Ærø Municipality / Ærø Ferries

Full Mission bridge Simulations of Navigation

Maneuver simulations - New ferries for Ærø Ferries

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Full Mission bridge Simulations of Navigation

Evaluation of double-ended ferry

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0. Executive summary

The aim of this project is to conduct a ship simulator-based study in collaboration with Ærøfærgerne (Ærø Ferries/Ærø Municipality) to assess the safety and manoeuvrability of a design double-ended ferry with propulsion via four azimuth thrusters (two in each end) within the areas: "Højesteneløb" and sailing via "Møllegab" to/from Ærøskøbing and when sailing to/from Svendborg.

Ærøfærgerne plans to invest in new ferries to replace/supplement existing ferries on the route between Ærøskøbing and Svendborg.

The objectives of the study are:

- Ensure that the increased ferry size can manoeuvre and sail safely in the relatively narrow waters with the same reliability as with the existing ferries (close to 100%), including a focus on power requirements for manoeuvring.

- Indicate whether there is a need for or suggestions for changes in the design or marking of the sailing route, with regard to "Højestene" and sailing via "Møllegab" to/from Ærøskøbing, as well as when sailing to/from Svendborg.

The study was carried out at the FORCE Technology Simulation Centre located in Kgs. Lyngby, Denmark using one full mission simulator, Bridge D.

Representatives from Ærøfærgerne were present during various stages of the simulations. Two FORCE Captains with experience in POD controlled the ferries and acted as Instructor/Captain during the simulations. The following participated in the simulations:

Name	Title	Company
Frank Pedersen	Skibsfører og Dpa	Ærø Færgerne
Lars Kristiansen	Captain	Ærø Færgerne
Henrik Faurskov	Captain	Ærø Færgerne
Svend Åge Korup	Teknisk chef	Ærø Færgerne
Cecilie Larsen	Project Manager	Ærø Færgerne
Jakob Møller	Captain/Instructor	FORCE Technology
Carl Thue Rajberg	Captain/Instructor	FORCE Technology
Clara Giarrusso	Project Manager	FORCE Technology
Bugge T. Jensen	Senior Project Manager	FORCE Technology

Table 0-1 List of Participants.

For the simulation study one mathematical ship model of the new ferry was implemented. The ferry reactions and handling were approved by the Captains. Main dimensions for the ferry are LOA 70 m, Beam 17 m and 2.6 m draft.

The observations and conclusions are based on the conducted simulations as well as on the evaluations carried out by FORCE Technology's Captain/Instructor for each run. For a detailed description of the conclusions and recommendations, please see section 3.

A total of 35 simulations were conducted over the 3 days. The simulations involved testing the double-ended ferry in the three different areas, in several scenarios.

The different wind speeds tested over the 3 days were 10, 12, 15 and 20 m/s coming from SE, E, W and NW. Several combinations were tested.

0.1. Conclusions general

When reading these conclusions, it should be taken into account that the mathematical model of the ship used in the study is constructed based on a concept design of the Ærøferry and on relatively few available details (see section 1.1 for more details).
Hence, the results are indicative, and further studies may be needed when the final design is chosen (e.g. steel/aluminium), as it could have an impact on some of the results. The tested ferry is in maximum loading condition with a draft of 2.6 m, and the study investigates the limits for safe operation, i.e. in many of the simulations the environmental conditions are above normal situations.

Højestene

- The channel has a sufficient width for safe passage.
- The marking of the channel is sufficient.
- Maximum speed should be kept between 6.4 - 7.0 knots.
- At low tide (-0.5 m) the maximum speed should be 4.5 knots.
- At high tide (+0.2 m) the channel can be passed with a speed of 8.4 knots.
- There is no big difference in passing the channel with 30 tons BP compared to 20 tons BP.

Ærøskøbing

- 30 tons BP is needed to manoeuvre safely.
- Arriving with wind 20 m/s from NW is above limit.
- The safe operational environmental limit for arrivals with 30 tons BP is NW wind between 15 and 20 m/s.
- SE wind of 15 m/s is the limit for arrivals.
- Departures handled safely from various directions up to 20 m/s.
- Passing Møllegabet was no issue in all tested conditions.

Svendborg

- 30 tons BP is needed to manoeuvre safely.
- When arriving from South towards the berth there is no space for ships moored at Træskibsbroen.
- Arriving from Southeast towards the berth is the safest strategy and will leave space for ships at Træskibsbroen.
- 3 knots of current is above limit.
- Arrivals conducted safely up to 15 m/s and 2 knots current.
- It was safe to depart in 20 m/s NE and 3 knots West bound current.

0.2. Recommendations

General

- It is recommended to have at least 30 tons BP in order to manoeuvre safely in situations with both high currents and strong winds.

- Conduct a risk assessment study:

    - What is the expected downtime?
    - How often will the ferry be fully loaded at low tide and high currents and wind?

Højestene

- Consider dredging Højestene to minimize squat and allow for higher speed through the channel.

- Ferry schedules should take into account that ships should avoid meeting each other in the channel. If ships pass each other in the channel, there will be interactions between the ships and the squat will be increased during the passage.

- Consider performing a detailed CFD analysis for a more precise squat and a consequence of speed profile.

- Consider improving the marking of the channel by placing green and red buoys in pairs. This will help vessels pass the channel in poor visibility.

Svendborg

- When approaching Svendborg, stay close to the green buoy South of the ferry berth and approach the berth in line with the berth.

- Consider moving the green buoy further South to allow the ferry to line up for approach to the berth.

- Consider reconstruction/realigning of the Ferry berth in Svendborg to ensure an optimal approach angle towards the berth.

- The ferry needs support in the aft end for the current, to avoid twisting.

- The quay should have strong fenders, and especially the end of the quay should have strong fenders to lean on when needed.

Ærøskøbing

- Reconsider placement and size of duc d'albe to fit the new ferry.

1. Introduction

The aim of this project is to conduct a ship simulator-based study in collaboration with Ærøfærgerne (Ærø Ferries/Ærø Municipality) to assess the safety and manoeuvrability of a design double-ended ferry with propulsion via four azimuth thrusters (two in each end) within the areas: "Højesteneløb" and sailing via "Møllegab" to/from Ærøskøbing and when sailing to/from Svendborg.

Ærøfærgerne plans to invest in new ferries to replace/supplement existing ferries on the route between Ærøskøbing and Svendborg.

The objectives of the study are:

- Ensure that the increased ferry size can manoeuvre and sail safely in the relatively narrow waters with the same reliability as with the existing ferries (close to 100%), including a focus on power requirements for manoeuvring.
- Indicate whether there is a need for or suggestions for changes in the design or marking of the sailing route, with regard to "Højestene" and sailing via "Møllegab" to/from Ærøskøbing, as well as when sailing to/from Svendborg.

The study was carried out at the FORCE Technology Simulation Centre located in Kgs. Lyngby, Denmark using one full mission simulators, Bridge D.

Representatives from Ærøfærgerne were present during various stages of the simulations. Two FORCE Captains with experience in POD controlled the ferries and acted as instructor/Captain during the simulations.

For the simulation study one mathematical ship model was implemented: "Ærø", LOA 70 m, Beam 17 m and 2.6 m draft.

The evaluation of results is based on the actual simulation runs and the tested environmental conditions as well as on the evaluations carried out by the participating Captains from Ærøfærgerne and the FORCE Technology Captain/instructor for each run. For a detailed description of the conclusions and recommendations, please see section 3.

The following hardware and software equipment were utilised during the study:

- One of FORCE Technology's full-mission bridge simulators running SimFlex4 ship simulator software.
- One database containing the two port areas Ærøskøbing and Svendborg, and the channel Højestene.
- Mathematical model of the double-ended Ferry.

1.1. The mathematical model of the ferry

The mathematical model relies on basic data provided by the Client, which primarily includes a preliminary general arrangement concept, details on installed power, and an expected service speed of 13.1 knots.

Based on this, a mathematical model of the Ferry is developed and used for the study. FT used data from a similar ferry and adjusted parameters according to given values.

It is important to acknowledge that several aspects of the mathematical model are derived from assumptions, which means that the resulting observations and conclusions may have some degree of uncertainty.

Hull steel/aluminum

The main difference between the two types of hulls when seen from a simulator viewpoint is the displacement/block coefficients, which differ between the two hulls. Both models have the exact same length, beam and draft, but the aluminum hull is slimmer and has a lower block coefficient.

The hull resistance was adjusted to give a nominal speed of 13.1 knots at its maximum.

Note also that the mathematical model is in fully loaded condition with a draft of 2.6 m. Most of the transits will probably be partly loaded, which means less draft. This will have an impact on how fast the vessel can safely pass the Højestene channel, with sufficient under-keel clearance.

Propulsion

In the mathematical model, 4 generators were installed with 335 kW each, running 1500 RPM and with a gear box giving 350 RPM on the propellers at maximum. The thrust was adjusted to give about 5 tons each in a bollard-pull situation.

To maneuver safely in Svendborg and in Ærøskøbing with both wind and current, the total bollard-pull was increased to 30 tons.

Squat

The "Squat" phenomenon occurs when a ship experiences an increase in its draft while moving at higher speeds in shallow waters. During the simulations, it was noted that the simulator model had to reduce its speed to a range of 6 to 7 knots (approximately 6.2 knots) in Højestene channel to prevent grounding caused by squat. This adjustment results in a 3-minute increase in transit time.

It is worth mentioning that the commonly used rules of thumb for squat calculations tend to be conservative, and therefore, the additional 3 minutes of transit time is not set in stone.

It should be noted that the squat formulas used are dependent on the block coefficient. Since the aluminum ferry has a lower block coefficient, the squat will be less for the aluminum hull.

If a more precise squat prediction/maximum speed in Højestene is needed, a detailed CFD study is required. This will allow taking the actual shape of the hull and a precise model of the sea bottom into account, giving the best possible squat prediction for different speeds.

2. Summary and observations

2.1. Summary

The track plots for each run are illustrated in Appendix A.

After each run, the instructor, and the Captain completed an electronic evaluation form with all relevant observations and remarks dealing with the corresponding runs. These comments together with the logged replays form the basis for the observations, conclusions and recommendations.

A total of 35 simulations were conducted over the 3 days. The simulations involved testing the double-ended ferry in the three different areas, in several scenarios.

The different wind speeds tested over the 3 days were 10, 12, 15 and 20 m/s coming from SE, E, W and NW. Several combinations were tested.
Waves are not considered an issue, therefore a constant significant wave height of 0.5 m following the wind direction was set in the simulator. For more details regarding the run list see section 7.1.

Regarding the first day of simulations, the ferry was tested within the channel named "Højesteneløb" or "Højestene", which connects Ærøskøbing and Svendborg. In total, 11 runs were conducted, 6 of them involved the ferry coming from NW and 5 with the ferry coming from SW. In general, no current is registered in this area.

The second day of simulation was focused on testing the ferry arrivals and departures to and from Svendborg ferry terminal. In total, 14 runs were conducted: the first two were still conducted in Højstene (test runs of specific conditions that will be explained later in this report), while 7 arrivals and 4 departures were conducted in Svendborg. In this area, the presence of current has a large influence on maneuvering. For this reason, different combinations of wind and current were considered, with a current speed of up to 3 knots.

In conclusion, the third day of simulation was mainly focused on testing the ferry arrivals and departures to and from Ærøskøbing ferry terminal. In total 10 simulations were conducted: 8 (4 arrivals and 4 departures, run 301 to 308) in Ærøskøbing, 1 in Højstene (run 309) and the last one in Svendborg (run 310).

2.2. Observations

All the track plots illustrating all the simulations conducted are illustrated in Appendix A.

Højestene

The channel was passed both ways with winds of up to 20 m/s from SE, E, W and NW.

An example of a part of the passage from run 104 is shown in Figure 2-1. The ferry sails towards Ærø, with a drift angle of about 7 degrees and hence occupies a large part of the dredged channel as seen in the figure.

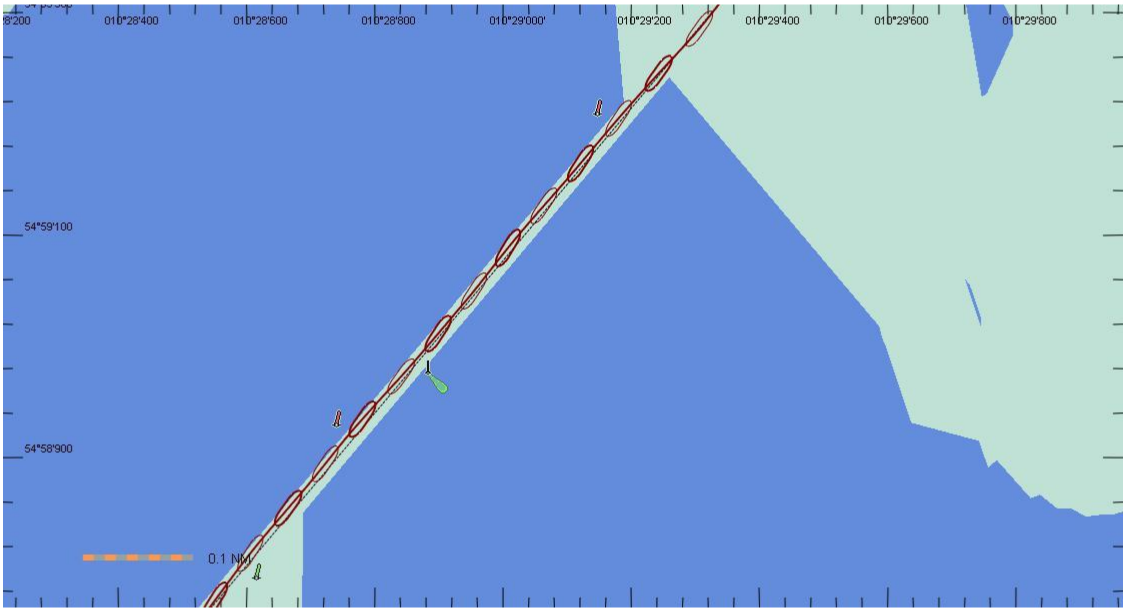


Figure 2-1 Run 104 part of the passage through Højestene wind 20 m/s.

It is seen that due to large drift angles the ferry occupies a lot of the available space in the channel.

Below is a table showing the minimum under-keel clearance for all runs in the Højestene channel. The under-keel clearance is measured in 4 points around the hull, forward and aft perpendicular as well as starboard and port midship.

In the table, the minimum value is highlighted in yellow.

In run 102, the ferry grounded, which is indicated by negative values. In this case, the wind was coming from SE with a speed of 12 m/s and according to the Captain's notes, it turned out to be challenging to control the ferry in these conditions, but still safe to manoeuvre, maintaining a speed between 6 and 7 knots maximum.
The ship grounded due to the increase of the speed and consequently, the squat effect generated. In fact, the Captain increased the speed to 8.5 knots to confirm the statement that 7 knots is the maximum speed that must be maintained in the channel.

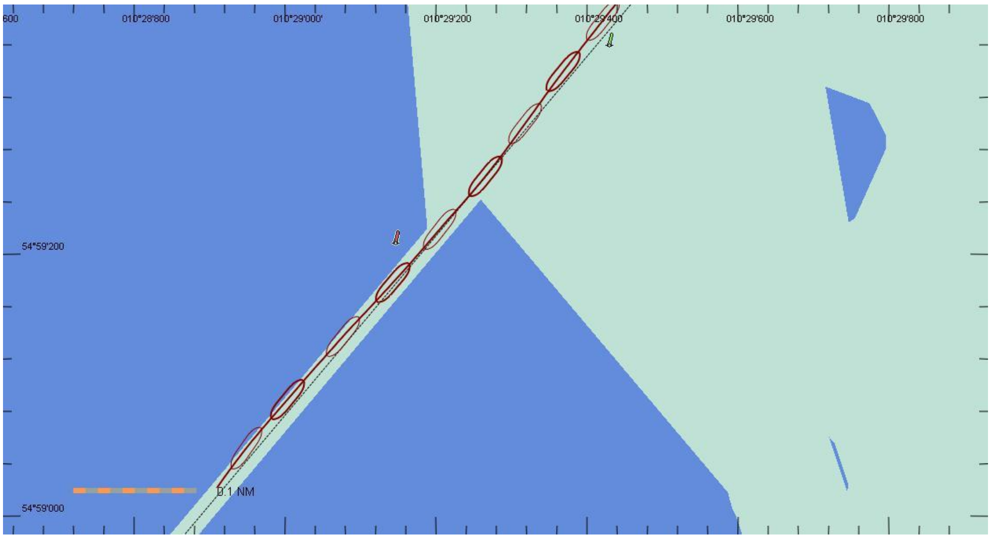


Figure 2-2 Run 102, ship coming from NE, towards Ærø ferry terminal.

When the under-keel clearance became very low due to squat, the Captain needed to maintain low speed.

A clear example is seen in run 202, in which the channel was passed at low tide equal to -0.5m. In this scenario, the wind was coming from NW with a speed of 15 m/s, which was quite on the limit. The simulation was feasible, but the UKC was very low (around 10 cm). For this reason, the maximum speed allowed was between 4 and 5 knots, leaving no room for mistakes.

In run 309, the ship comes from NE, heading towards Ærø terminal, with wind coming from W at 12 m/s. The channel was passed at high tide +0.2 m allowing the speed to be increased to 8.4 knots. The aft and fore thrusters were used at 100% and 50% of full power, respectively.

UKC Overview

Run#	Min UKC Fore	Min UKC Port	Min UKC Stbd	Min UKC
101	0.07 m	0.09 m	0.05 m	0.10 m
102	-0.23 m	-0.24 m	-0.25 m	-0.25 m
103	0.34 m	0.41 m	0.15 m	0.38 m
104	0.44 m	0.44 m	0.38 m	0.40 m
105	0.40 m	0.38 m	0.43 m	0.37 m
106	0.33 m	0.30 m	0.39 m	0.30 m
107	1.07 m	1.09 m	1.11 m	1.09 m
108	0.31 m	0.30 m	0.41 m	0.26 m
109	0.29 m	0.35 m	0.38 m	0.28 m
110	0.41 m	0.34 m	0.26 m	0.37 m
111	0.32 m	0.34 m	0.29 m	0.40 m
201	0.38 m	0.31 m	0.43 m	0.34 m
202	0.10 m	0.10 m	0.09 m	0.05 m
309	0.40 m	0.42 m	0.43 m	0.41 m

Figure 2-3 Minimum under-keel clearance for all runs in Højestene.

Figure 2-4 below illustrates the swept area/heat map[1] for all simulations in Svendborg. The chart shows that using the current manoeuvring strategy, all available space in the port is utilized, leaving no space for ships to be moored at "Træskibsbroen".

After adjusting the approach strategy, which involves passing the green buoy on the opposite side and aligning the ship's course before berthing, a safer and more efficient berthing process at "Træskibsbroen" is successfully achieved. This new strategy is represented by the blue route to the East visible in Figure 2-4.

This approach optimizes safety and efficiency.

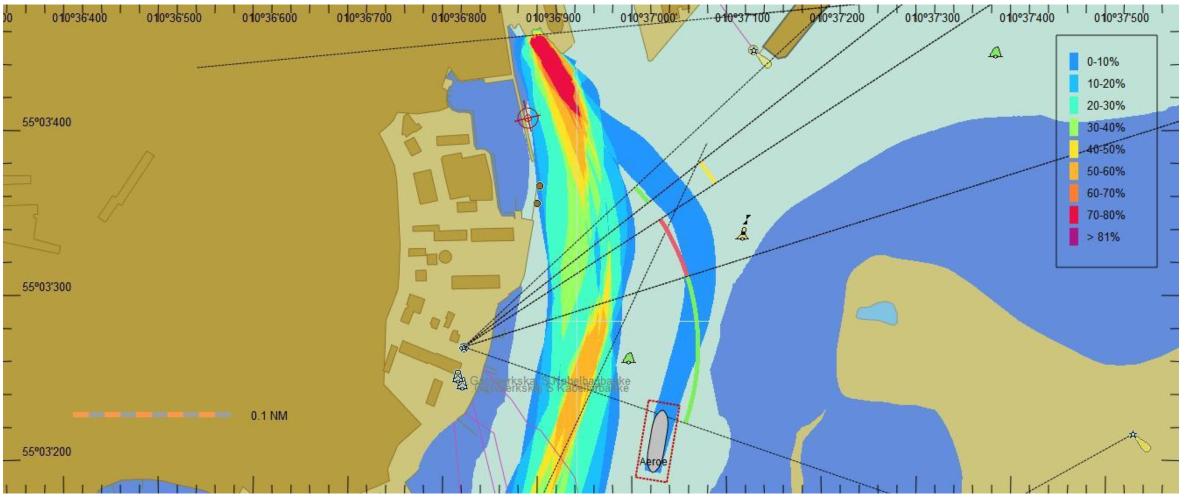


Figure 2-4 Swept area for operations at Svendborg.

In strong winds and current, 30 tons bollard pull was needed to manoeuvre safely. Consequently, the operational limits should be increased.

The most challenging parameter in this area is the current. In all the simulations conducted in Svendborg, the current was varying between 1.0 and 3.0 knots. The results show that currents between 1.0 and 2.0 knots are relatively challenging, but feasible.

In run 204 (see Figure 2-5), strong wind of 15 m/s coming from W and 3.0 knots east going current were tested with the 20 tons BP ferry. As stated by the Captain, these conditions are above the limit and it is not safe to manoeuvre the ship.

[1] The heat-map is a statical tool used to visualize the magnitude of a specific variable in different scenarios. In this specific case, it is used to visualize the traffic concentration or in other words, how much the area is used during the simulations.

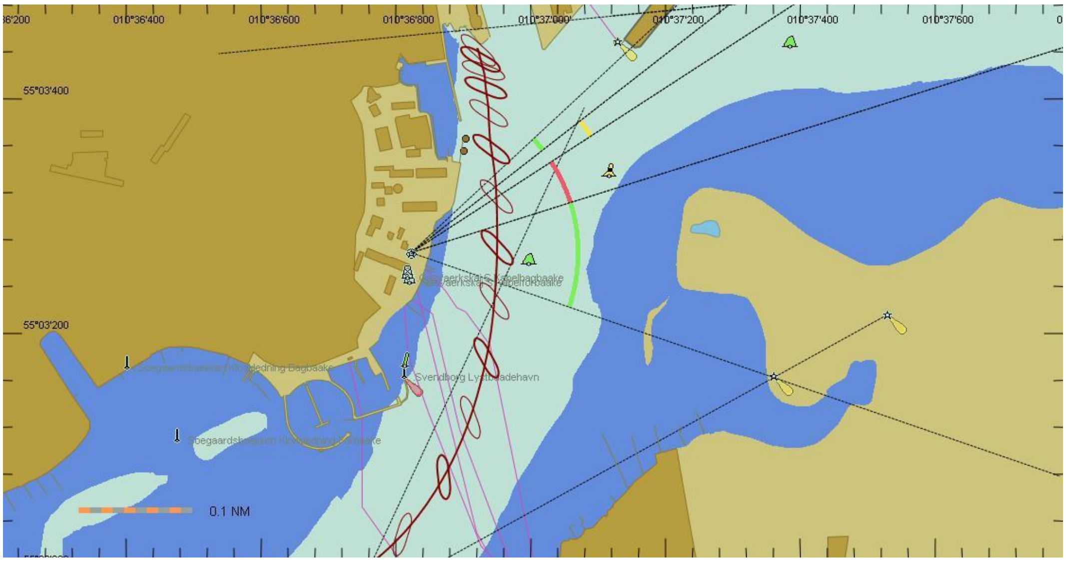
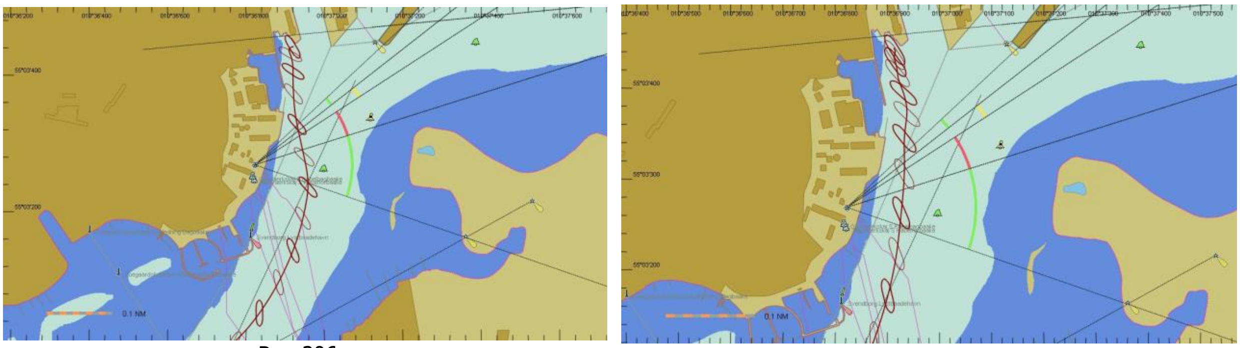


Figure 2-5 Run 204, arrival in Svendborg with 20 tons BP ferry and in extreme conditions.

In runs 206 and 207 (see Figure 2-6), the 30 tons BP vessel was used, but also in this case the conditions (15 m/s westerly coming wind and 2.0 -3.0 knots easterly going current) were very challenging and made the manoeuvres unsafe. In fact, in these runs the current was too strong and to berth the ship required 100 % of the thruster's power.



Run 206 Run 207

Figure 2-6 Run 206 and 207, arrivals in Svendborg with 30 tons BP vessel.

The departures (runs 208 to 211) were completed safely.

In run 310, another approach strategy to Svendborg was tested, as illustrated in Figure 2-7 below. The strategy was tested to give more sea room to Træskibsbroen. Here, the green buoy South of the berth is passed on the wrong side as there is sufficient water depth, and the ferry keeps to the East side of the channel until in line with the ferry berth. It is seen from the track plot that this strategy gives space for ships to be moored at Træskibsbroen.

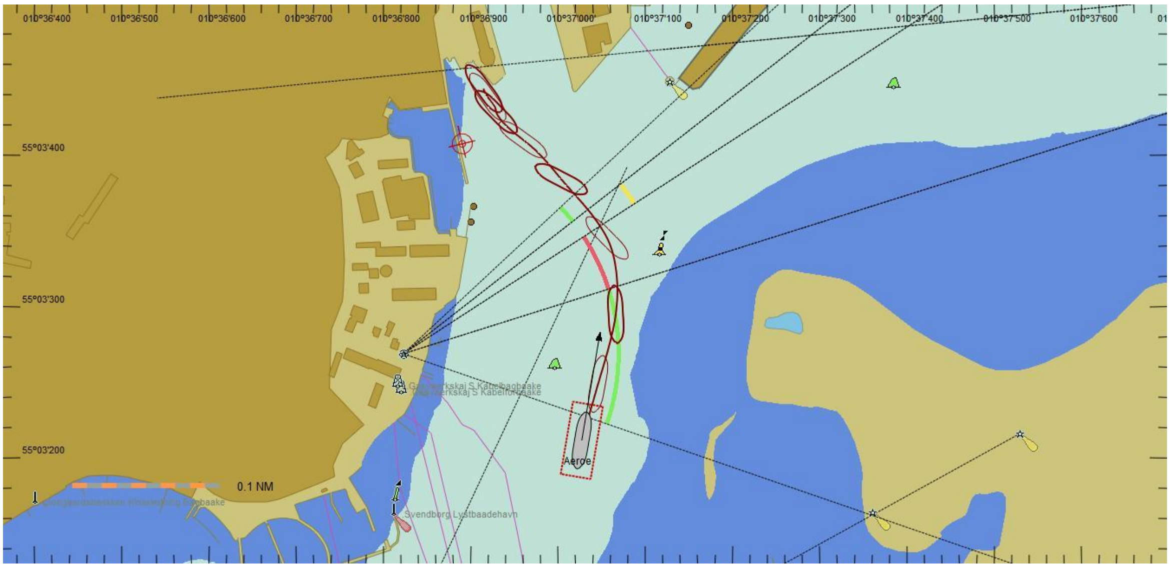


Figure 2-7 Approach strategy for Svendborg berth.

Ærøskøbing

Figure 2-8 illustrates swept area/heat map plot for all simulations conducted in Ærøskøbing.
In the simulations conducted, the most challenging parameter is the wind since according to the Captains from Ærøfærgerne no current is registered in this area.
The wind conditions tested were similar to the previous scenarios, but this time the most challenging wind direction is considered to be from North.

To manoeuvre safely in high winds 30 tons bollard pull was needed.

Departures were conducted safely, and no issues were reported.

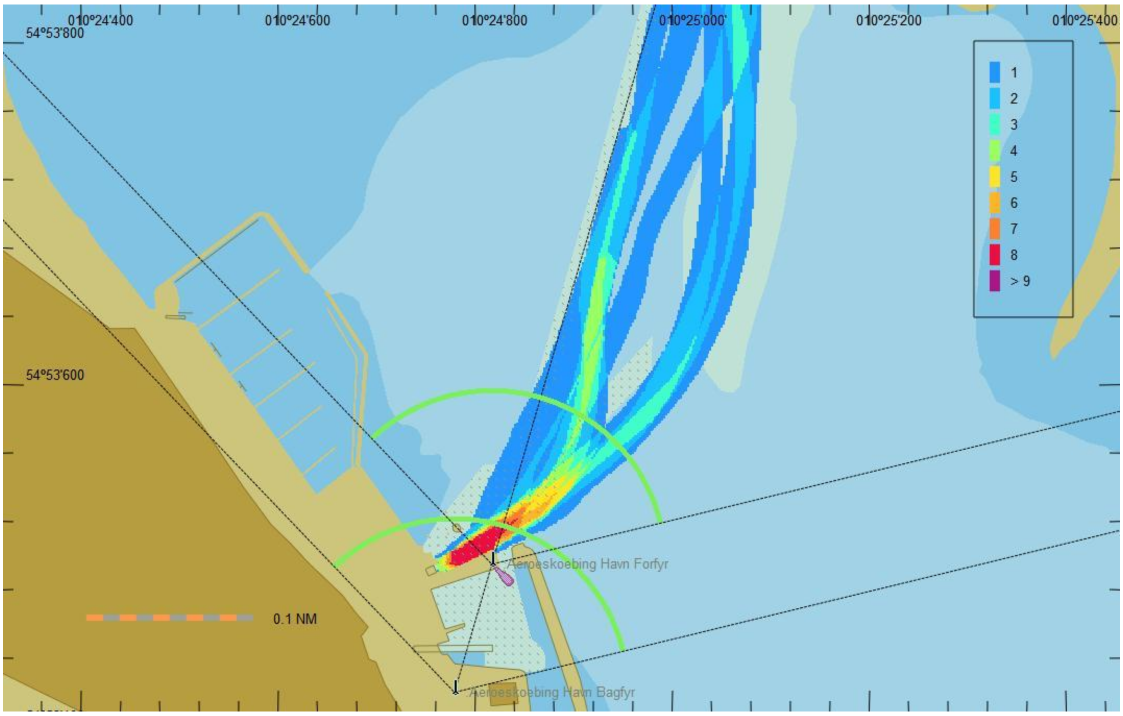


Figure 2-8 Swept area for all runs at Ærøskøbing.

During the simulations, the wind was increased gradually between one simulation and the next. In the first two runs it was not an issue, while the approaching manoeuvres began to be more challenging in runs 303 and 304, with a higher wind speed of 15 m/s coming from SE and 20 m/s from NW.

Run 303 is shown in Figure 2-9 below, and Figure 2-10 shows the thruster usage. It is clear that the units are used at their maximum to keep the ferry in position in the SE 15 m/s wind.

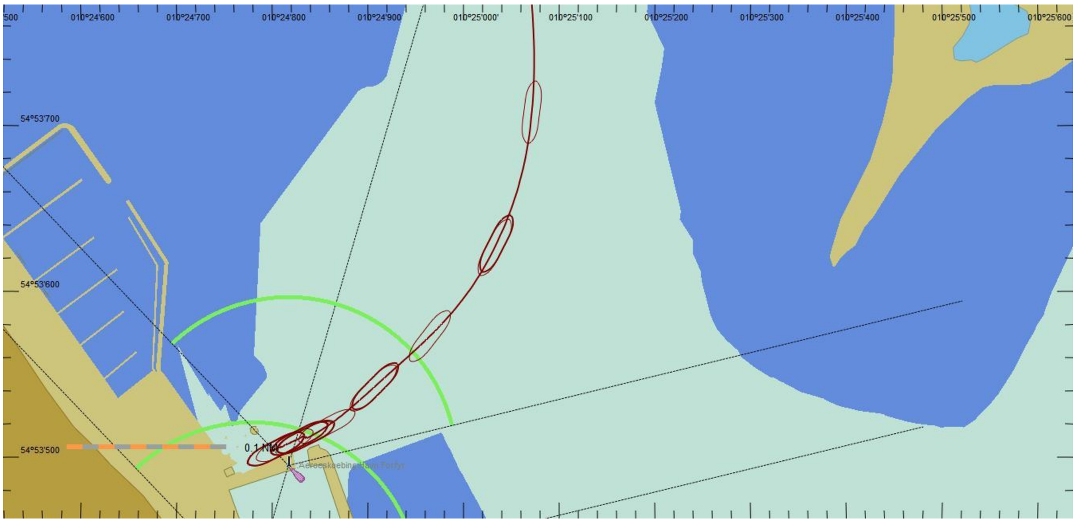


Figure 2-9 Run 303 Wind speed SE 15 m/s.

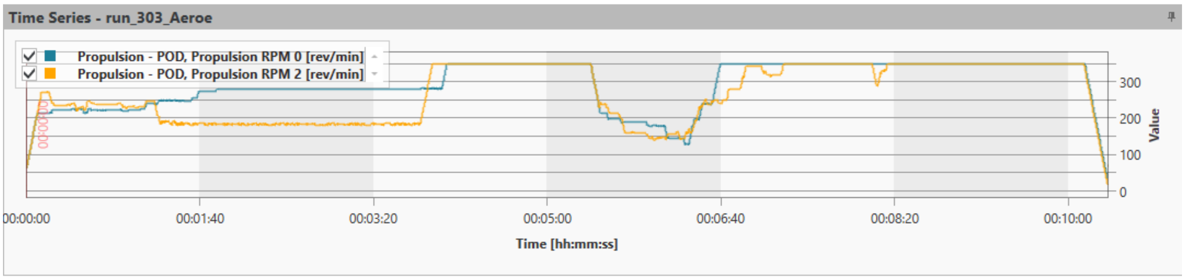


Figure 2-10 Run 303 thruster usage.

According to the Captains' notes, a wind speed of 20 m/s is above the operational limit.

3. Conclusions and recommendations

The following summarises conclusions and recommendations, based on discussions with the local Captains in the debriefing sessions.

3.1. Conclusions

When reading these conclusions, it should be taken into account that the mathematical model of the ship used in the study is constructed based on a concept design of the Ærø ferry and on relatively few available details (see section 1.1 for more details). Hence, the results are indicative, and further studies may be needed when the final design is chosen (e.g. steel/aluminium), which makes a difference for some of the results. The tested ferry is in maximum loading condition with a draft of 2.6 m, and the study investigates the limits for safe operation, i.e. in many of the simulations the environmental conditions are above normal situations.

Højestene

In summary, the following is noted as conclusions for Højestene:

- The channel has a sufficient width for safe passage.
- The marking of the channel is sufficient.
- Maximum speed should be kept between 6.4 - 7.0 knots.
- At low tide (-0.5 m) the maximum speed should be 4.5 knots.
- At high tide (+0.2 m) the channel can be passed at a speed of 8.4 knots.
- There is no big difference in passing the channel with 30 tons BP compared to 20 tons BP.

Svendborg

In summary, the following is concluded:

- 30 tons BP is needed to manoeuvre safely.
- When arriving from South towards the berth there is no space for ships moored at Træskibsbroen.
- Arriving from Southeast towards the berth is the safest strategy and will leave space for ships at Træskibsbroen
- 3 knots of current is above limit.
- Arrivals conducted safely in wind up to 15 m/s and 2 knots current.
- It was safe to depart in 20 m/s NE and 3 knots Westbound current.

Ærøskøbing

In summary, the following is concluded:

- 30 tons BP is needed to manoeuvre safely.
- For arrivals, 20 m/s wind speed from NW is above limit.
- The safe operational environmental limit for arrivals with 30 tons BP is **NW** wind between 15 and 20 m/s.
- **SE** wind of 15 m/s is the limit for arrivals.
- Departures were handled safely from various directions up to 20 m/s.
- Passing Møllegabet was no issue in all tested conditions.

3.2. Recommendations

General

- It is recommended to have at least 30 tons BP in order to manoeuvre safely in situations with both high currents and strong winds.

- Conduct a risk assessment study to investigate how often a fully loaded ferry sails at low tide, in strong winds. This will give insights into the needs for dredging the Højestene channel.

    - What is the expected downtime.
    - How often will the ferry be fully loaded at low tide and high currents and wind.

Højestene

- Consider dredging Højestene to minimize squat and allow for a higher speed through the channel.

- Ferry schedules should take into account that ships should avoid meeting each other in the channel. If ships pass each other in the channel, there will be interactions between the ships and the squat will be increased during the passage.

- Consider performing a detailed CFD analysis for a more precise squat and consequence of speed profile.

- Consider improving the marking of the channel by placing green and red buoys in pairs. This will help vessels pass the channel in poor visibility.

Svendborg

- When approaching Svendborg stay close to the green buoy South of the ferry berth and approach the berth in line with the berth.

- Consider moving the green buoy further South, to allow the ferry to line up for approach to the berth.

- Consider reconstruction/realigning of the Ferry berth in Svendborg to ensure a more optimal approach angle towards the berth.

- The ferry needs support in the aft end for the current, to avoid twisting.

- The quay should have strong fenders, and especially the end of the quay should have strong fenders to lean on when needed.

Ærøskøbing

- Reconsider placement and size of duc d'albae to fit the new ferry.

4. Method

4.1. General

The background for the present study was based on a request from Ærøfærgerne to examine different scenarios for approach/departure to/from Ærøskøbing and Svendborg, with a design double-ended ferry ("Ærø double", 70 m and 2.6 m draft). The aim of the study is to evaluate the safety and manoeuvrability of the previously mentioned vessel in the two ports mentioned above as well as during the sailing within the Højestene channel.

The method consists of the following:

- Develop the databases for Ærøskøbing, Svendborg and Højestene, with markings and bathymetry.
- Develop a new mathematical model of the "Ærø double" double-ended ferry.
- Use of this ferry for the simulations.
- Develop a list of simulations with environment settings.
- Scenario development.
- Simulations of different scenarios to evaluate the safety for departures/arrivals, berthing/unberthing and sailing within the channel.
- Debriefing and evaluation of runs.

4.2. List of simulations

A list of runs was created by the participants and FORCE Technology in cooperation to be used for the evaluation simulations. Before the full-mission simulations, an indicative list was created, as it could be changed during the simulations, due to findings. The list of conducted simulations is illustrated in section 7.1 List of simulation runs.

4.3. Scenario development

The scenarios were selected by the participants in cooperation with FORCE Technology with respect to prevailing and critical wind speeds and directions as well as currents. The initial positioning of the ship, whether on arrival or departure, was chosen in order for Captains/Pilots to control the ship initially, assuring that they had full control before beginning the manoeuvre.

4.4. Simulations

The simulations conducted were carried out at FORCE Technology's ship simulator facilities using full mission bridges from where the Pilots and Captains manoeuvred the different ships. Regarding the simulations set-up, a detailed description can be found in Chapter 6.

4.5. Debriefing

After each simulation day, a short debriefing session was conducted to sum up the findings of the simulations. The participants could elaborate on the conducted runs and give their comments on what they had experienced, thereby giving their observations and conclusions to what they had seen. The debriefings together with the evaluation of each run are used to extract the relevant observations and conclusions.

4.6. Evaluation of runs

The evaluation of the different manoeuvres is based on the participants' perceptions of the runs as seen during the simulations.

After each run, the participants Captains (from ÆrøFærgerne and FORCE Technology) and the FORCE Technology instructor each filled out an evaluation form with their experience of the newly finished run.

Further, the in-house developed evaluation program "Analyser" was used to replay each run, thereby being able to show tracks and time series for several variables.

5. Ships

The ship used in the simulations is a six degree-of-freedom mathematical ship model of one double-ended ferry, which was designed for this study according to the data provided by the Client. Table 5-1 illustrates the characteristics of the ship used in the simulations.

Ship nr.	Name	type	Description	Load Con.	LOA m	Lpp m	Bmld m	Tf m	Ta m	Displacement cbm	Prop.	Rudd.	Bow thrst.	Stern thrst.
4031	Ærø double	Ferry	double ender AZIMUTH	L	70	68	17	2.6	2.6	1903	2AZ(fp)	2AZ(fp)	4031	Ærø double

Table 5-1 Ship used in the simulations.

Bridge posters for the individual ships are found in Appendix B.

6. Simulator description

During the full-mission simulations, the FORCE Technology Bridge D was used.

Bridge D is one of the full mission bridges characterized by a 360 degrees field of view. Buttons are used to simulate walking onto the bridge wing and looking from the side of the ship.

The simulator bridges are equipped with instruments similar to those found on a real ship bridge, including radar and electronic chart, as well as portable pilot units.

Based on the information displayed, the navigator can activate engines, rudders, and azipods by means of the analogue control handles.

All simulation runs are logged electronically ("black box") to be able to replay second by second what happened during the runs. This includes time series of several parameters, e.g. speed over ground and through water, azipod angle, propeller revolutions etc. This provides the opportunity to investigate all runs in detail at a later stage.

The replay system has been used to generate the track plots in Appendix A.

7. Documentation of simulations

7.1. List of simulation runs

The lists of simulations conducted during the two weeks are illustrated in the following tables.

Run no.	Ship Name	Ship no.			Wind		Current		Waves / Swell			Day	Comments
			Man.	Layout	speed	direc.	Speed	going	Hs	Periode	from	Night	
					Knob ~ m/s		Knots		m	s			
101	Aeroe	4031	NE	Højestene	10	SE	no		0.5		NW		
102	Aeroe	4031	NE	Højestene	12	SE	no		0.5		NW		
103	Aeroe	4031	NE	Højestene	15	SE	no		0.5		NW		
104	Aeroe	4031	NE	Højestene	20	SE	no		0.5		NW		
105	Aeroe	4031	SW	Højestene	10	E	no		0.5		W		
106	Aeroe	4031	SW	Højestene	12	E	no		0.5		W		
107	Aeroe	4031	SW	Højestene	15	W	no		0.5		W		repeated / wrong
108	Aeroe	4031	SW	Højestene	15	W	no		0.5		W		
109	Aeroe	4031	SW	Højestene	20	W	no		0.5		W		
110	Aeroe	4031	NE	Højestene	15	NW	no		0.5		NW		
111	Aeroe	4031	NE	Højestene	20	NW	no		0.5		NW		

Table 7-1 List of simulations conducted during day 1.

Run no.	Ship Name	Ship no.			Wind		Current		Waves / Swell			Day	Comments
			Man.	Place	speed	direc.	Speed	going	Hs	Periode	from	Night	
					Knob ~ m/s		Knots		m	s			
201	Aeroe	4031	NE	Højestene	15	SE	no		0.5		NW		
202	Aeroe	4031	SW	Højestene	15	NW	no		0.5		NW		Tide -0,5m
203	Aeroe	4031	Arrival	Svendborg	10	W	1.5	E	0.5		W	Day	
204	Aeroe	4031	Arrival	Svendborg	15	W	3.0	E	0.5		W	Day	
205	Aeroe	4031	Arrival	Svendborg	12	W	3.0	E	0.5		W	Day	
206	Aeroe	4031	Arrival	Svendborg	15	W	3.0	E	0.5		W	Day	
207	Aeroe	4031	Arrival	Svendborg	15	W	2.0	E	0.5		SW	Day	increased thruster effect
208	Aeroe	4031	Departure	Svendborg	12	SW	3.0	W	0.5		SW	Day	
209	Aeroe	4031	Departure	Svendborg	12	SE	3.0	W	0.5		SW	Day	
210	Aeroe	4031	Departure	Svendborg	15	NE	3.0	W	0.5		SW	Day	
211	Aeroe	4031	Departure	Svendborg	20	NE	3.0	W	0.5		SW	Day	
212	Aeroe	4031	Arrival	Svendborg	12	NE	2.0	W	0.5		W	Day	
213	Aeroe	4031	Arrival	Svendborg	15	NE	2.0	W	0.5		SW	Day	
214	Aeroe	4031	Arrival	Deadmen	12	SW	1.0	E	0.5		W	Day	Test between two cardinals

Table 7-2 List of simulations conducted during day 2.

Run no.	Ship Name	Ship no.			Wind		Current		Waves / Swell			Day	Comments
			Man.	Layout	speed	direc.	Speed	going	Hs	Periode	from	Night	
					Knob ~ m/s		Knots		m	s			
301	Aeroe	4031	Arrival	Aeroe	10	SW	no		0.5		NW		
302	Aeroe	4031	Arrival	Aeroe	12	S	no		0.5		NW		
303	Aeroe	4031	Arrival	Aeroe	15	SE	no		0.5		NW		
304	Aeroe	4031	Arrival	Aeroe	20	NW	no		0.5		NW		
305	Aeroe	4031	Departure	Aeroe	10	SW	no		0.5		SW		
306	Aeroe	4031	Departure	Aeroe	12	S	no		0.5		SW		
307	Aeroe	4031	Departure	Aeroe	15	SE	no		0.5		SW		
308	Aeroe	4031	Departure	Aeroe	20	NW	no		0.5		SW		
309	Aeroe	4031	NE	Højestene	12	W	no		0.5		W		high tide +0.2 m
310	Aeroe	4031	Arrival	Svendborg	7	W	2.0	E	0.5		W		Approching berth from other direction

Table 7-3 List of simulations conducted during day 3.

7.2. Geographical plots of manoeuvres

The simulated manoeuvres are shown as sweep plots in Appendix A. Each plot contains land contours, leading lines, and marks.

8. Nomenclature

LOA	=	Length over all	[m]
Lpp	=	Length between perpendiculars	[m]
B	=	Breadth	[m]
Ta	=	Draft aft	[m]
Tf	=	Draft forward	[m]
UKC	=	Under-keel Clearance	[m]

9. References

[1] IALA Guidelines

Appendix A

Track Plots

Appendix B

Ship descriptions

Aeroe #4031

Manoevering Characteristics

Parameter	Ferry	IMO limit
Turning circle, Advance	2.5 x Lpp	4.5 x Lpp
Turning circle, Tactical diameter	2.3 x Lpp	5.0 x Lpp
10/10 zig-zag, 1st overshoot angle	6.9 deg	10.1 deg
10/10 zig-zag, 2nd overshoot angle	18.2 deg	25.1 deg
20/20 zig-zag, 1st overshoot angle	14.1 deg	25 deg
Crash stop, Track reach	4.5 x Lpp	15 x Lpp

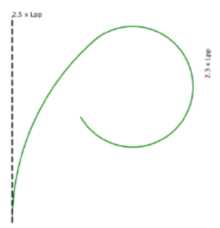
Rudder details

Parameter	
Number of rudders	4
Type of rudder	POD
Area of Rudder (movable part) [m^2]	0.00
Total rudder Area/(Lpp x T) [%]	0.00
Pod angle [deg/min]	20
Max. rudder Angle [deg]	0

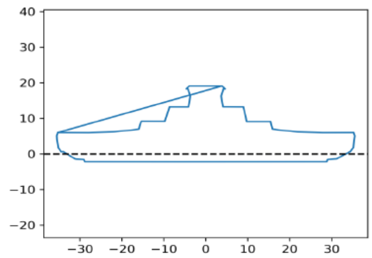
Speed Table

Handle	RPM	Deep [kn]	Shallow [kn]
Sea	350	13.39	12.56
Full Ahead	280	10.72	10.04
Half Ahead	175	6.37	5.83
Slow Ahead	87	1.79	1.28
Dead Slow Ahead	43	0.32	0.27
Dead Slow Astern	43	0.05	0.04
Slow Astern	87	0.18	0.15
Half Astern	175	0.69	0.58
Full Astern	308	2.60	2.25

Turning Circle



Outline



Particulars

LPP	68.00 [m]
LOA	70.00 [m]
Beam	17.00 [m]
TF/TA	2.60/2.60 [m]
Disp	1902 [Tons]
Lateral wind area	864 [m^2]
Propeller NA dir	Unknown
# Blades	0
Diameter	1.6 [m]
Engine kW	4 x 335 [kW]
Bow Thruster kW	- [kW]
Stern Thruster kW	- [kW]
Air draft	14.00 [m]

Ship*. Double-ended ferry designed for the simulations.*

Appendix C

Wind in the simulator

Wind definitions in the simulator

Wind definitions in relation to the simulator's wind speed indicator versus the ship's wind speed indicator.

In the simulator, the wind speed is given in "meteorological wind speed". This wind speed is not equal to the wind speed read from the wind indicator of the ship. As a tentative comparison the following facts and assumptions can be given:

Wind indicator registers the wind speed at e.g. 35 meters height.

The coefficient for calculating wind forces in the simulator refers to wind speed at 10 meters height and a mean value of a 10-minute sampling period.

Wind information from meteorological sources should refer to wind at 10 meters height.

Read-out from a wind indicator will typically refer to the mean value of a 5 second sampling period.

The variation of the mean wind in the height z above ground level is found by the formula:

$$u_z = u_{10} \times \left(\frac{z}{10}\right)^{\alpha}$$

u_z = Wind speed at a certain height

u_{10} = Wind speed at 10 meters height

α = Power constant (0.12 over sea, 0.16 over land, 0.28 over town).

z = Wind speed indicator height above the surface

Using Engineering Sciences Data Unit (ESDU) 72026 we find the following ratio between "Max 5 second wind" and "mean 10 minutes wind" equal to 1.25.

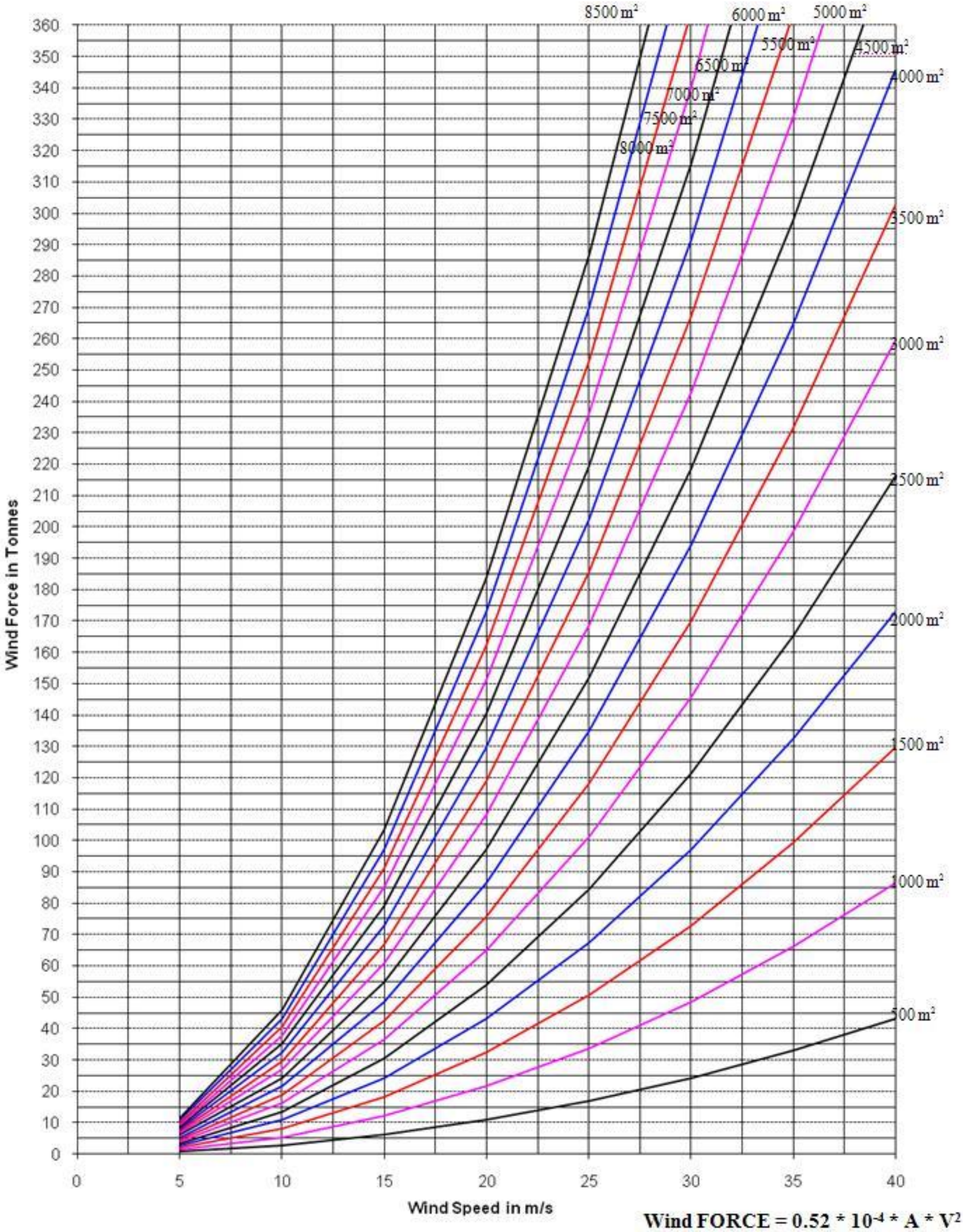
Example:

Wind read out on wind indicator (on ship, height 35 m) = 25 m/s

10 min. mean wind at e.g. 35 m height = 25 / 1,25 = 20 m/s

10 min. mean wind at 10 m height = $20/\left(\frac{35}{10}\right)^{0,12}$ = 17.2 ms

This means that what the navigator correctly reads as a wind speed of 25 m/s corresponds to a "meteorological" wind speed of 17.2 m/s.



Wind FORCE = $0.52 * 10^{-4} * A * V^2$
A = Beam Wind area in m^2
V = Wind speed in m/s

Approximate wind forces; standard formula used by navigators.

Appendix D

Time Series

Appendix E

UKC Tables