Wavefoil Savings Analysis

Ro Spirit, Rostein AS

WF3970

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Summary

This report provides a comprehensive analysis of the impact of Wavefoil's retractable bow foils WF3970 installed on Ro Spirit, a live fish carrier owned by Rostein AS. A nearly four hour systematic test conducted in September 2024 aimed to evaluate the propulsion power savings when the Wavefoils were deployed. Data was gathered switching between deployed and retracted Wavefoils every 10 minutes.

The test revealed a significant reduction in propulsion power when the foils were deployed, with a power saving of about 10 % under the test conditions.

The analysis included a one-dimensional regression model based on vessel speed, which illustrated that the Wavefoils reduced wave resistance and increased forward thrust.

These findings validate the effectiveness of Wavefoil's technology in enhancing vessel efficiency, particularly in wave-dominated environments, offering both economic and environmental benefits to the maritime industry.

Summary	
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1 Introduction

The Ro Spirit is a state-of-the-art live fish carrier owned and operated by Rostein AS, a leading company in the aquaculture industry. Ro Spirit is the first live fish carrier equipped with Wavefoil's retractable bow foils WF3970. The vessel operates in harsh conditions all along the Norwegian coastline ensuring safe and efficient transportation of salmon. The Wavefoils enhance the vessel's hydrodynamic performance, reducing break power, improving stability, and lowering operational costs in waves, all while minimizing environmental impact.

The response from the crew on board Ro Spirit has been nothing but positive regarding the Wavefoil WF3970. They can really feel the difference in the ship's motions, but there is no easy way of knowing whether the Wavefoils provide any reduction in propulsion power.

While theoretical models and simulations have indicated promising potential for fuel savings, real-world data from vessels like Ro Spirit provides valuable insights into the actual impact of the Wavefoils. More details about the Wavefoil Simulations are given in the Appendix. This technical article presents a detailed analysis of the reduction in propulsion power for Ro Spirit in testing of the WF3970, offering an evidence-based assessment of its performance.

Figure 1: Ro Spirit with Wavefoil WF3970 bow foils installed.

Table 1: Ro Spirit vessel information.

Vessel name	Ro Spirit
Type of vessel	Live Fish Carrier
Owner	Rostein AS
Build year	2022
Length over all	79.3 m
Breadth	15 m
Draft	3.3 - 6.8 m
Service speed	10-12 knots
Installed propulsion power	3000.0 kW

2 Test objective

During the first half of 2024, Ro Spirit was equipped with test equipment including a wave radar. This allowed for monitoring the wave conditions the vessel was exposed to during transit. Wave data was recorded and acquired, together with sensory data from the engine, vessel speed, foil deployment, positioning and weather data. The data in this report will be analyzed with the objective of investigating the actual differences in propulsion power, with and without the Wavefoils deployed.

3 Data Analysis

The sensory data from the engine was acquired with a sample frequency of 1 sample per minute and this was chosen as the baseline for the analysis. The data from the wave radar was however sampled with a frequency of around 80 seconds and was linearly interpolated and re-sampled to fit the same time series as the engine data. The same procedure was done for the vessel speed.

Ro Spirit performed a nearly four hour systematic test northwards in Lopphavet heading to Sørøya, September 23rd - 24th 2024, as shown in Figure 2. The test was carried out with a constant heading, constant engine load, anti-roll tanks filled, and empty cargo. The only variable tested was alternating between having the Wavefoils deployed and retracted every 10 minutes. A total of 10 cycles was performed from UTC 23-09-2024 23:00 to UTC 24-09-2024 02:44. Measured data are shown in Figure 3. The resulting time series of all parameters included a total of 224 samples, where 106 of these samples were measured with the foils deployed. Plots over the whole trip can be found in appendix A.

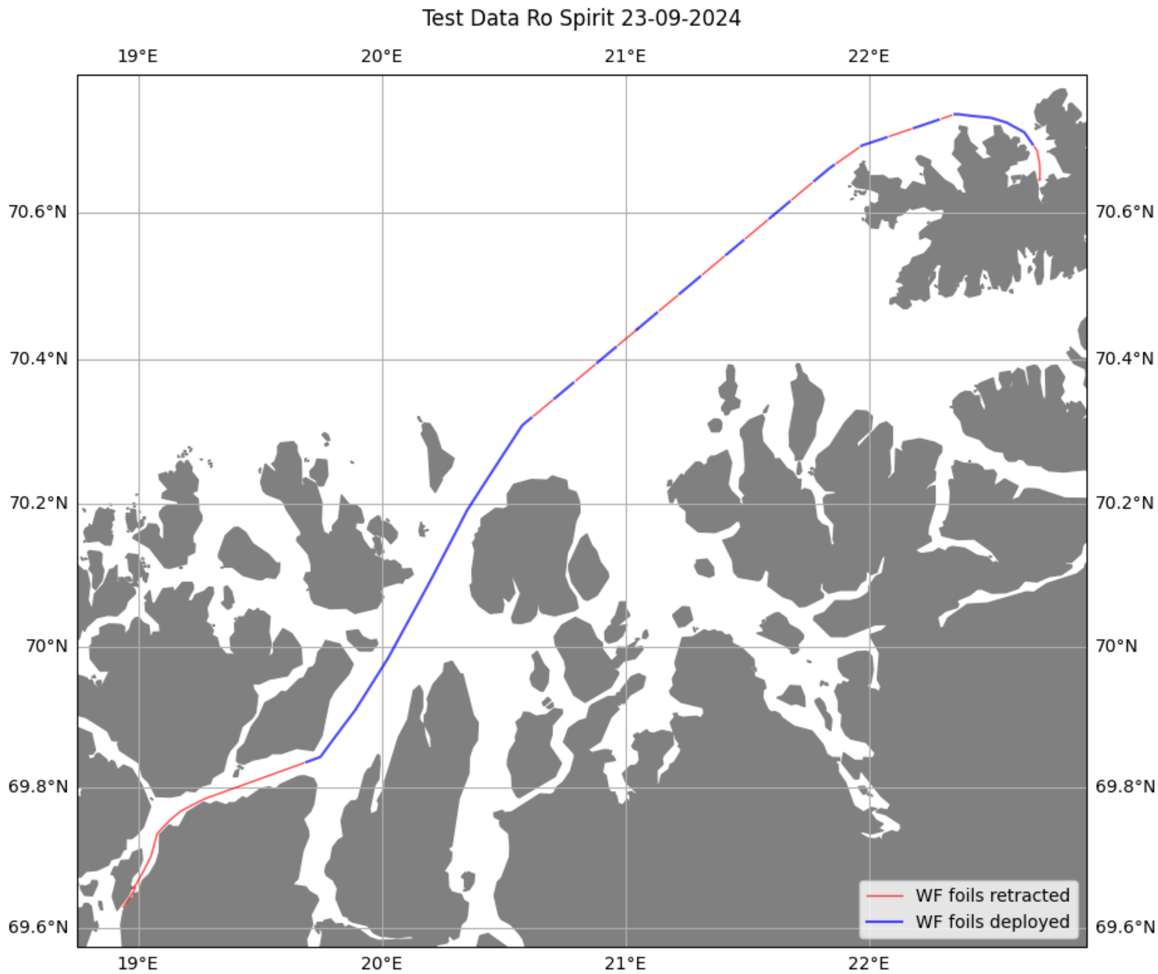


Figure 2: Map showing position and bow foil status of Ro Spirit northwards at Lopphavet during test.

Figure 3 show the different data measurements from the ship during the test. Hs (significant wave height) is a result of the main wave sets, often a first- and secondary wave set. Tp (peak wave period) describes the period of the most energetic wave component. Relative mwd (mean wave direction) is the weighted mean direction of the wave sets relative to the vessel's heading. The vessel's speed through water (TW) are used in the analysis to include potential currents which the speed over ground does not include. The wind is relative to the vessel's heading.

The distribution of the gathered data points is explored through the histograms given in Figure 4. The wave directions shows a somewhat even distribution of Hs, Tp and Mwd. The test conditions were influenced by a strong breeze, generating wind waves from the side. This is not ideal for the test, as it can introduce noise into the measurements and potentially affect the accuracy of the results. The data clearly shows that the vessel reaches a higher speed through water with the Wavefoils deployed compared to when they are retracted. However, accurately quantifying the power savings is difficult, as the energy saved is utilized to increase the vessel's speed rather than being directly measurable as reduced power consumption.

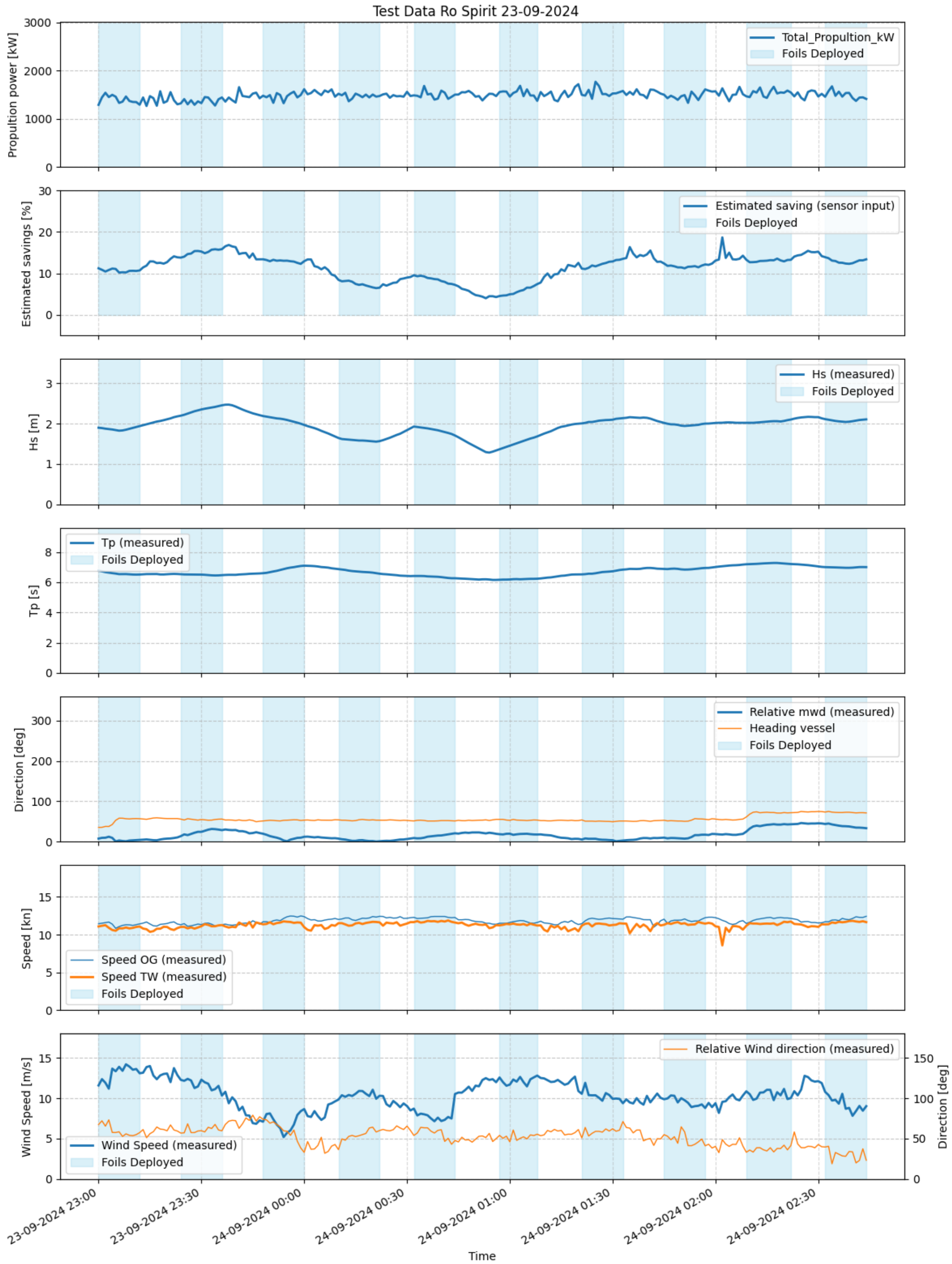


Figure 3: Measured data during test.

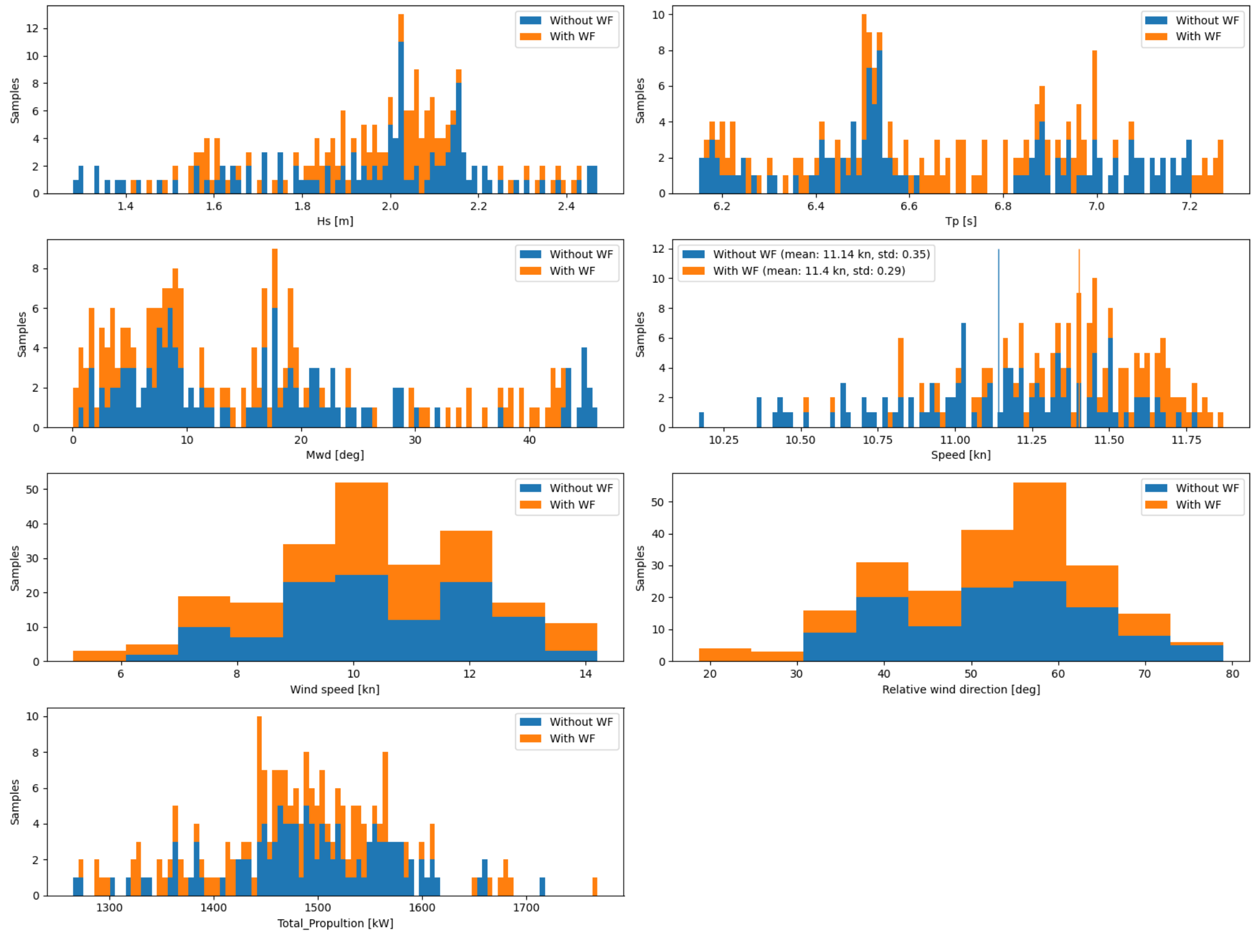


Figure 4: Histogram of data with and without Wavefoils deployed.

4 One-dimensional regression analysis

Considering the increasing vessel speed, a regression analysis was performed with speed as the primary variable. Other factors, such as wave conditions, were treated as discrete variables. When plotting the speed-power curve, the data should follow a third-order polynomial, and the regression curve should be fitted accordingly.

$$p(v) = \alpha v^3 \tag{1}$$

where v is the vessel speed through water and α is the parameter to be tuned.

Figure 5 shows the propulsion power plotted against the vessel speed for Hs 1.75 - 2.25 m, Tp 6 - 8 s and Mwd 0° - 20°, giving a total of 119 samples. The full lines represent the regression curve based on the speed of the vessel. The blue data represent cases with the Wavefoils retracted, while the orange data is when the Wavefoils are deployed. The red lines marks the propulsion power for the test's mean speed of 11.4 knots. The results shows that the propulsion power is reduced by 10.4 % when having the Wavefoils deployed. Table 2 shows the details for the results.

The data clearly shows an increase in speed when the Wavefoils are deployed. Additionally, note the difference in data spread: with the Wavefoils deployed, the data aligns much more closely with the regression curve than when retracted. This variation is due to increased wave resistance without Wavefoils. When the Wavefoils

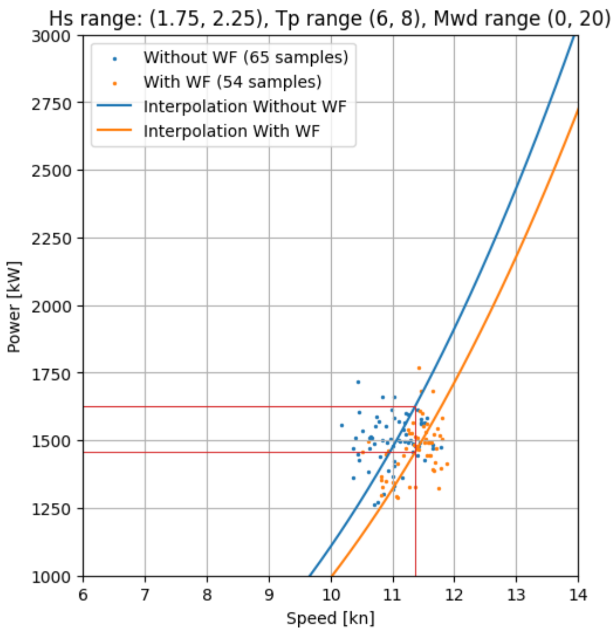


Figure 5: Measured power plot for test with given conditions. Full lines represent regression curve for cases with and without Wavefoil deployed.

are deployed, the additional thrust and stabilization from the foils help counteract this added resistance, resulting in a more consistent performance.

Table 2: Propulsion power savings with Wavefoil.

Condition	**Hs 1.75 - 2.25 m** **Tp 6 - 8 s** **Mwd 0° - 20°**
Propulsion power Wavefoils retracted [kW]	1626.97
Propulsion power Wavefoils deployed [kW]	1457.59
Propulsion power saving with Wavefoils [kW]	169.38
Propulsion power saving with Wavefoils [%]	**10.4**

5 Conclusion

The analysis presented in this report confirms the effectiveness of Wavefoil's retractable bow foils WF3970 installed on Ro Spirit. Based on the systematic test carried out in September 2024, the results show a significant reduction in propulsion power when the foils were deployed, with savings of 10.4 %.

Appendices

A Total trip Ro Spirit, 23-24.09.24

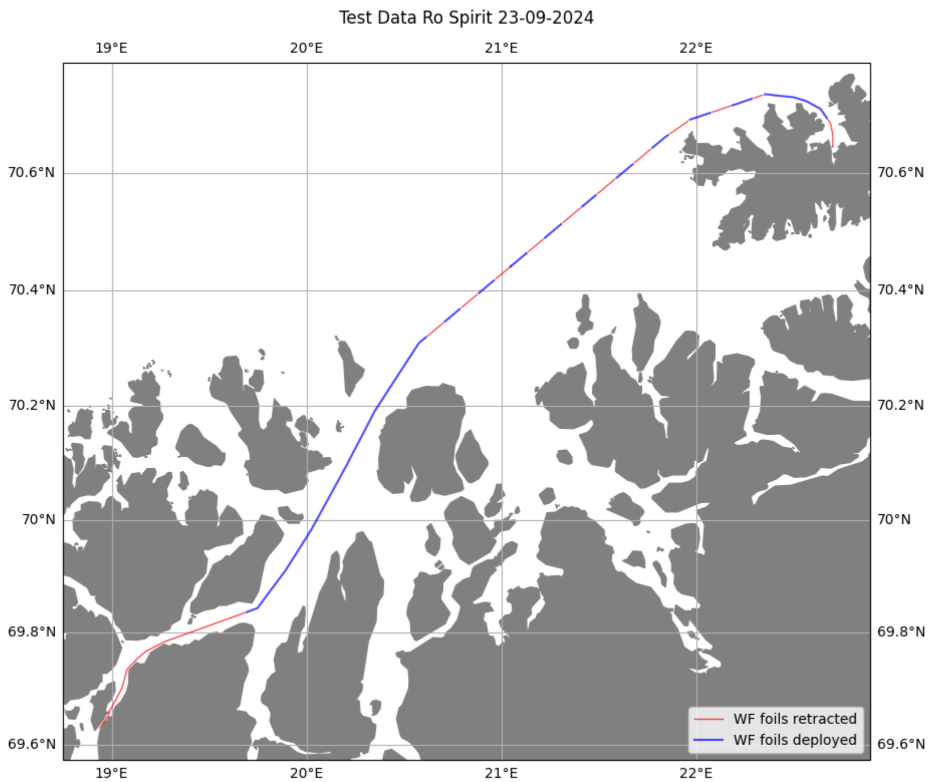


Figure 6: Map showing position and bow foil status of Ro Spirit northwards at Lopphavet.

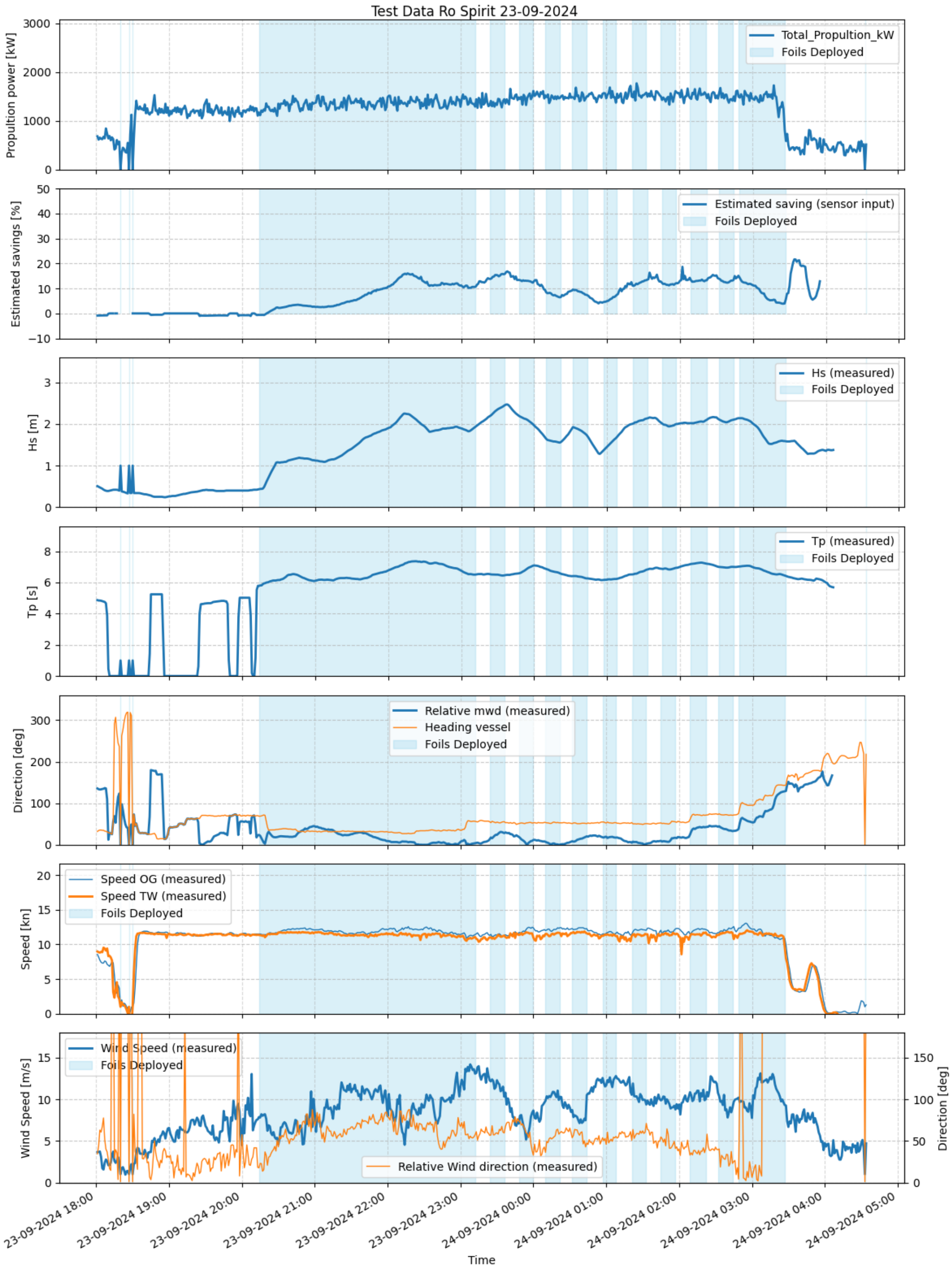
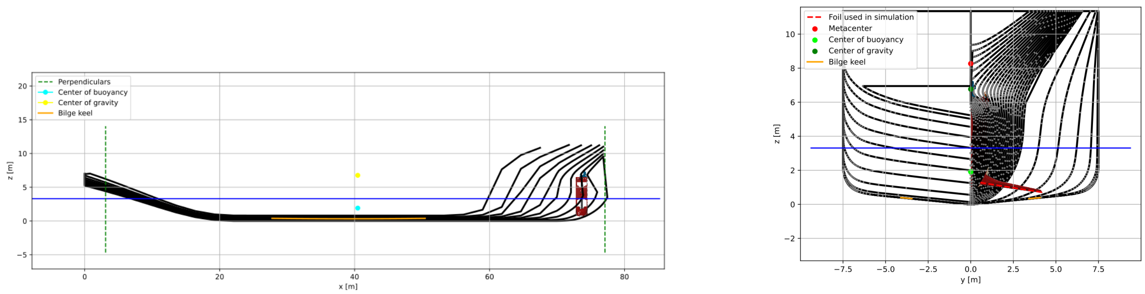


Figure 7: Measured data during trip.

B Wavefoil simulation Ro Spirit

Wavefoil delivers in depth simulations to calculate the power savings obtained with Wavefoils. More details of the simulation method is found in appendix D. The validation of the simulation results are found in appendix C. The Wavefoil Simulation uses the vessel's hull geometry together with a selected foil module in a suitable position in the hull. The input for Ro Spirit are shown in Figure 8a, 8b and Table 3.



(a) (b)

Figure 8: Ro Spirit linedrawings with Wavefoil WF3970.

Table 3: Ro Spirit simulation input.

Vessel name	Ro Spirit
Owner	Rostein AS
Length over all	79.3 m
Breadth	15 m
Draft	3.3 m
Service speed	10-12 knots
Installed propulsion power	3000.0 kW

The RAO's (Response Amplitude Operator, e.g. heave, roll, pitch) and brake power are calculated in all sea conditions. Hindcast metocean data are used to calculate the specific shaft power savings along selected sailing routes using the simulation data shown in Figure 9. See Figure 12 and 13 in appendix D for an example of sailing route.

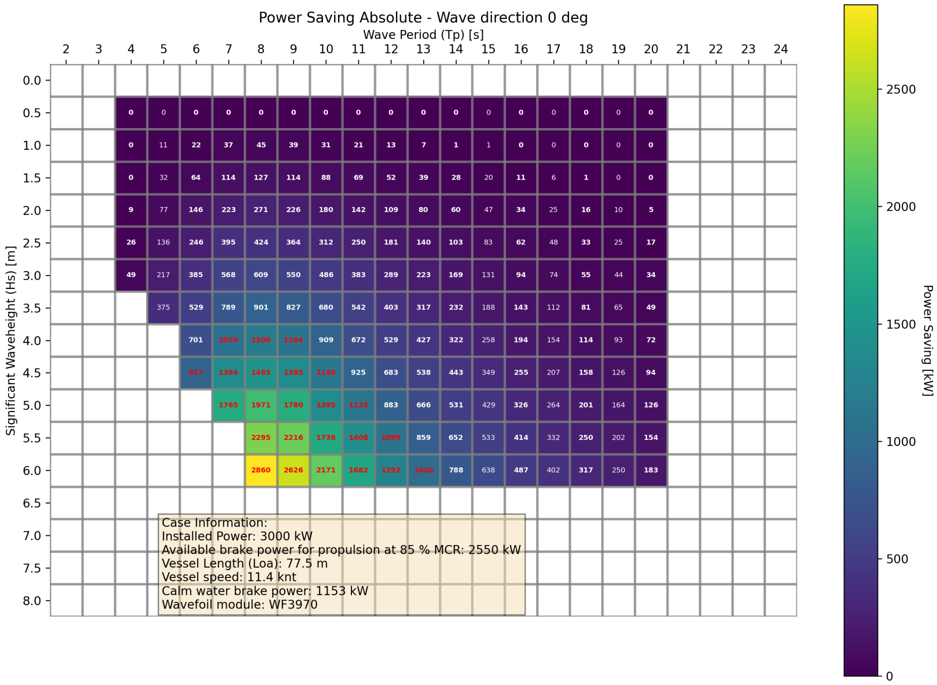


Figure 9: Power saving matrix for Ro Spirit in 11.4 knots and Mwd 0°. Red numbers simulate the limits of installed brake power for a given speed.

C Validation of Wavefoils's simulation results for Ro Spirit

The measures test data from Ro Spirit can be used to validate the Wavefoil Simulation results.

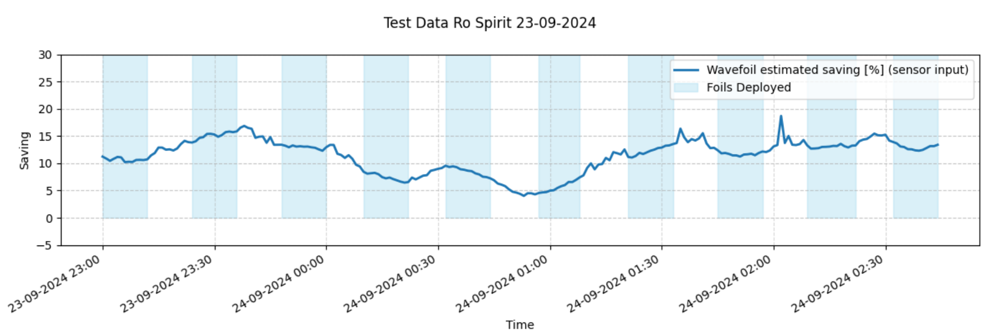


Figure 10: Estimated savings for Ro Spirit during test.

Figure 10 shows the estimated savings for the total test given the sensor data inputs (Hs, Tp, mwd, speed). Using the same filters for sea conditions as applied in Figure 5 in Section 4 with Hs 1.75 - 2.25 m, Tp 6 - 8 s, Mwd 0° - 20°, yield an estimated total mean power saving of 11.52 %, compared to a measured mean power saving of 10.4 %. The estimation focuses solely on the data when the Wavefoils are deployed, during which both speed and, consequently, brake power are at their highest. This gives an error of 1.11 percentage points or 29.05 kW between the Wavefoil Simulation estimations and the measured propulsion power.

Table 4 shows the simulated and measured mean power from the test. Wavefoil's simulation slightly over-

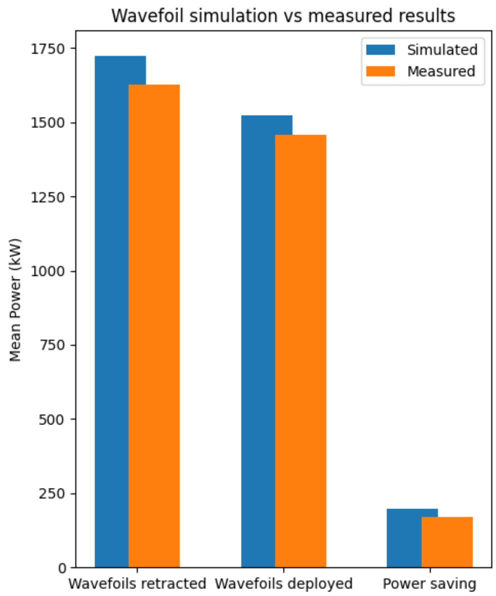


Figure 11: Comparison of Wavefoil Simulation and measured results on Ro Spirit.

Table 4: Comparison of Wavefoil Simulation and measured results on Ro Spirit.

	Wavefoils retracted	Wavefoil deployed	Power saving	Power saving
Mean power simulated	1722.39 kW	1523.96 kW	198.43 kW	**11.5 %**
Mean power measured	1626.97 kW	1457.59 kW	169.38 kW	**10.4 %**
Difference	95.42 kW (5.5 %)	66.37 kW (4.4 %)	29.05 kW (14.6 %)	**1.1**

predicts the vessel's break power in wave conditions. Several factors could contribute to this discrepancy, including suboptimal test conditions, as the wave environment was significantly influenced by wind swell and winds up to 14 m/s.

Conclusion of simulation validation

The precision of Wavefoil's simulation results are remarkably good given the test conditions. The comparison between measured test data and Wavefoil's simulation model reveals a close alignment with a deviation of only about 29 kW between predicted and measured power savings. These results underscore the reliability of the simulation tool for accurately predicting power savings with Wavefoils across various vessels and sea conditions, ensuring consistent and trustworthy performance assessments.

D Wavefoil Simulation Model Method Description

The following is a short description of Wavefoil's methodology for calculating the power saving obtained with our retractable bow foils on a specific vessel.

Brake Power

The brake power with the bow foils retracted in a given sea condition, P_{Bw}, is calculated as

$$P_{Bw} = \frac{R_{Tw} V}{\eta_{Dw} \eta_S}.$$

Where R_{Tw} is the ship resistance in the given sea condition with the foils retracted, V is the ship speed, η_{Dw} is the propulsion efficiency in waves with the foils retracted, and η_S is the transmission efficiency.

The brake power with the bow foils deployed in a given sea condition, $P_{Bw,foils}$, is calculated as

$$P_{Bw,foils} = \frac{(R_{Tw,foils} - T_{foils}) V}{\eta_{Dw,foils} \eta_S}.$$

where $R_{Tw,foil}$ is the ship resistance in the given sea condition with the foils deployed (accounting for the motion-damping effect of the foils but not the foil thrust), T_{foils} is the foil thrust, and $\eta_{Dw,foil}$ is the propulsion efficiency in waves with the foils deployed.

Propulsion efficiency is estimated using variable propulsion efficiency with Wageningen_B propeller data.The ship resistance in the given sea condition is composed of calm-water resistance, wind resistance and added resistance in waves. If Wavefoil does not have calm-water resistance from CFD or a model test available, we use Hollenbach's model for the calm-water resistance (Hollenbach, 1998). The added resistance in waves is calculated using SINTEF Ocean's software ShipX VERES, and more specifically, by using the method "Direct Pressure Integration" within this software.

Route Simulations

Wavefoil performs route simulations, to calculate the power saving for a given route, by using hindcast metocean data from the Copernicus database (Global Monitoring and ForecastingCenter, 2018). The simulations uses the Pierson-Moskowitz wave spectrum to simulate irregular sea. In the route simulations, a ship equipped with retractable bow foils from Wavefoil is compared with a ship without retractable bow foils from Wavefoil. Both ships are set to sail at constant speed, but within limits of the engine power. If engine power is exceeded the respective ship will operate at constant maximum power until the average voyage velocity is maintained. Figure 12 and 13 shows an example of sailing route and metocean data.

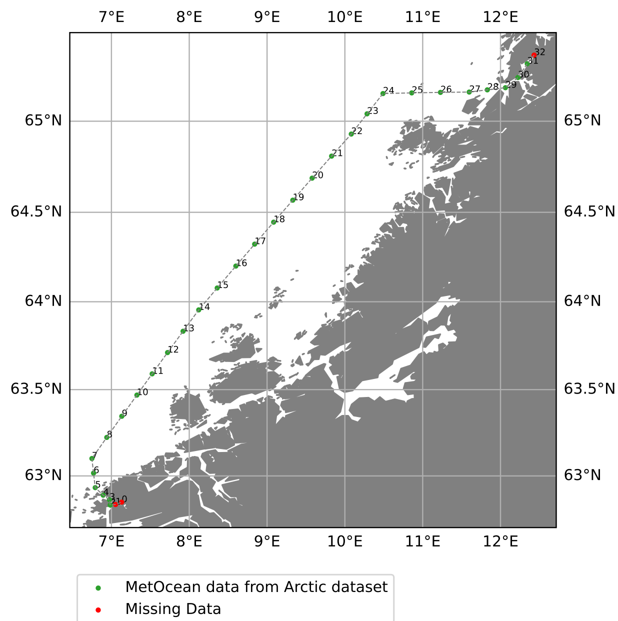


Figure 12: Sea route between Elnesvågen and Bronnøy. Data from the Copernicus database.

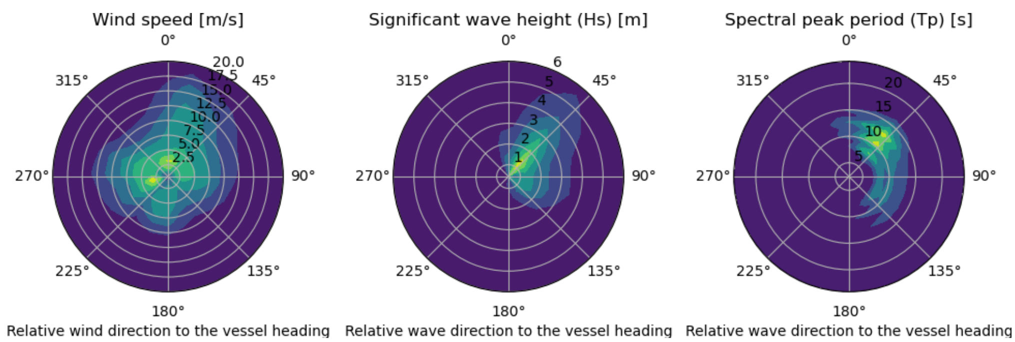


Figure 13: Polar plot illustrating wind speed, wave height and wave period encountered when sailing from Elnesvågen to Bronnøy.

E Appendix References

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