propulsion devices.

1. **Turning Stop**. Stopping the ship utilizing hull drag and making sharp turn with combination of braking as shown before. Speed has to be reduced because otherways large heel might occur. Turning diameter and advance in this manoeuvre are very small and stopping occurs at a very small distance, however some lateral clearance is required.

In fig 16 subsequent positions of the model of the gas carrier equipped with twin azimuthing propulsion devices tested in SRTC are shown. Approach speeed 10 knots, pod deflection 70^0. As it may be seen advance is sligtly more than one ship length, and tactical diameter little more than half length.

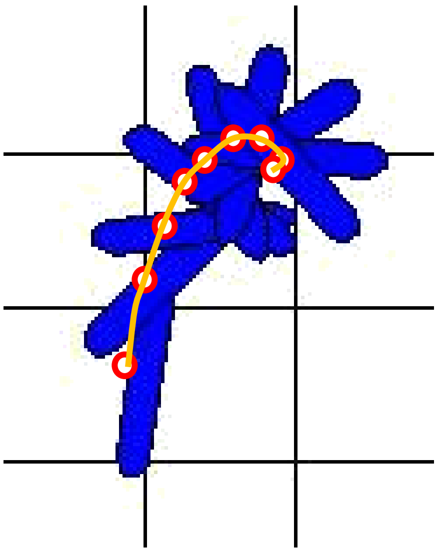


Fig.16 Track of the model performing hard turn manoeuvre

2. **Crash stop POD WAY**. Traditionally crash stop is performed by reversing direction of rotation of propeller from ahead to astern. However using reverse RPM in azimuthing control devices is in general, not recommended. On the other hand pods could be rotated by 180^0 , therefore crash stop could be done POD WAY without reversing propeller rotation.

It is recommended that in this manoeuvre pods are rotated outwards, but rotating them inwards is not prohibited. The crash stop POD WAY is more lenient on the power plant due to decrease in both fluctations of the propulsion power and reverse power generated by the propulsion system. Propellers develop more thrust because they rotate ahead direction, the loads on the pod units are reduced and the time and stopping distance is shorter. During crash stop the ship’s course can be controlled.

Procedure of the crash stop POD WAY is shown in table 3.

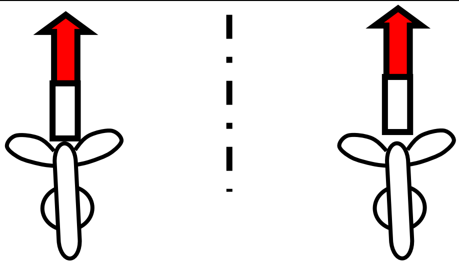
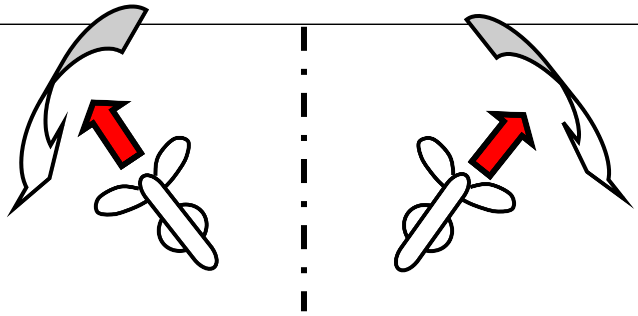
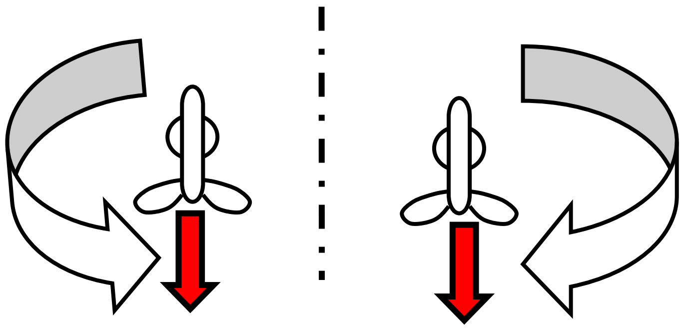
On bridge	Azipod position
Cruise mode is changing to strong manoeuvring (AZIMAN) mode, the system will automatically **reduce power** if there is power limit in this mode. Otherwise RPM must be reduced	
Pod units are turned 35 to 45^0 outwards Wait until ship speed is about 15 knots	
Pods units are turned simultaneously to 180^0	

Table 3. Procedure of the crash stop POD WAY –pulling propellers (ABB instruction)

3. **Crash stop, reverse RPM**. This is traditional crash stop manoeuvre. Reversing RPM at high speed is not recommeded by the manufactureres (Compare Table 2). Before RPM are reversed power has to be reduced, or if it is automatically reduced by the system, cruise mode has to be changed to STRONGg or AZIMAN mode.

4. **Crash stop –tranverse arrest procedure.** Within this procedure both pods are turned by 90^0 to the position opposing each other –to the Tranvers Arrest (TA) position. This gives a very high rate of slow down at higher speeds. As the speed drops down to about 5 knots range, then retardation will be greater by further rotating pods to create astern thrust. (see fig. 17).

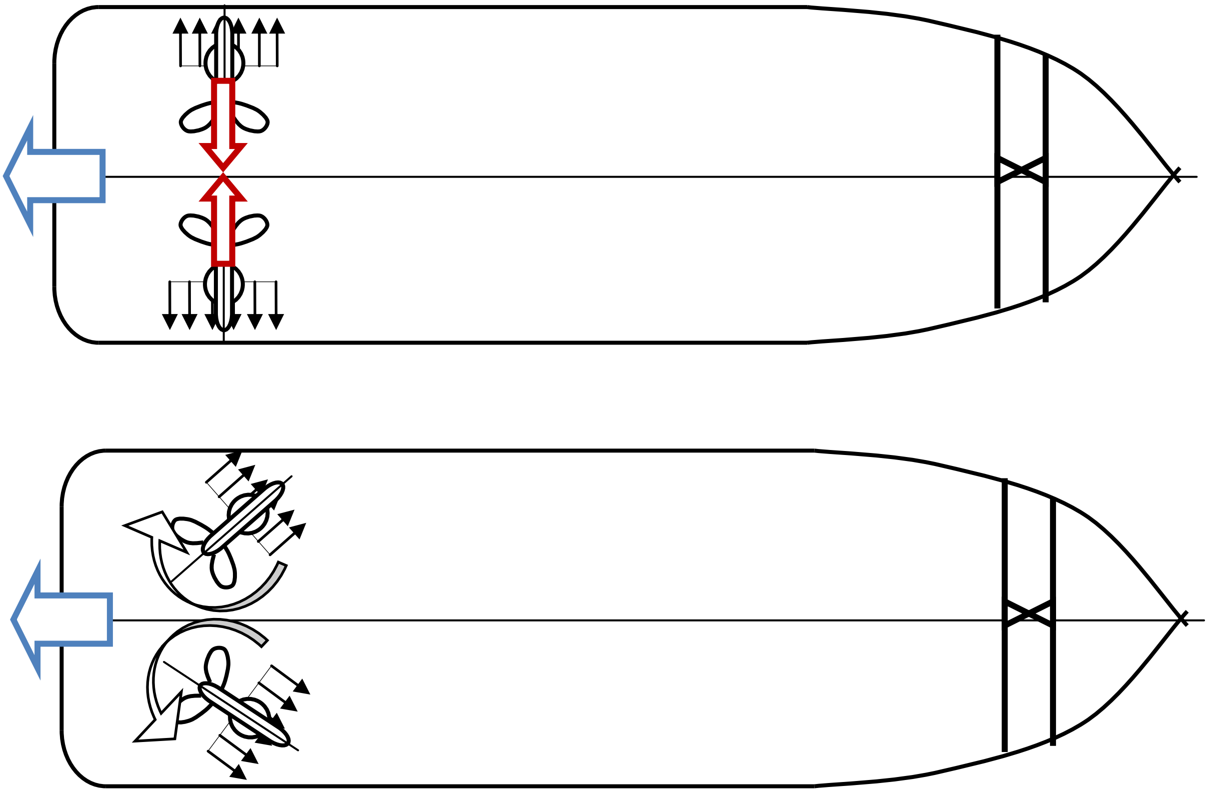


Fig. 17. Crash stop – transverse arrest (TA procedure)

Comparison of the effectiveness of various methods of stopping is difficult because of the limitations imposed on the operation modes of azipods and automatic reduction of RPM when switching mode of operation from cruise mode to AZIMAN or SOFT mode. If there is a possibility to overcame the automatics full RPM could be used in POD WAY method as well as when reversing propeller, but such test can not be performed without serious damage to the propulsion system. Such manoeuvres theoretically could be executed in real emergency situation if the master would decide to prevent imminent collision for the price of damaging pods.

In model tests both methods could be used and comparison of their effectiveness would be possible, even with full RPM. Tests performed in Port Revel Training Centre several scenarios of stopping the model fitted with pod units (de Graauw 2011) were tested and the results of these tests are shown in the Table 4. (all tests were executed at approach speed 13.5 – 14 knots, except test 1, 5.1 and 5.2 that were executed at approach speed 10 knots):

Table 4. Stopping tests performed with model equipped with pod in Port Revel

Test No	Description	Stopping distance in ship lenghts SL
0	Propellers in line and stopped	4.1
1	Reverse propellers to full negative RPM (full astern)	3.0
2	Turn both pods 180^0outboard with full positive RPM	2.3
3	Turn both pods 180^0inboard with full positive RPM (pod way crash stop)	2.1
4	Turn both pods 90^0inboard with full positive RPM (tranverse arrest)	2.9
5.1	Turn both pods 90^0inboard with propellers ordered to stop	5.0
5.2	Turn both pods 90^0outboard with propellers ordered to stop	5.0
6	Turn both pods 60^0outboard with propellers ordered at full negative RPM	2.6
7	Turn both pods 35^0outboard with reduced RPM until speed is reduced to 8 knots, then turn both pods further to $180^0$with increased RPM	4.9
8	Reduce to 80 RPM, then turn pods 180^0outboard, then at 11 knots reduce to 50 RPM and at 8 knots reduce to 30 RPM (fast deceleration)	4.4
9	Reduce to 80 RPM, then at 11 knots reduce to 50 RPM, and at 8 knots reduce to 30 RPM then turn pods 180^0outboard (smooth deceleration)	6.1
10	Turn port pod 45^0 outboard and the starboard pod 135^0 inboard with full positive RPM	2.0

The conclusions with regard to stopping from the tests shown in Table 4 could be summarized as follows:

- The shortest stopping distance was obtained when turning both pods 180^0 inboard at full positive RPM (POD WAY stop)

- Turning both pods 180^0 outboard was slightly less efficient and increases mechanical stress (this is opposite to the ABB instruction).
- The "TRANSVERSE ARREST STOP" (turning both pods 90^0 inboard) is even less efficient and increases mechanical stresses
- Other crash stop scenarios are inferior to the ones mentioned above, except for the TURNING STOP, which can be used if sufficient lateral area is available.

6. CONTROLS IN SHIPS EQUIPPED WITH AZIMUTHING PROPULSION DEVICES

In general, control levers for azimuthing propulsion devices consist of a rotating handle with a circular scale at the base. Usually an arrow or sketch of the ship located at the handle shows the thrust direction ot the pod from this scale. The handle may pushed forward or back controlling RPM of the electric motor or pitch of the propeller in ships fitted with controllable pitch propellers.

Controls panels in azipod propelled vessels look generally quite different from control panels in vessels with conventional propulsion.

Typical control panels in pod driven ships areas shown in fig .18. and 19.

Fig. 18 Centre console onboard Swedish car ferry

As it can be seen from fig. 18 and 19 control levers along with associated displays look different, however the way how they work is essentially the same.

There is abundance of different configurations of azimuthing devices and their associated controls, however. There are pushing or pulling type, fitted with CP propellers, tandem propellers twin propellers etc. built by different manufacturers. These configuration may require handling in their own special way and may require special displays that may differ from the others. As there is no standarization of displays particular manufacturers may choose displays that differ from the others in substantial way. This may be confusing for the operator who learned to operate one particular ship where particular display is provided when he is onboard other ship with different configuration of the control panel.

Usually display panel shows direction of thrust of the pod. This is seen clearly in fig. 20. In this photo the control levers are positioned in order to stop the ship by opposing the two pods.

4

Fig. 20. Typical control panel on board pod driven ship –FOX LUNA (R. Gargiulo et al 2010)

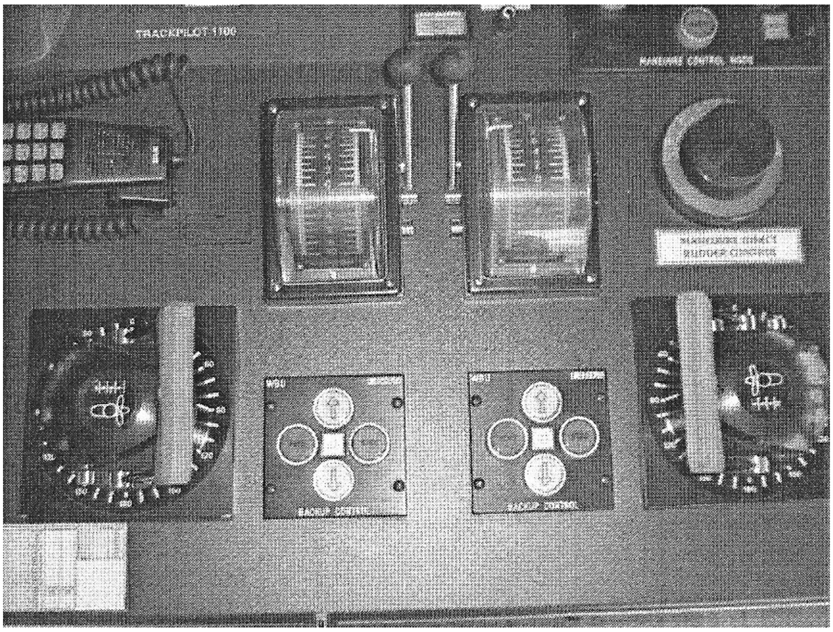


Fig.21 Configuration of display in Costa Crociere (R. Gargiulo et al 2010)

Example of thrust direction indicator (TDI) is shown in fig. 22. This indicator works onboard a vessel equipped with ABB Azipods. Position of the pod and its thrust turned to port by 30^0 is shown, but the ship turns to starboard. The rear pointer shows helm angle that is in this case 30^0 to starboard to be in line with the normal operation of ships with conventional rudder – starboard rudder, ships turns to starboard.. It is not known in this case whether the control lever is turned to port or to starboard by 30^0, but in some ships in this situation control lever may be turned to starboard, in direction in which ship turns. Such arrangement may be provided in order to make control of the pod intuitive. However this should be clearly indicated, because otherwise it may be confusing and leading to accidents.

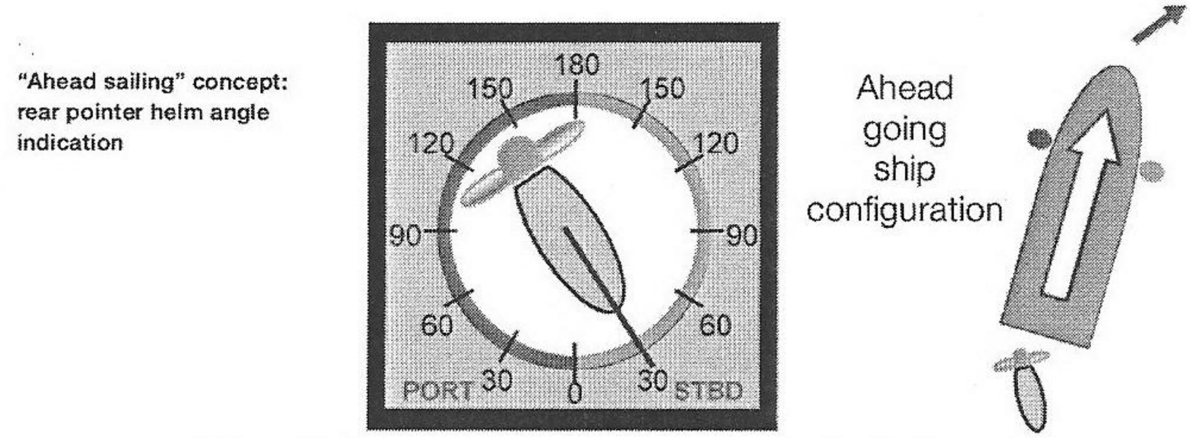


Fig. 22. Example of Thrust Direction Indicator

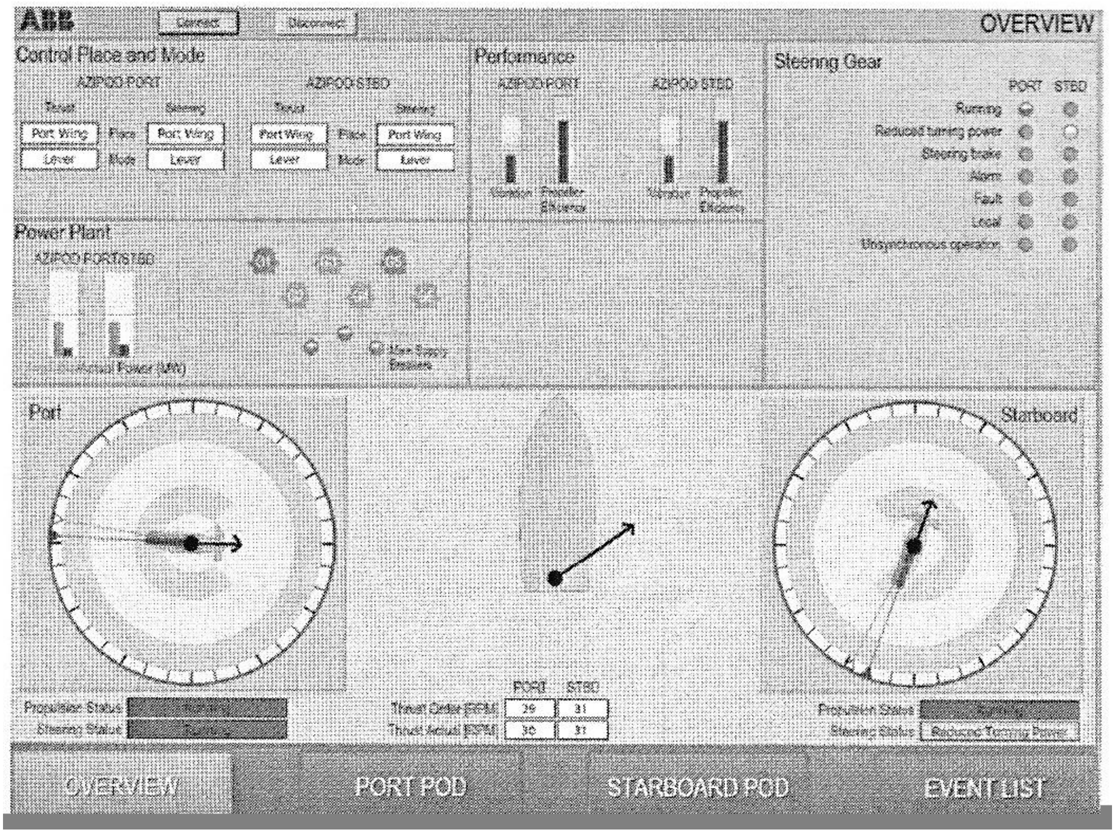


Fig. 23. ABB intelligent bridge control interface

Fig. 23. shows screen of the ABB intelligent control interface for Azipod devices. Display shows direction of thrust of both pods and in the middle resulting thrust direction. Display shows also mode of operation, of where the pods are controlled from (the port wing in this case) and addition information as to how the Azipods are performing along with any limitations that are imposed on Azipods.

Some guidelines and recommendations related to bridge control system have to be noted, applicable to all ships but at the same time having impact on bridge control system of ships equipped with azimuting propulsion devices.

One of this is the recommendation of Marine Safety Committee of IMO (MSC Circ. 982) “Guidelines on Ergonomic Criteria for Bridge Equipment and Layout”. Those guidelines provide general recommendation related to bridge design.

From the operational point of view important recommedations are included in **MSC Circular 1061 – “Guidance for the Operational use of Integrated Bridge Systems (IBS)”,** the extract of which is given below:

2.1. Mode awareness

Mode awareness is based on the knowledge and purpose of various operation modes included in the IBS. Use of different operational modes should follow bridge procedures based on company automation policy

The other recommendation is included in the **Safety of Navigation Circular 265 “ Guidance on the Application of SOLAS Regulation V/15 to INS, IBS and Bridge Design”** the extract of which is given below:

8. Operation mode awareness

8.1. The system and its physical arrangement should provide convenient and continuous access to essential information such as heading, rudder or azipod angle, and propeller RPM or pitch and, if available, rate of turn to provide information necessary for safe navigation for both the bridge team and the pilot. If any auxiliary or separate console or workstation is provided for the pilot, it should provide the same quality and quantity of navigation information needed by the pilot as the main console or workstation.

8.2. The system should continuously indicate to the bridge team and pilot the system operating modes currently in use and provide simple access to other available operating modes.

8.3. The system should indicate failures in a clear and unambiguous manner to enable the bridge team and pilot to understand the nature of the failure.

8.4. Information should be presented consistently within and between different subsystems. Standarized information presentation, symbols, abbreviations and coding should be used according to resolution MSC.191(79).

8.5. When standarized symbols are not available, information, symbols and coding should be visually representative and should be consistent with established information presentation, symbols and coding. The used symbols should not conflict with the symbols specified in SN/Circ.243. Any inconsistencies that might cause confusion or errors should be avoided.

In manned models control panel used are arranged in a similar way.. Example of the control panels on model SRTC is shown in fig. 29.

7. MODEL USED FOR TRAINING, DESCRIPTION, CONTROLS

In SRTC model of the gas carrier of capacity 140 000 m^3, fitted with two POD propulsion units with pulling fixed pitch propellers is available for training. The model was build in model scale 1:24. Fig. 24 shows the photograph of the model, and the dimensions of the model are shown in the table 5.

Fig.24. Model of POD driven gas carrier in SHRTC

Table 5. Dimensions of the model used in SHRTC

Dimension	Real ship	Model
Length [m]	277.45	11.56
Breadth [m]	43.2	1.80
Draft [m]	12.0	0.50
Block coefficient [-]	0.79	0.79

Fig. 25. Model equipped with azimuthing propulsion device at SRTC

The SHRTC uses also the POD driven models of tugs. They are equipped with two propulsion units, one with pushing propellers, the other with pulling propellers at the bow, that are controlled separately, no reverse revolutions, but they can be rotated 360 deg. The models are shown in fig 26 and 27.. The tug models are used in escorting operations. Fig 28 shows escorting tug at work with the model of the large tanker.

Fig. 26. Model af the ASD tug at SRTC

Fig. 27. Model of the pod propelled tractor tug at SRTC

Fig. 28. Model of the ASD tug working at ster of a tanker (SRTC).

Control panel in the model is shown in fig. 29. In the panel position of both pods is shown –arrow indicate direction of thrust. Levers are use to rotate pods by 360^0 and to control RPM.

Switch is provided to change the mode of operation that could be cruise mode or manoeuvring mode (AZIMAN). In cruise mode both pods could be controlled by left hand lever or by right hand lever. In the centre part of panel position of pods and the their power is shown.

No limitations of RPM (or power) are imposed in the cruise mode, because the speed of the model is limited to manoeuvring speed.

Fig. 29 . control panel on the model of pod propelled ship (SRTC)

8. COMMANDS USED IN AZIMUTHING EQUIPPED VESSESL

Commands used when manoeuvring azimuthing equipped vessels in different ship owner companies differ widely from one to other. Therefore it would be difficult at present to recommend one standarized set of commands and masters and pilots coming onboard of different ships should first of all familiarize with the system used in this particular ship.

Cpt. Jeff Baken and Mr. Geoarge Burkley in their paper (2008) offeres Azipod Manoeuvring Terminology and commands developed primarily to ABB/EMRI azipod comntrol systems. The essential part of this paper is reproduced here.

Command Terminology for Manual Azipod Manoeuvring

Term	Command definition	Spoken as…
Pods	Azipods	“Pods”
Direction of rotation	Inboard or outboard	“Inboard” or “Outboard”
Degree of pod rotation	Degrees from 0^0 to 180^0 (inboard or outboard) *(Note: may substitute “midships” for 0^0 if marked as such on the console)*	“40 degrees”
Direction of power application	Propellers pulling (Ahead) or pushing (Astern)	“Positive” or “Negative”
-.Amount of power in RPMs	Amount ot RPM spoken as integer	“30 RPMs”
-.Amount of power in pitch settings	Amount of pitch spoken as an integer or percentage	“Pitch- 3” or “Pitch-30%”
-.Amount of power in lever settings	Lever setting spoken as integer	“Lever -3”

Example Commands for Manual Azipod Maneouvring

Command sequence					
POD ID	**Direction of Pod rotation**	**Degree of POD rotation**	**Direction of power**	**RPM Pitch Lever**	**Spoken command**
Starboard POD	Inboard	136^0	None	None	“Starboard POD… inboard…135 Degrees”
Starboard POD	Already in position	Already in position	Positive	30 RPM’s	“Starboard POD… Positive…30 RPM’s”
Port POD	Already in position	Already in position	Negative	40 RPM’s	“Port POD…. Negative….40 RPM’s”
Both PODS	Already in position	Already in position	Direction previously applied	Zero (RPM’s, Pitch or Lever)	“Both PODS…… Stop”
Both PODS	Inboard (or Outboard)	0^0 (Midships)	Direction previously applied	35 RPM’s	“Both PODS…… Midships”

9. PROGRAMME OF THE COURSE

Model training programme for ship masters and pilots on azipods driven ship for manned models simulators

Objectives of training
Enhance the knowledge of and skills in handling azipod propelled ships. In particular enhance the knowledge of manoeuvring characteristics and specifics of operation of azimuth propelled ships, various factors affecting their manoeuvrability including environment. Help the participants to understand the importance of safety by showing the effects of handling errors. Show the participants the ways to handle critical situations. Enhance safety by applying the proper procedures
Lectures
General information on the simulator facility. Principles of manned models technique. Similitude laws. Characteristics and types of azipod driven ships and azimuthing propulsion. Principles of work and operation of azimuthing propulsion devices. Hydrodynamic characteristics of pod driven ships Manoeuvring characteristics of ships equipped with azimuthing propulsion devices. Basic manoeuvres. IMO requirements related to manoeuvrability. Operation modes of azipod driven ships. Various modes of stopping. Slow speed manoeuvring. Harbour manoeuvres. Operational restrictions related to azimuth propulsion. Principles of interaction effects – bank effect, shallow water effect, canal effect, ship/ship interaction effect. Sailing in current. Current forces. Manoeuvring principles in current from different directions. Inertia effects in current. Effect of wind. Wind force. Manoeuvring principles under wind effect. Human factor issues contributing to safe operation. Handling emergency situations.
Pratical exercises

Familiarization with the simulator. Procedures for start-up and stop. Familiarization with controls and equipment.

Unberthing and berthing; crabbing towards the jetty or away from the jetty without or with bow thruster use. Leaving the harbor basin making turns with different modes , pods coupled or independent, steering in different modes, cruise soft and strong. Steering onto navigational marks. Executing standards manoeuvres: turning circle and zig-zag manoeuvres. Slow speed manoeuvring in different modes.. Stopping in different modes Negotiating narrow passages and entering locks, bow first or stern first. Steering in narrow fairway with several bends.

Manoeuvring feeling interaction effects - shallow water, bank effect and canal effect. Meeting and overtaking other ship in a narrow canal feeling interaction effects between two ships.

Manoeuvring in current, steering with or against current, entering dock with current, from different directions, bow or stern first, turning in current, feeling inertia effects in non-uniform current, entering lock with or against weak current.

Emergency manoeuvres involving engine failure forcing to steer with one pod only, the other blocked in different positions.

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