Discussion of Stern-First-Method in Ship Handling for Ship Operation, Education & Training using Fast Time Simulation

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Keywords

Ship-handling, Voyage planning, Simulator Training, Fast-time simulation

Abstract

Some port approaches require challenging manoeuvring strategies for arrival and departure, specifically under heavy wind and current conditions. In recent papers a discussion of the "Stern-First-Method" SFM was started suggesting that it would be beneficial to go astern into the harbour instead of the conventional bow first method. In this paper the SAMMON software for "Simulation Augmented Manoeuvring Design, Monitoring & Conning" will be used to analyse this SFM for challenging scenarios to provide insights into the potential benefits of this methods.
This software is based on the innovative "Rapid Advanced Prediction & Interface Technology" (RAPIT) to simulate the ships motion with complex dynamic math models and to display the ships' future track immediately based on Fast Time Simulation in an Electronic Navigational Chart for any rudder, thruster or engine manoeuvre planned by the navigator.
The SAMMON system has been developed and matured over years, and promising experiences were made at the Maritime Simulation Centre Warnemuende MSCW and other centres. Currently, specifically the use of the SAMMON Manoeuvring Planning tool will be an element of the transfer of knowledge within the current ERASMUS+ project EURO-ZA between the partners from Europe South Africa.
The benefits for increasing the effectiveness of lecturing and simulator training have been proven in previous publications and will be made visible in this paper by using simulator ships both twin screw and azimuth propulsion for discussion of the SFM manoeuvring strategies.

1. INTRODUCTION

Some port approaches require challenging manoeuvring strategies for arrival and departure: Specifically, when the waterways are very narrow and therefore only small drift angles would be allowed to keep the swept path of the ship to minimum width. This might be even more challenging, if the ship has to manoeuvre under heavy wind and current conditions.
In recent papers [1] a discussion of the "Stern-First-Method" SFM was started and the pros and cons were analysed for an arrival at Southampton (see **Fig. 1**). The conclusion was that it would have benefits to go astern into the harbour instead of conventional procedures going ahead with bow first. These investigations were made specifically with a twin-screw passenger vessel in a full mission simulator environment at CSMART. Numerous exercise results made by several trainees based on their individual strategies were considered. The disadvantage of this method is: it is very time consuming and the findings are based on the exercise results of the trainees as they were, based on their decisions.

In this paper the principles of stern first motion will be analysed in detail - in general and specifically for ships with azimuth propellers / podded ships, which is not available in the literature yet. Instead of time-consuming exercises in full mission simulators fast time simulation will be used: the SAMMON software for "Simulation Augmented Manoeuvring Design, Monitoring & Conning" is unique to analyse the technology of manoeuvres and specifically this SFM for challenging scenarios to provide insights into the potential benefits of this methods:

- That SAMMON system represents the full information from ship's manoeuvring documentation and additional trial measurements, which have been condensed in a complex ship dynamic simulation model, capable of simulating environmental effects by using the innovative "Rapid Advanced Prediction & Interface Technology" (RAPIT). Even with standard computers it simulates 1000 times faster than real time: in 1 second computing time it achieves simulates a manoeuvre lasting up to 20 minutes. This technology was initiated in research activities of the "Institute for Innovative Ship Simulation and Maritime Systems" ISSIMS at the Maritime Simulation Centre Warnemuende - MSCW, which is a part of Hochschule Wismar, University of Applied Sciences - Technology, Business & Design in Germany, specifically in its Department of Maritime Studies. The technology has been further developed by the start-up company ISSIMS GmbH [6].
- There are several modules of the FTS simulation system: In the centre stands SAMMON as the innovative system for "Simulation Augmented Manoeuvring – Design, Monitoring & Conning". It comprises several software modules, the two most important are (a) the Manoeuvring Design & Planning Module and (b) the Manoeuvring Monitoring & Conning Module with Multiple Dynamic Manoeuvring Prediction. These modules are made for both for lecturing and simulator training for ship handling and also to assist manoeuvring of real ships on-board, e.g. to pre-pare manoeuvring plans for challenging harbour approaches / departures [3][4]. First results were presented where even fuel consumption was involved into SAMMON [6] to find out optimal strategies to handle podded ships as part of the EURO ZA project [5].
- Important tools are made to support the SAMMON, e.g. the SIMOPT software for modifying ship math model parameters both for simulator ships in SHS and for on board application of the SAMMON System and the SIMDAT software module for analysing / displaying simulation results both from simulations in SHS or SIMOPT /SAMMON and from real ship trials. [6]

Several movies are available to demonstrate ship dynamics and ship handling discussions using the SAMMON tools for lecturing and training [8]-[12].

In this paper at first the sample manoeuvre from [1] will be used as a reference to model this manoeuvre and the strategy used with the SAMMON Planning tool. Some conclusions will be drawn on the usability of SAMMON and several parameters are varied to see what effect they have on the success of the manoeuvre.
Then a discussion will follow what effect the application of rudders / thrusters / pods on manoeuvring motion has in general and how these effects can be explained. This goes beyond the discussion in [2], where the effectiveness of thrusters in astern motion was seen as more positive as for ahead motion. Finally, samples are given how the SFM can have advantage under strong wind.

2. Sample of SFM for Twin Screw Vessel for Port Arrival

2.1 The concept of the manoeuvre and the presentation in the Full Mission Simulator

Here the sample manoeuvre will be introduced which were used in [1] to successfully demonstrate the SFM: It is a stern-first entrance into the Ocean Dock Cruise Terminal (ODCT) in Southampton - where the ship must moor starboard side alongside. The design specification contains a number of cruise ship manoeuvres executed at the right time in the right place. Here, an arrival in Southampton's ODCT consists of swinging around in ebb current of 1.5 knots, and manoeuvring into the dock to the required mooring position. A detailed description of the specific actions to be taken and where they are to be carried out are given and discussed in [1]. Here they are briefly outlined as follows and described in **Fig. 1**:

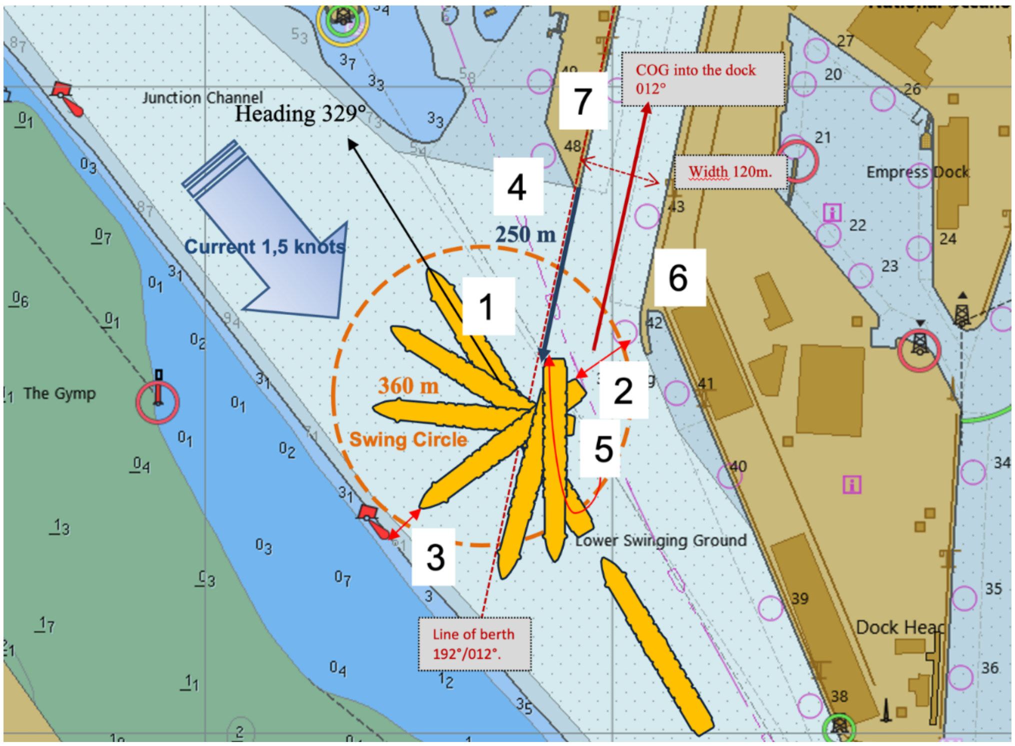


Fig. 1 Scenario and critical positions in the SFM during arrival and berthing a cruise ship at the Ocean Dock Cruise Terminal (ODCT) in Southampton / UK *[1]*

"…The turn is best initiated at 2.9 knots STW ahead, when the ship is in the middle of the fairway, with the stern abeam berth 41. The stern is now already in the right position for the subsequent approach to the basin, after the turn has been completed. When all means of propulsion are used, the ship turns as fast as possible. To initiate the turn, the bow and stern thruster can be used, and the navigator can split the two engines and the rudders. Splitting the engines and turning over port is done as follows: starboard engine ahead (60 RPM) with rudder hard to port, and port engine astern (60 RPM) with the rudders midships. A ROT of 30° per minute is possible; with la lower ROT, the ship is exposed to the current for a longer time. The consequence of a longer exposure to the current is an extra set to the south-east in the direction of the current. The turn from 329° to 176° amounts to 155°. At an average turning speed of 25° /minute the turn takes 372 seconds. The current of 0.772 m/s (1.5knots) will theoretically set the ship 287 meters to the south/east during the turn. The set to the south-east is already compensated for in two ways: first, by the dynamic transition into the turn with speed ahead; and second, by 'overshooting' with the stern to a position on the line of berth. Although the speed drops in the turn, there is a danger of overshooting the red buoy line in the west indicating the 10 m contour. To monitor this potential danger, the distance from the bow to the red buoy must be checked. … The ship must keep turning over port until a heading of 175° is reached. Approximately one minute before reaching the required heading of 176°, the position of the starboard side of the stern in relation to the 192° line of berth (LOB) alignment, should be checked.

Controlling the stern position, which must be in position 5, abeam berth 42 can be achieved with the stern thruster to port, in order to fix the stern to this position. The starboard side of the stern should be 5 m –10 m east of the 192° LOB alignment. The turn is safely performed when the stern is more than 250 m to the south of the entrance and in the above-mentioned position (see position 5)…."

From this description is to be seen that Stern First Method this is not an easy manoeuvre and many parameters could influence the outcome. And going astern for long distances would also raise concerns with respect to efficiency aspects:

- moving astern means always higher hull resistance than making headway.
- Also, the efficiency of the propellers is smaller, specifically on normal single or twin propellers going astern. In contrast, pod propellers turned astern has much less losses and nearly keeps the full thrust.

This means the Stern First Manoeuvres should only be used if the advantages of the manoeuvring benefits are dominating against efficiency losses.

2.2 Modelling and discussing this manoeuvre concept with SAMMON

To investigate and optimise potential parameter changes in complex manoeuvres as SFM, it would be very time consuming to do that in Full Mission Simulator as a real time simulation. Therefore, the SAMMON Fast time simulation tool was used to model this manoeuvre and to look if it is feasible to come to the same conclusions in less time. It should be underlined that the focus and benefits of this tool is on the technical part of the ship handling process, i.e., to find out the best application of the controls to use the full but safe range of the ship's dynamic characteristic, seeing the technical limits of her manoeuvrability even under environmental challenges – nd to create a workable concept as a manoeuvring plan (further consideration of human and tactical aspects, i.e. how to manage the operational challenges to follow a complex manoeuvring plan and to manually control the ships motion,- e.g., with restricted view from the bridge during Stern First Manoeuvres - can be additionally investigated and trained in a Full Mission simulator using the findings from the fast time simulation to save time)

The complete Manoeuvring Plan made by means of the SAMMON Planning Tool is shown in **Fig. 2** where at each blue shape a Manoeuvring Point MP was set with a number in consecutive order, representing the position where a new command for the controls was ordered. In the following the description is provided on how this manoeuvring plan was made at picking out selected MPs, starting with the first MP0 of the manoeuvring plan. It should be highlighted that this plan can be made by an experienced navigator in about 10 minutes only!
Before going into detail, the interface of the SAMMON Manoeuvring Design & Planning tool is explained which combines the following three windows to be seen in all the following figures:

- The right window represents the steering / control panel: this is for adjusting the controls for the selected actual Manoeuvring Point MP (actual position in red) or entering the environment conditions e.g. wind, current and water depths (bottom right),
- The centre window displays the electronic navigational chart (ENC) where the simulated ship's motion is visualised: the predicted ships positions are shown as black contours indicating the time intervals for the display range (top left). The reference position (blue shape with red frame) can be shifted by means of the time slider at the bottom left to any position of the already predicted track. There a new MP can be set and controls may be changed there.
- The left and top window display the ship status at the reference ship position on the track– this status is defined by e.g. the current navigation data, environmental conditions and actual ship manoeuvring control data.

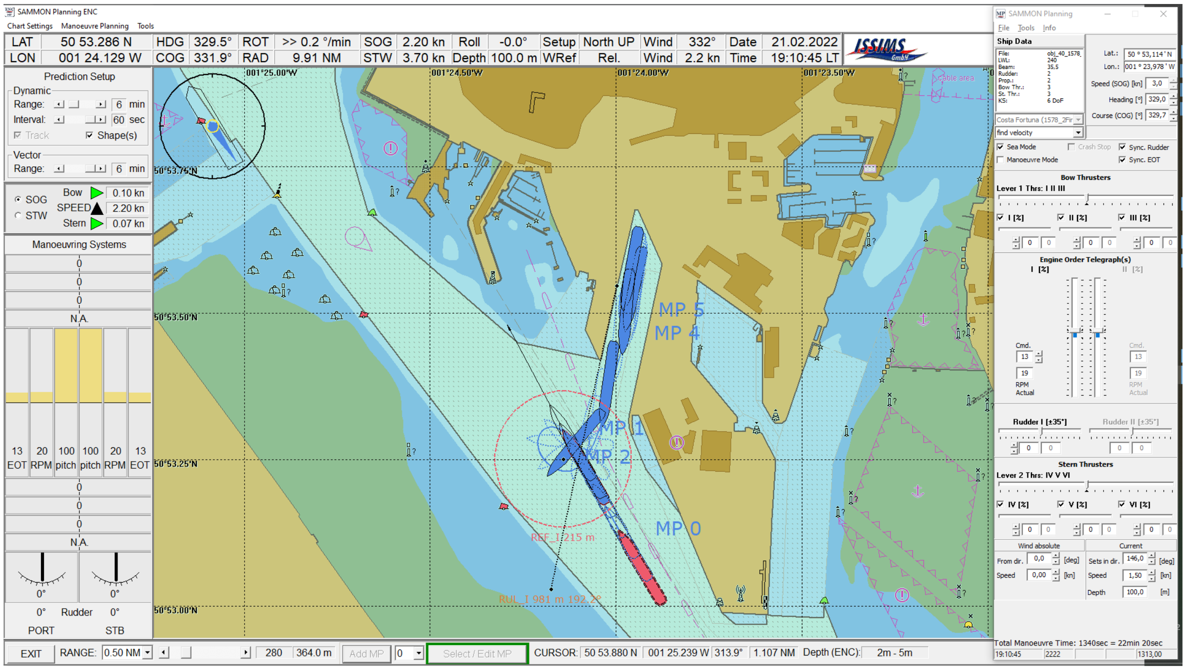


Fig. 2 SAMMON Planning tool interface with complete Manoeuvring Plan with manoeuvring Points MP. The tool is in Edit Mode and the focus is on the red shape at MP0 – this is the initial situation when approaching the turning area

The scenario starts at MP0: this is the initial situation when approaching the turning area with 3kn and HDG= 329° under current 1.5 kn setting in 146°; the ships is slightly slowing down to 2 kn due to the reduction of EOT to 12% in order to prepare for turning. The black contours are the prediction every minute for the next 6 minutes, the reference position (seen as blue shape with red frame) is moved by the time slider 280s ahead and is nearly at the centre of the planned turning area (marked as red dotted circle). This position and the current speed there of 2.20kn is suitable to set this position as new MP1.

This MP1 is the start of a new manoeuvring segment which is described in **Fig. 3**: Nearly at the centre of the turning area she is starting turning with split engines, Port (PT) engine astern EOT 30%, Starboard (SB) engine remains ahead EOT 15%; the turning is increase by rudder PT 35° and additionally stern thruster 100° to SB. It was tried to use the bow thruster to PT to increase turning, but finally it was not used because it could easily be seen by the tests that then the bow moves downstream with the current – therefore all turning power is generated by rudder and thruster forces holding the ship against the current… The blue shape is the position of the time slider at 200s where the next MP 2 will be set.

At MP 2 in **Fig. 4** the turning has to be reduced by stopping the stern thrusters and going astern with EOT -60% on both engines - the controls can be easily adjusted so that the stern and specifically the predictions start to point into the basin.

In **Fig. 5** is shown the situation at MP 3: When the stern is coming close to pier the turning is counteracted with the stern thruster by -41% PT, the engines are kicked ahead 40% EOT for reducing astern speed; the current speed is set to zero because the stern is in the basin.

The berthing process continues with the final approach to the berth – there is no extra figure but in the **Fig. 2** the remaining manoeuvring points can be seen:

- at MP 4 the Speed has reduced to 0.6kn therefore engines STOP; bow and stern thrusters are used to move the ship to the berth.
- At MP 6: Finally the engines and thrusters are used to finetune the position at the berth.

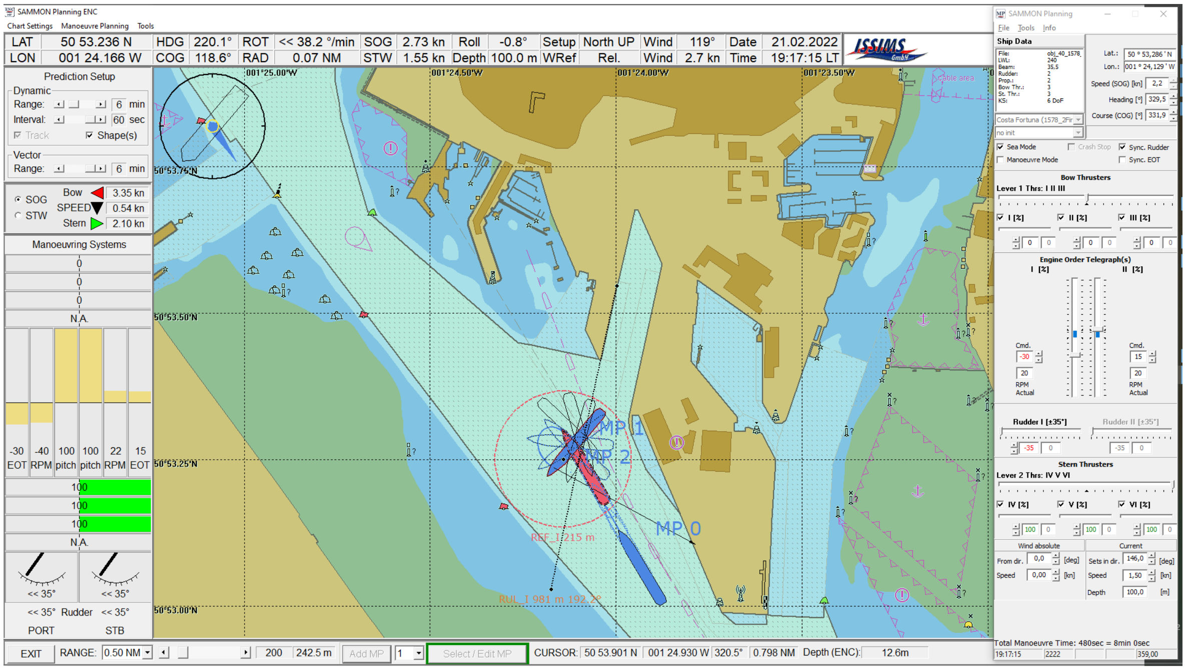


Fig. 3 At MP1 the ship has reached the turning area, starting turning with PT engine astern 30, SB engine remains ahead 15; turning is increase by rudder PT 35° and stern thruster 100° to SB.

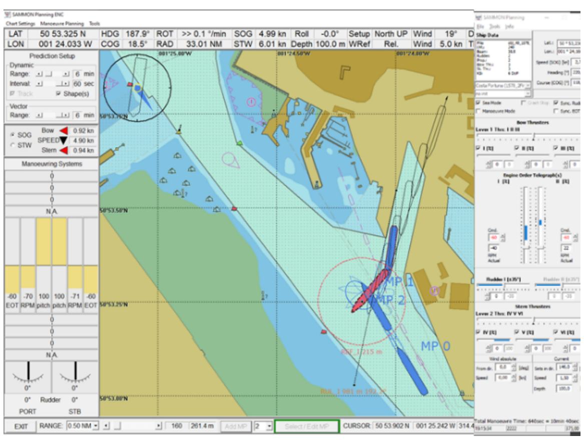


Fig. 4 Setting the controls at MP 2: stop stern thrusters for reducing turning and go astern with EOT -60% on both engines

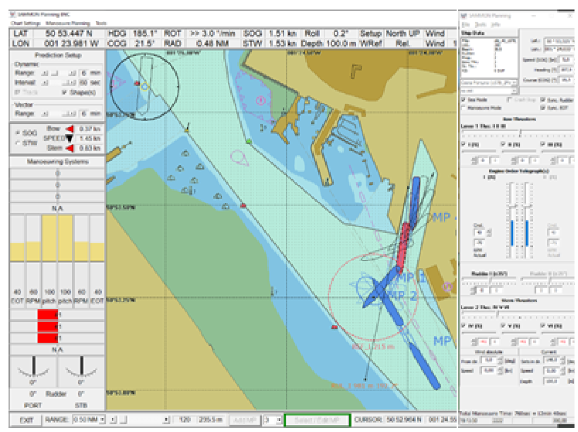


Fig. 5 Setting the controls at MP3: stop turning with stern thruster -41% PT, engines are kicked ahead 40% EOT. set current to zero in the basin.

It is obvious from this sample that the SAMMON fast time simulation allows to model manoeuvring strategies in very short time. This make it possible to fine-tune manoeuvring strategies, discuss what-if decisions and to find out limits with respect to selection of action time and magnitude, limitations of environmental conditions and manoeuvring thresholds. By means of the application of the SAMMON Planning tool could be shown that the stern first method is applicable and has several advantages which will be investigated now in more detail.

3. General discussion of the different effect of manoeuvring controls in ahead and astern motion and location of pivot point (PP)

The most important effect on the manoeuvring motion and the consequences on swept path has the location of the controls used, i.e. at the bow or stern and the direction of motion, i.e. ahead / bow first or astern / stern first. Some movies were made to demonstrate these effects [9]. In general, it can be shown that for generating a turning circle to port:

Bow first motion:

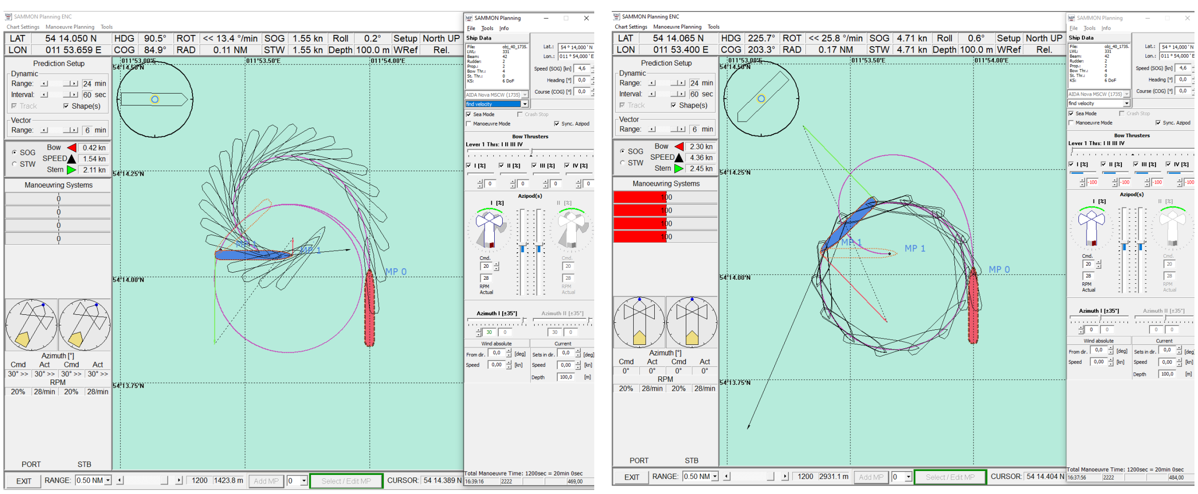
- Using controls like rudders, thrusters or pods at the stern in ahead motion then these controls generate forces to the outside and therefore the ship has big drift angles which are necessary to create lift forces at the hull to move the ship into the turning circle.
- When using controls at the bow like bow thrusters then the drift angles and swept path are small because the thruster create forces into the turning circle.

Stern First Motion:

- Using controls like rudders or stern thrusters - or even more powerful pods! - at the stern (which is now going first!) then these controls create forces into the turning circle - in this case the drift angles and swept path are small!
- When using controls at the bow like bow thrusters then the ship has big drift angles which are necessary to move the ship into the turning circle.

Several experiments will be shown for turning manoeuvres with rudder / PODs and with Bow Thruster to demonstrate the difference and advantage of SFM to standard Bow First Method in certain conditions.

In **Fig. 6** the Bow First Method is shown in two versions: in the left figure the turning is created with the PODs in sync mode and both angles 30° to SB: this version has a bigger advance and smaller final speed 1.55kn (i.e. covered distance 1423m after 1200s) – the reason is the big drift angle compared to the version with turning only by bow thrusters in the right figure. When turning with Bow Thruster there is a smaller Advance, less resistance because of small drift angle and therefore higher final speed 4,71kn and covered distance 2931m after 1200s, minimum swept path.



Both pods in sync mode to SB 30° (IN 30 / OUT 30), no thruster | Both pods in sync mode amidships 0°; Bow Thruster 100% to PT

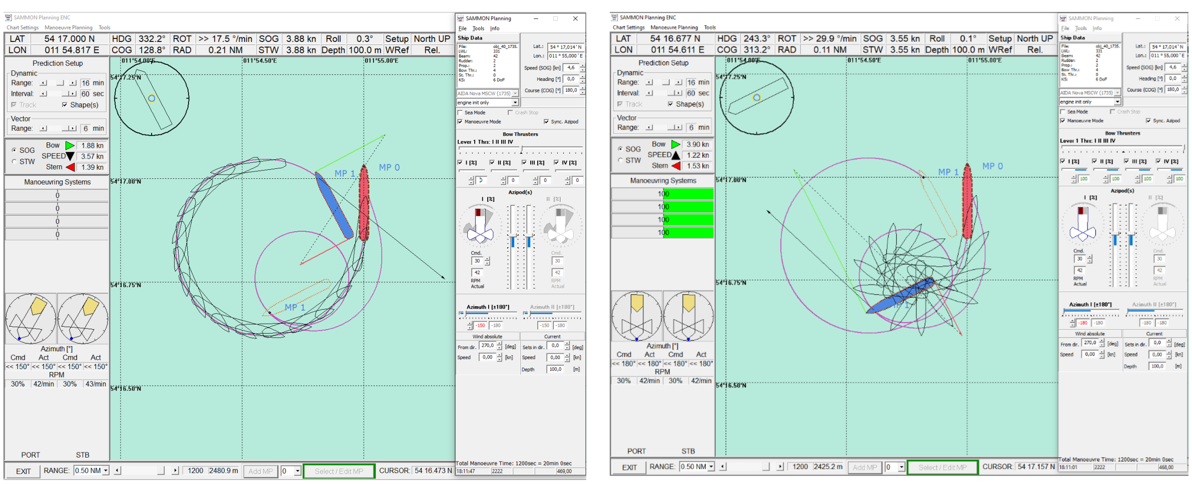
Fig. 6 Bow First Method during Turning circles for a cruise vessel with two pod propellers and bow thruster (Initial conditions: Speed 4.6kn, Both Pods in Sync mode at 0°, EOT 20%)

In **Fig. 7** now the Stern First Motion is shown when the ship going Astern with POD -180°: The initial speed should be the same – therefore the propellers are set to EOT -30% to get the same initial speed 4.5kn as for the experiments with ahead motion; this is because the same magnitude of EOT as for ahead brings too small speed because of higher resistance for astern motion.

In contrast to the Bow First motion now the turning with pods at the front end of the ship shows much smaller drift angles than turning with the Bow Thrusters which are now at the aft end of the moving ship. This effect comes because the pods are now pulling the ship into the turning circle, whereas the bow thruster are creating thrust to the outside and therefore the drift angle is needed to bring the ship into the turning motion, connected with bigger swept path and speed loss.

It is also important to discuss the location of the Pivot Point (PP) during Bow First and Stern First motion: Normally in seamanship books it is mentioned as a "sort of rule" that when the ship is sailing bow first the PP is placed at ¼ of length from bow, or when is sailing astern the PP is placed at ¼ of length from stern. However, this is much too simple and cannot be generalised [12] because the PP is highly depending on where the steering force is acting – this can be seen in **Fig. 6** to **Fig. 8**: In all these figures the transverse speed vectors are shown at bow and stern (green to SB, red to PT), and the connecting dotted line between the tips of these vectors indicates where the PP is when its crossing the ships' centreline:

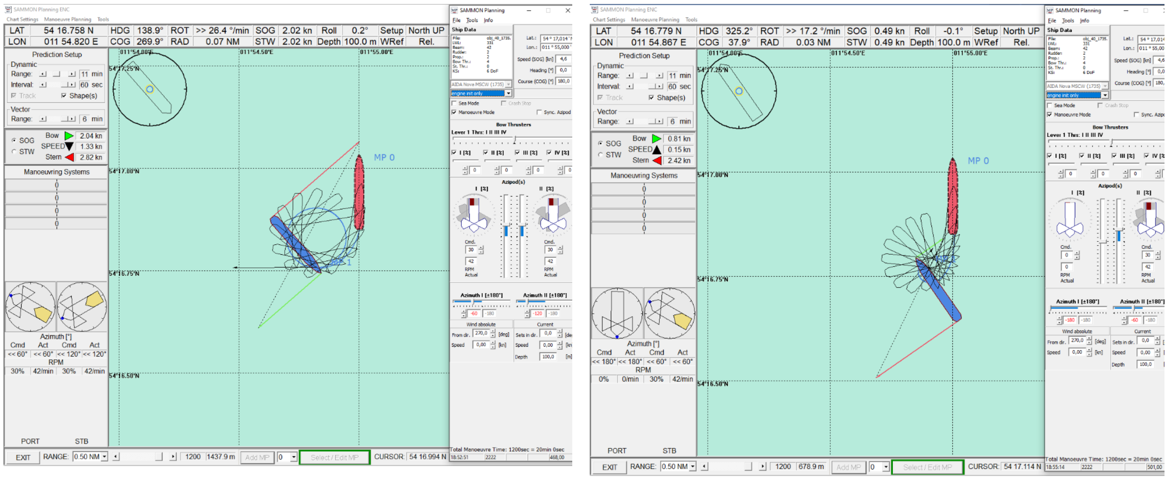
- during Bow First motion in **Fig. 6** in the left picture the PP is placed at ¼ of length from bow because the control force is the transverse thrust out of the turning circle at the stern due to the pod angle, creating big drift angles. But in the right picture the PP is placed nearly at half of the ship length because the control force is the thruster at the bow, pulling into the turning circle - therefore no drift angle is existing (or even negative drift angle can occur)
- during Stern First motion in **Fig. 6**the situation is conversely: in the left picture the PP is placed nearly at half of the ship length because the control force is the pod now at the front end of the motion, pulling into the turning circle, therefore no drift angle is existing (or even negative drift angle can occur). But in the right picture, now using the bow thruster at the end of the ship during astern motion, the PP is placed at about ¼ of length from stern because the control force is the transverse thruster force is now acting out of the turning circle, creating big drift angles.



Turning with both pods in sync mode to OUT 150° / IN 150°), no thrusters | Turning only with Bow Thruster 100% to PT, both pods in sync mode amidships 180°;

Fig. 7 Stern First Method during Turning circles for cruise vessel comparing pod and thruster operation (Initial conditions: Speed 4.6kn, EOT 30%, Both Pods in Sync mode at 180°)

The big advantage of pods is their ability to produce transverse thrust with high power [11] – therefore very small turning circles can be realised as to be seen in **Fig. 8** e.g. for pod angles of OUT 60° / IN 120°, i.e. with a combined thrust vector of 90° - or even with a smaller circle for one pod on PT side stopped and the other one with SB IN 60° is producing transvers forces and at the same time is working against the motion. The pivot point is in the situation placed nearly at half of the ship length or even behind (that means to the bow) because the big control force of the pod now at the front end of the motion is pulling <u>into</u> the turning circle - so strong that even negative drift angle can occur.



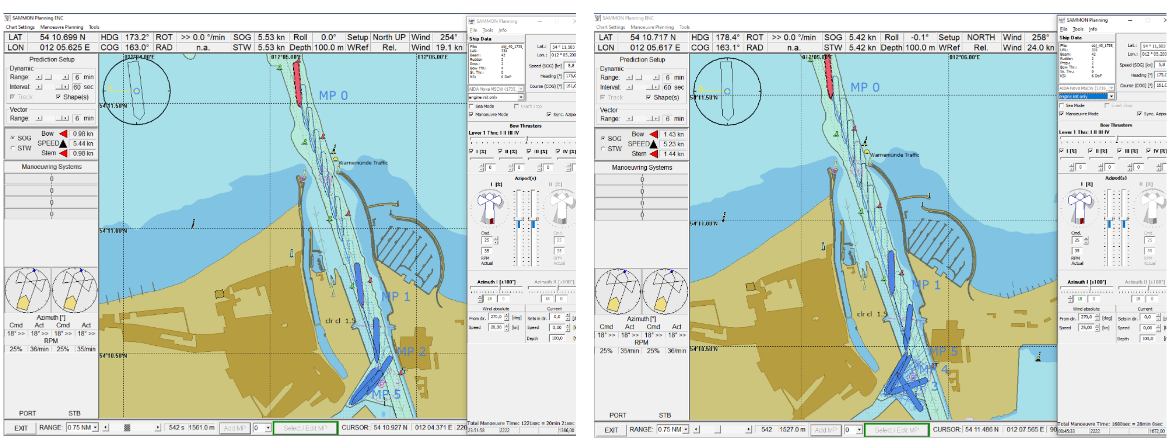
Turning with pods in split mode to OUT 60° / IN 120°, no thrusters

Turning with one pod: SB active to IN 90° EOT 30%, the other stopped, no thrusters

Fig. 8 Stern First Method during Turning circles for cruise vessel for different pod configurations (Initial conditions: Speed 4.6kn, EOT 30%, Both Pods in Sync mode at 180°)

4. Advantage of SFM under strong wind with POD ships

When moving under strong wind then specifically for beam wind high drift angles are needed to create lift forces at the hull to balance the wind force. For demonstration of the difference between Bow First and Stern First Methods a sample will be discussed for manoeuvres for entering the port of Rostock with a cruise ship with two pod propellers and berthing at the cruise terminal under strong beam wind 25kn from 270°. The speed is limited in this fairway to 6.5 kn and in the sample an initial speed of 5.8kn is used.
In **Fig. 9** the Bow First Method is shown where the big drift angle is already at the limits because the swept path is so big that nearly the full fairway width is used. Specifically, when the ship should be berthed with PT side then the turning of the ship in the shipyard basin is absolutely at the limits of the manoeuvrability.

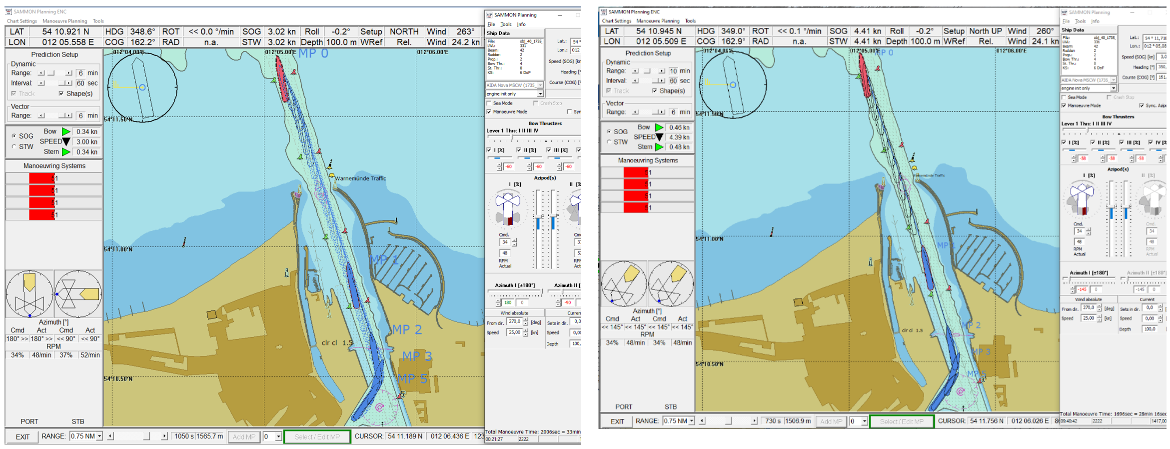


making SB side alongside

making PT side alongside

Fig. 9 Bow First Method for entering the port of Rostock with a cruise ship with two pod propellers and berthing at the cruise terminal under strong beam wind 25kn from 270°

In contrast the Stern First Method is used in **Fig. 10**: in the left picture the pods are used in T-BONE configuration, so one pod at PT side works to control the speed and the other on SB side is for steering and working the stern against the wind, and also the Bow Thruster at the aft end is working the bow against the wind! This makes it possible that the drift angle and therefore the swept path is very small. Also, the berthing manoeuvre with PT can be made very smoothly. This shows that in some cases the Stern First Method makes sense and has a lot of benefits. Alternatively, in the right picture the pods can also be used together in sync mode to get the same result. Other tests were made with slightly higher speed of the vessel close to the fairway limit of 6.5 kn to try out whether the drift angle can be reduced for a smaller swept path – However, this was not the case because with increasing speed the bow thruster is losing its efficiency (located now at the aft end of the ship in astern motion where the efficiency might be still high, even with no anti-suction tunnel) and therefore could not contribute to the balance against the wind in the same way as in the sample for lower speed.



manoeuvring with T-Bone pod position — manoeuvring with sync mode of both pods

Fig. 10 Stern First Method for entering the port of Rostock with a cruise ship with two pod propellers and berthing with port side at the cruise terminal under strong beam wind 25kn from 270°

5. Conclusions and Discussion of results

SAMMON Planning tools' strength lays in the ability for demonstrating and investigating manoeuvring strategies - which is very advantageous for planning and training. E.g., it could be shown that the Stern First Method has benefits in various manoeuvring and environmental conditions. By means of Fast Time Simulation based on the RAPIT technology the intensions and expertise of human operators can be brought into the planning process to find out optimal solutions for manoeuvring strategies, even considering adverse environmental conditions.

And also, many important aspects of ships dynamic like pivot point location and turning / drifting relations can be demonstrated effectively, as well as energy-efficient manoeuvring strategies [13] and support shore-based operators [14] can be supported.

The focus of this tool is clearly on the technical part of the ship handling process, i.e., how to make the best use of the full but safe range of the ship's dynamic characteristics, seeing the technical limits of her manoeuvrability even under environmental challenges. It could be shown with the SAMMON planning in which way pods have advantages controlling the ship under various strong wind and current conditions, specifically when using the Stern First Method.

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