Memo to:		**Memo No:**	11HCQIFE-1/ CIORT
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		Date:	2021-03-26
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CFD assessment of Wavefoil effect

As part of a GSP Service Office for Fleet Renewal project for a shipping company, DNV has performed an assessment of the effect of a Wavefoil on the resistance of the ship. The study comprised several steps, outlined below:

1. Effect of the foil on still water resistance
    a. Mesh convergence study for the foil
    b. Assessment of increase in resistance due to the presence of the foil
2. Effect of the foil on resistance in a regular wave train
    a. Mesh convergence study for the foil
    b. Assessment of savings in one regular wave

The simulations are performed for a ship in the fleet, at a typical draft of 7.83 m, trim 0.62 by stern, displacement 14130 t. The main characteristics of the ship are provided below, see Table 1.

Length between perpendiculars [m]	126
Breadth on waterline [m]	20
Moulded draft [m]	8.0
Moulded displacement volume [m^3]	14043

Table 1 Main characteristics for typical ship

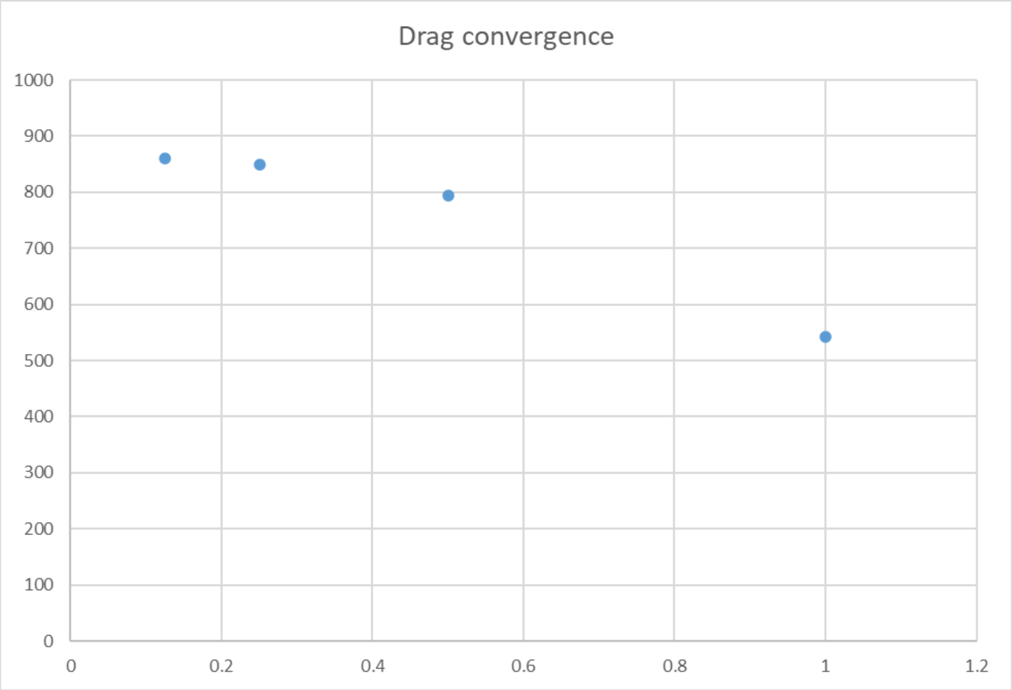
The general CFD code Star-CCM+ is used for carrying out the simulations. All simulations are performed starting from DNV's standard still water resistance setup. Menter's Shear Stress Transport (SST) is used for turbulence closure. For the simulations in a regular wave train, the necessary changes to the mesh are carried out to adapt the mesh and solver to the different requirements. Again, all settings are based on standard DNV practice.

1. **Effect of the foil on still water resistance**

a. Mesh convergence study for the foil

The simulations are performed starting from a standard still water simulation. Only the mesh on the foil and its immediate vicinity is changed. The convergence criterion is change in drag and lift produced by the foil, see Figure 1.

The mesh next to the foil is changed starting from a coarse cell size (corresponding to "1" in Figure 1), and then decreased by a factor of 2 every time (hence values of 0.5, 0.25 and 0.125 in Figure 1). It is emphasized that in this case, "1" is only used for reference and does not represent the actual value of the cell size on the foil.



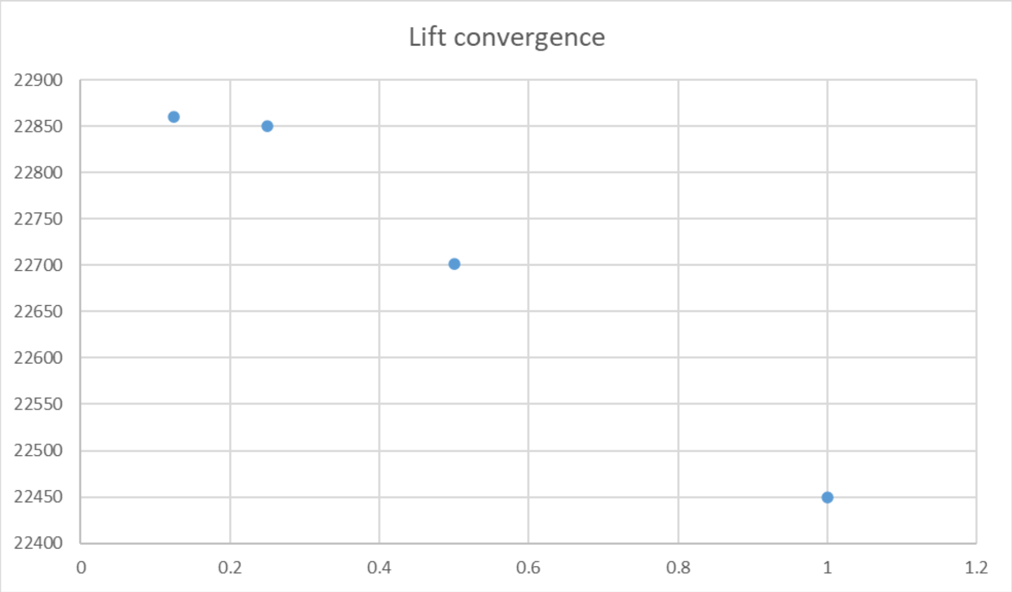


Figure 1 Drag (above) and lift (below) convergence on the foil

For practical purposes, the cell size corresponding to “0.25” is used in the resistance comparison simulations.

b. The study consists of two separate still water resistance simulations. One of the simulations is performed without the foil (considered in retracted position), whereas the second simulation is performed with the foil in extended position. Dynamic sinkage and trim are accounted for in both simulations. The number of cells is 4.1 million for the hull without the foil, and 4.4 for the hull with the foil.

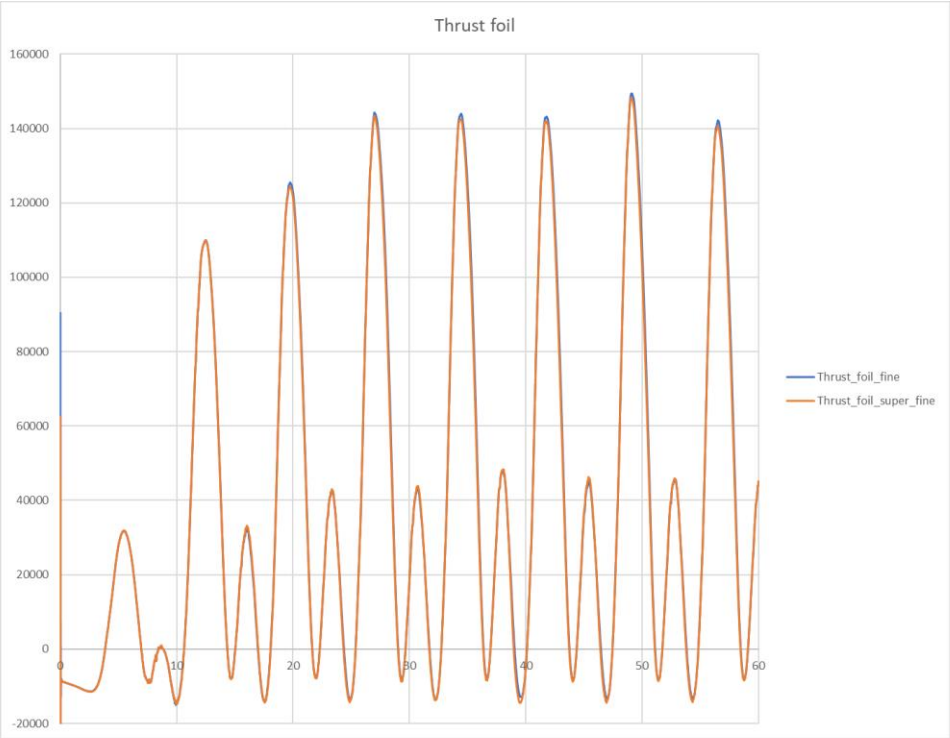
The simulations show an increase of 3.4% in resistance due to the presence of the extended foil. The increase in power will be smaller, since in this case only bare hull resistance is accounted for and no other component of total resistance is considered.

2. Effect of the foil on resistance in a regular wave

The simulations in a regular wave are carried out in head waves of 2.0 m height and 10.4 s wave period. The ship velocity is 13.0 kn.

a. Mesh convergence study for the foil

For the hull in regular waves with extended foil, several sets of simulations are performed. Like the still water resistance convergence test, only the mesh on the foil is changed, starting from coarse to very fine. The criterion is the thrust and lift on the foil. For all practical purposes, the measured force on the foil is insensitive to mesh size, see Figure 2. A comparison of the total resistance is also performed, see Figure 3.



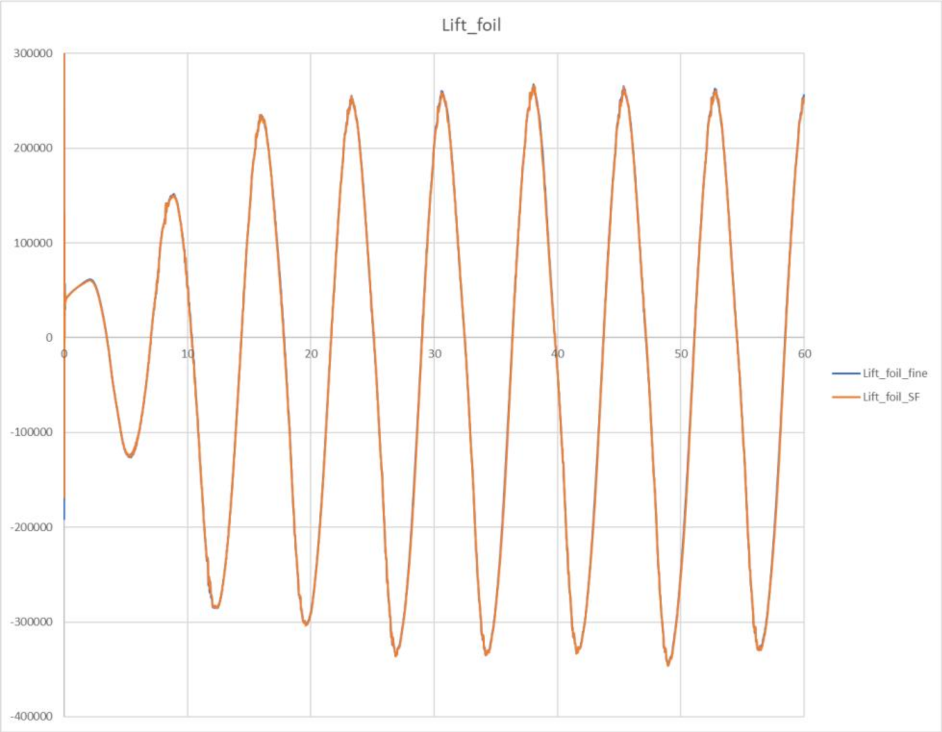


Figure 2 Thrust force on the foil, thrust (above) and lift (below)

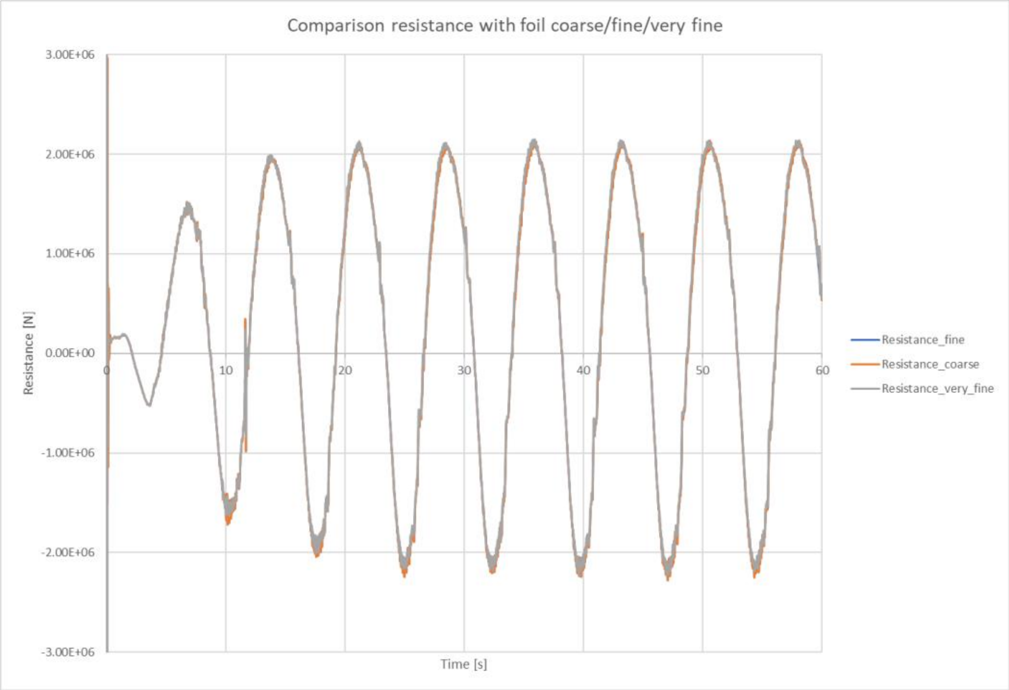


Figure 3 Comparison of resistance with three meshes on the foil

The fine mesh (i.e., the one with the middle cell size) is used in the simulations. The number of cells in this case is 4.0 million cells. The mesh size in the wave propagation is of about 60 cells / wavelength and 16 cells/wave height. On the foil, the same size as used in the resistance simulations is imposed.

b. Assessment of savings in a regular wave train

Two sets of simulations are performed: one with the foil, the other one without the foil. To minimize the numerical uncertainties, the simulations are basically identical except the presence of the foil.

As a quality assurance step, ensuring the highest confidence in the results, an independent set of simulations is carried out, with simulation setup done independently by a different engineer. With a complicated numerical set-up, this is a more efficient and robust way to check the simulations.

Since the results are practically identical, further in the memo only one set of results will be presented. Reference to the independent set of simulations will be made only when referring to the assessment of the savings.

The results are presented in Figure 4 as time series of the resistance, orange curve (hull with foil) and blue curve (clean hull). It can be clearly noticed that the average force of the “with foil simulation” is higher (in the simulations, resistance is negative, hence higher average means less resistance). This is supported by the reduced amplitude of the motions, see Figure 5; the motions of the hull with foil are of smaller amplitude, which means lower added resistance in waves for wave frequencies around pitch resonance.

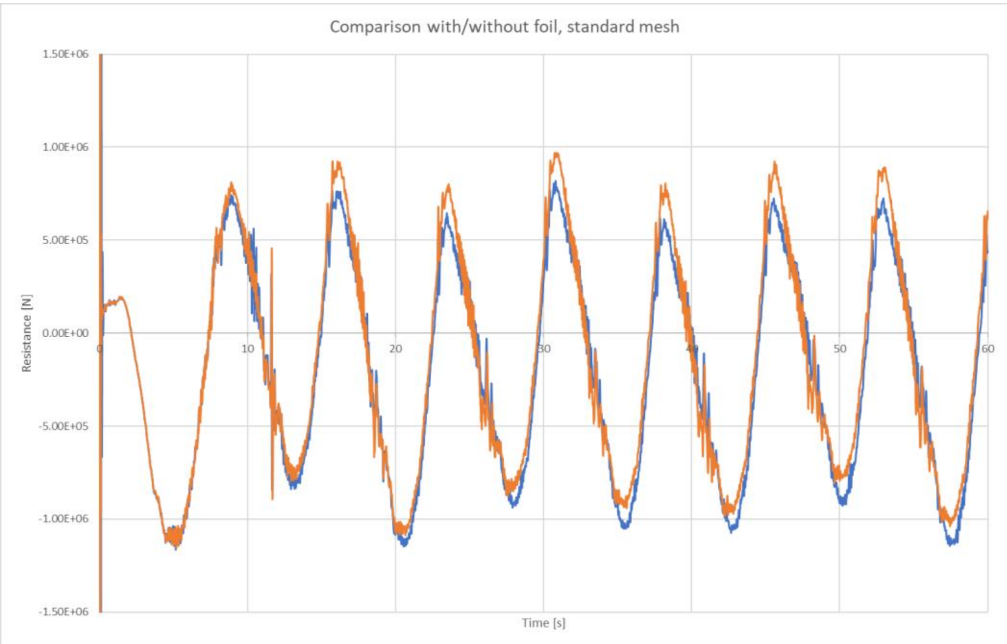
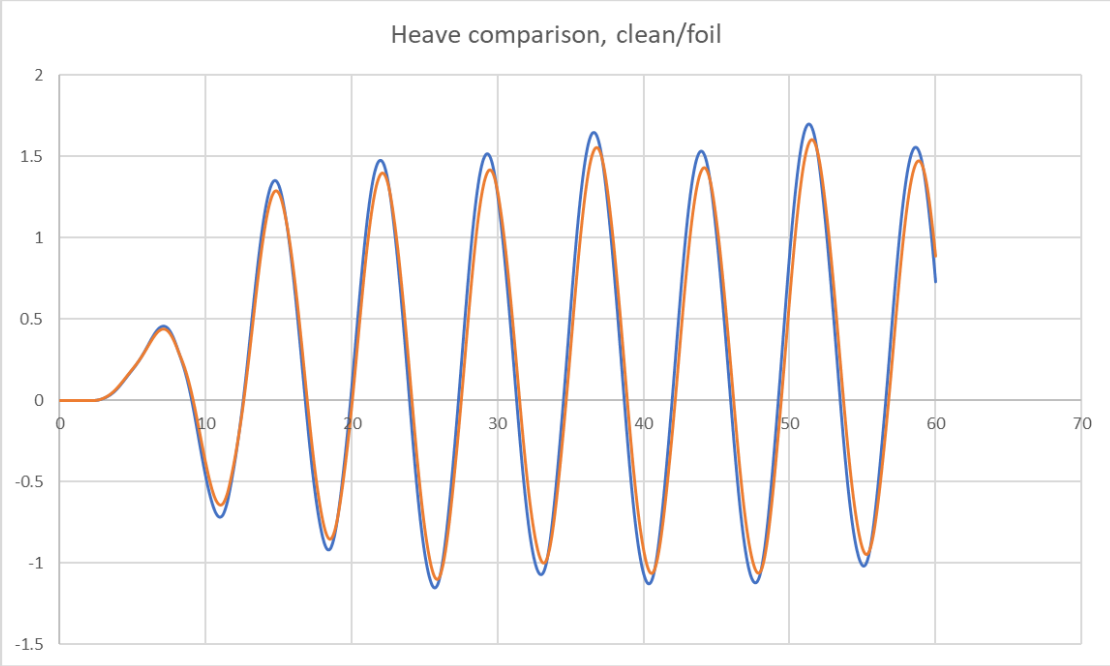


Figure 4 Comparison of resistance, clean hull (orange) and with foil (blue)



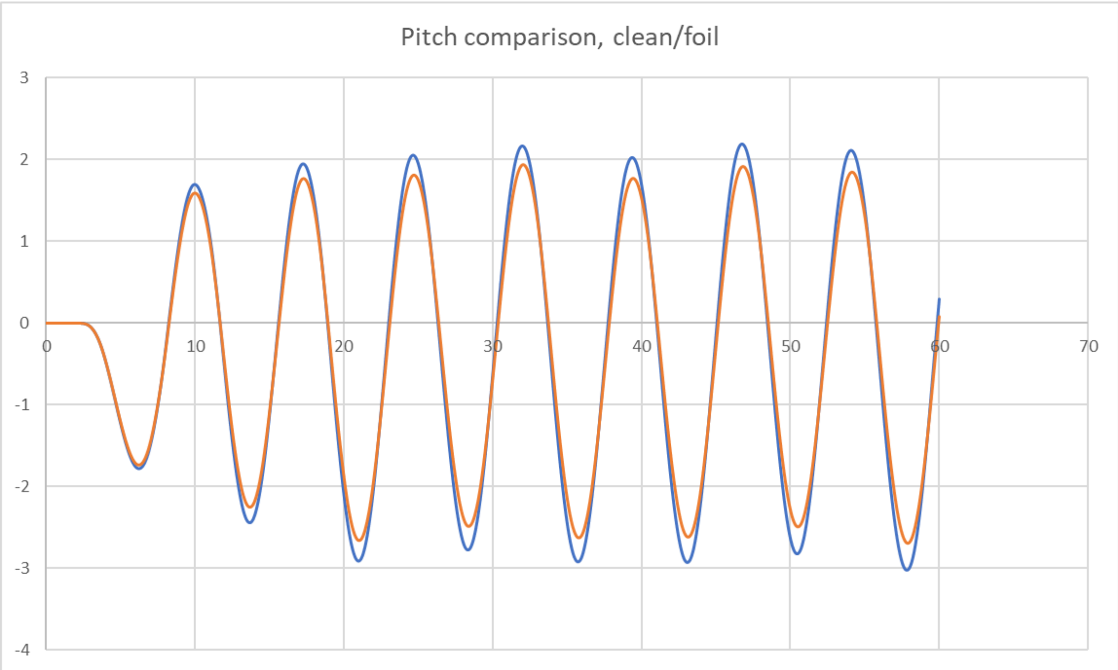


Figure 5 Comparison of motions, time series, clean hull (blue) and hull with foil (orange)

The assessment of the added resistance in waves is challenging, due to its high sensitivity to the time window used, number of cycles, etc.

In this case, the assessment of the average resistance is made is an iterative manner: first, the forces are averaged between zero-up crossings over the last, say, 3 integer number of cycles. This average becomes the new reference for zero-up crossings, and a new average is calculated. The process is repeated until convergence is obtained.

It is reminded that two sets of independent simulations are carried out by two engineers. In both cases, the results show a reduction in resistance due to the presence of the foil. In one case, the reduction is 28%, while in the other case the reduction is 29%. The results can be considered as identical for this type of assessment.

Conclusions

The Wavefoil installation reduces the total resistance in a regular wave train with 28%. The wave frequency is chosen from the peak of the estimated added resistance quadratic transfer function, meaning the wavelength that gives maximum added resistance, typically corresponding to maximum pitch. The 2m wave height roughly doubles the total resistance compared with still water, and the Wavefoil installation drastically reduces the wave added resistance part.

It is important to underline the difference between regular waves and irregular waves: Regular waves are waves with constant amplitude and period, whereas irregular waves – as occur on the ocean – can be described as a superposition of many regular waves with different amplitudes and periods. An irregular – or real – sea state with significant wave height of two meters, implies that the average height of the highest one-third of the waves is two meters. The resistance reduction with a Wavefoil installation in a real sea state with significant wave height two meters would therefore be lower than the regular wave result in this study. The saving is larger when the vessel operates in sea-states with wave energy centered around wavelengths resulting in large pitch motions. The added resistance in waves typically increases with the wave height squared. The relative saving is much larger in high seas, when the added resistance in waves becomes a significant part of the total resistance.

The resulting average fuel saving over time will depend on the route and operational profile. A complete assessment of the benefit of a Wavefoil installation for a given ship must therefore use wave statistics for the relevant routes combined with the hull lines of the ship in question.