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Fuel savings for a general cargo ship employing retractable bow foils

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ABSTRACT

Route simulations were performed on a 100 m long (between perpendiculars) general cargo ship equipped with retractable bow-mounted foils, so-called wavefoils, for resistance reduction and motion damping in waves. Two round-trip routes were simulated: Orkney Islands to Iceland and across the Bay of Biscay. Ship motions and added resistance in waves were calculated in the frequency domain. Foil thrust was calculated in the time domain, based on a frequency-domain model of the vessel motions with wavefoils, using a slightly modified version of the Leishman–Beddoes dynamic stall model [22]. For both directions of each route, 1000 journeys with and without wavefoils were simulated, with wind and wave conditions obtained from ECMWF hindcast data. In the simulations, two identical ships, one equipped with wavefoils and the other without, were assumed operating in parallel, starting their journeys at random times between January 1, 2000, and December 1, 2014. The brake power was constant for the ship without wavefoils, whereas the ship with wavefoils reduced its power to obtain the same speed as the ship without wavefoils. For the most favorable route with respect to this study, Orkney Islands to Iceland, the average fuel saving was 22% for a constant brake power without foils that corresponds to a calm-water speed of 14 knots.

1. Introduction

The environmental motivations for reducing a ship's fuel consumption are obvious and well known and do not require further elaboration. Lower fuel consumption also implies lower operating costs for the ship owner. One promising way of saving fuel for ships operating in areas with strong seaways is employing bow foils for resistance and motion reduction in waves. Such foils, known as wavefoils, work best for wavelength-to-shiplength ratios bewteen between 1 and 2 [1,2]. Typical spectral peak periods (T_p) in the North Atlantic from 7 to 15 s imply wavelengths of 76–351 m based on T_p, or 45–208 m based on the mean period (T_{m01}). Therefore, the optimal ship length for a ship employing wavefoils in this region can be said to be in the 50–150 m range. The present paper presents simulated energy savings, or fuel savings, for a general cargo vessel in this length range employing wavefoils on two round-trip routes.

Published studies on achievable mean fuel savings for ships employing wavefoils in realistic ocean wave conditions are very limited. Veritec, a former subsidiary of Det Norske Veritas (today DNV GL Group) analyzed the propulsive effect of wavefoils on vessels of lengths 20, 40, and 70 m [3,4], operating in the North Sea. Total foil areas of 2%, 4% and 6% of the vessel water plane area were studied. The fuel saving percentage increased with increasing foil area for all three ships. For the 70 m vessel with a foil of 6% of the vessel water plane area, the fuel saving was 43% at 10.6 knots and 10% at 15.9 knots. The vessel motions were calculated using a strip theory program, but the heave and pitch damping due to the foils was not accounted for. Furthermore, neither drag nor dynamic lift effects were accounted for.

Naito and Isshiki [1] presented a graph of speed loss as a function of significant wave height (H_S) for a ship with and without wavefoils, but only for one mean wave period. They also state that "Economical advantage of bow wings has not been demonstrated". Angvik [5] and Borgen [6] calculated fuel savings for an offshore supply vessel employing wavefoils. Borgen also studied a coastal tanker and a purse seiner. They obtained the ship motions with and without foils from the frequency-domain module VERES of the computer program ShipX from SINTEF Ocean (formerly MARINTEK). Foil drag and finite span effects were accounted for, but stall was neglected since the foils were assumed to be actively controlled in pitch. Borgen used a simple correction for unsteady effects and he also assumed a benefit of chordwise flexibility. Of the two, only Borgen studied irregular waves, with wave directions from head to following sea in steps of 45°, but he only considered one significant wave height (2.51 s) and one mean zero-up-crossing period (6.77 s). The reported fuel savings were large and so were the foils considered: For instance, for the offshore supply vessel, Borgen found that the fuel saving averaged over all wave directions was 39% at 10 knots and 24% at 15 knots, when employing foils with a total foil planform area of 6% of the vessel's water plane area and a span-to-

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Fig. 1. The case vessel with wavefoils deployed.

Table 1
Main particulars of the case vessel.

Length overall	110.39 m
Length betw. perp.	99.90 m
Length on waterline	106.61 m
Breath on waterline	19.39 m
Draught at amidships	6.00 m
Volume displacement	7706.41 m^3
Wetted surface area	2588.62 m^2
Water plane area	1687.55 m^2
Projected front area above the waterline	400 m^2
Projected side area above the waterline	1161 m^2
Water plane area coefficient	0.816
Prismatic coefficient	0.616
Block coefficient	0.612
Midship coefficient	0.993
Main engine power (MCR)	3900 kW
Service speed	14 knots

Table 2
Main particulars of the wavefoils.

Profile	NACA 0015
Length	8.50 m
Inner chord	3.20 m
Outer chord	2.00 m
Foil area	22.10 m^2
Planform	Tapered

chord-ratio (span being the distance from foil root to tip) of 5.

Bøckmann [2] calculated fuel savings for a platform supply vessel equipped with a large wavefoil underneath the bow in his Ph.D. thesis. A two-way coupling between non-harmonically varying foil forces and the ship motions, meaning that the foil forces affect the ship motions and vice versa, was obtained by implementing a dynamic stall model for the foil forces in the time-domain ship seakeeping and maneuvering simulator VeSim from SINTEF Ocean. Fuel savings were calculated in short-crested irregular waves for wave directions ranging from head to following sea in steps of 45°, but only for one significant wave height (H_S) and three values of T_p. The fuel saving was 9% when averaged over all wave directions, for a ship speed of 12 knots and a significant wave height of 2.5 m. To calculate the speed loss or power saving for a motorized vessel employing wavefoils on a given route, the speed-power curve must be obtained for all combinations of sea state and wave direction, which makes such an analysis extremely time consuming, unless the approach in the present work is adopted.

With this background in mind, the motivation for the present paper was to answer the question “What is the fuel saving with wavefoils?” by calculating mean fuel savings for selected routes – not only selected wave conditions – for a ship with realistically large wavefoils. In the present work, we also compare three different models for calculating the foil thrust. We show that calculating the ship motions in the frequency domain and the foil forces in the time domain, with a one-way coupling from ship motions to foil thrust, give conservative fuel saving results relative to simulating two-way-coupled ship motions and foil thrust in the time domain. The latter approach was compared with experiment results in [2,7].

2. Case vessel

The vessel studied in the present work, illustrated in Fig. 1 with the wavefoils deployed, is a general cargo vessel designed by the second author. Main particulars of the vessel are given in Table 1.

The wavefoils – or simply referred to as “the foils” – with main particulars given in Table 2, are mounted to the ship with the span axis sloping 6 degrees tip-down and a fixed pitch angle of 0° when deployed. The foils have no sweep angle relative to the quarter-chord, and the horizontal distance from the aft perpendicular to the quarter-chord of the foils is 94.448 m. The total foil planform area is 2.6% of the ship's water plane area.

The foils can be retracted through apertures in the hull. The additional resistance that these apertures are causing is neglected in the present work.

3. Routes

Two different routes were studied, see Fig. 2. These routes were chosen because they are frequently sailed by ships in the same size range as the case vessels and because they are particularly wave-rich. The two routes both follow great circle routes and their start and end coordinates are given in Table 3.

Route A goes from north of the Orkney Islands to near Reykjavik, and route B goes across the Bay of Biscay. Route B has very high ship

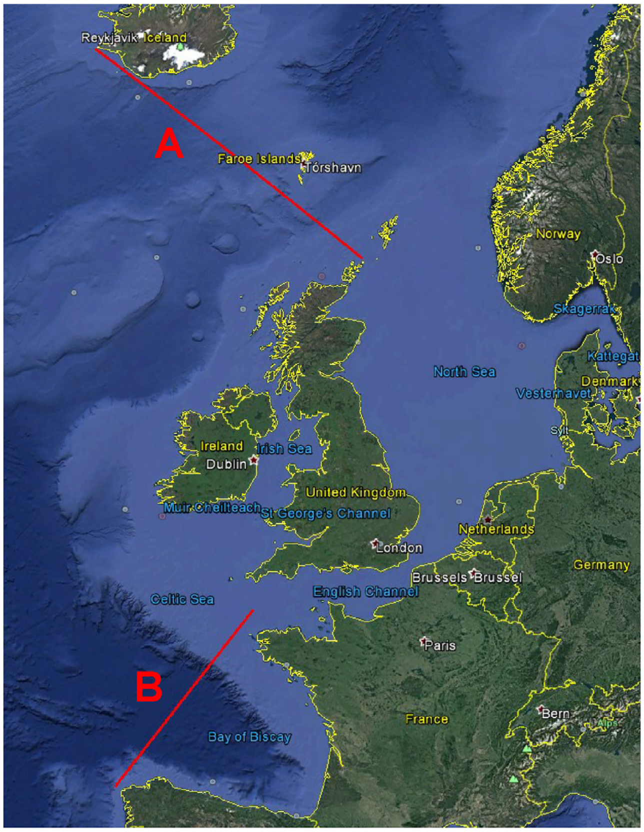

Fig. 2. Routes studied.

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