What to expect from the hydrodynamic energy saving devices

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Abstract

Many retrofitting technologies have been proposed to improve the hydrodynamic performance of existing fleets with the aim of reducing the fuel consumption and consequently CO_2 emission. The magnitudes of savings predicted by manufacturers are very promising however ship owners are often still doubtful whether they can achieve what is claimed in operations. This study evaluates the performance of four energy saving devices (ESDs) at ship scale with the aim of assisting ship owners with the decision of selecting suitable devices for their ships. Due to the uncertainties associated with extrapolation of viscous flows from model to full scale it is proposed that investigations must be carried out at full scale; hence a full-scale computational model was adopted as the only feasible method at the design stage. Two vessels representing different types of ship were selected: a gas carrier and a container ship. Various retrofitting technologies to reduce resistance or to improve the propulsive efficiency were considered. The latter group is subdivided into devices located before, at and aft of the propeller. The resistance induced by large openings on the hull, such as a bow thruster tunnel was quantified and several devices designed to streamline the flow in this region were evaluated. Pre-swirl fins technology was the ESD investigated from preswirl devices. The existing propeller of the gas carrier was replaced with a new type profile propeller which improved the propulsive efficiency. Twisted rudder was the technology investigated from post-swirl ESDs. The level of savings obtained from these technologies was generally less than the values published in the literature. It was concluded that this discrepancy arose for one of three reasons: either the metric used to evaluate the savings was inappropriate, or that the method used to quantify the measure was inaccurate, or finally, because the designs examined in the case studies were not suitable optimised. However if some of these devices did not deliver the expected savings because the designs considered in this study were not sufficiently optimised, then the question arises as to whether these devices must be optimised for a specific operational conditions and how well these ESDs behave when the vessel is not operating in the design conditions.

Keywords: Low carbon shipping, Hydrodynamics, Full Scale, Bow Thruster Tunnel, Pre-swirl Fin, Twisted Rudder

1 Introduction

The reduction of fuel cost has always been one of the key strategic business goals for ship owners and operators. In the current climate of high oil prices, the reduction of fuel costs becomes essential; and furthermore a variety of recent legislations require owners and operators to move towards the reduction of emissions from ships of SOx, NOx and CO_2. Hence the pressure on designers to achieve both reduced fuel costs and reduced emissions by optimising the hull and propeller has never been higher. In parallel to the performance improvement of new built vessels, there has been great interest in the potential to enhance the performance of existing vessels through retrofit of devices to the hull. A wide

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range of concepts has been proposed, many of which involve modification or control of the flow in the vicinity of the propeller. The interest in these devices arises with increasing oil price. These devices are commonly called “energy saving devices (ESD)” and sometimes “retrofitting technologies” although many can be considered for new designs as well.

Regardless of the application on new built or existing vessels, ESDs vary substantially in terms of the working principles. Very broadly they can be classified into those devices which reduce resistance and those that improve the performance of the propulsion system. The latter can be subdivided into pre-swirl devices located before the propeller, devices at the propeller location and also post-swirl devices. The savings claimed for these devices vary substantially, with designers of some of these devices claiming very promising figures. Table 1 presents some of the commercialised technologies along with the claimed energy saving levels (OCIMF, 2011).

Table 1: ESDs and proposed energy saving.

Device	Impact	Energy savings %
Twisted rudder	resistance	4
Twisted rudder and bulb	resistance	2-8
New propeller design	propulsion	4-6
Pre-swirl fins	propulsion	3.5
Rudder stator fins	propulsion	9
Propeller boss cap fins	propulsion	3-7
Wake equalising duct	propulsion	6-7
Mewis duct	propulsion	7-9

These figures naturally look very attractive to ship operators, for instance a saving of 6-7% from installation of a wake equalising duct (Schneekluth, 1986, Schneekluth and Bertram, 1998) or 7-9% from a combination of wake equalising duct and pre-swirl fins (Mewis, 2008, Mewis, 2009). In general, the negative aspects of the devices include the considerable cost of installation, and also the reported reluctance of manufacturers to guarantee the claimed savings. These factors can combine to make the potential buyers doubtful about the reliability of the claimed savings. The claims may not give details as to the conditions under which the savings have been achieved and/or how the savings have been calculated and/or measured. Furthermore, the magnitude of the savings may well be within the range of uncertainties and measurement errors on the full-scale vessel. Consequently, cautious operators may well be sceptical about the validity of the figures being presented to the market, and it is absolutely reasonable and necessary for a buyer to verify independently the amount of savings before any investment on an ESD or ESDs.

This paper presents a series of case studies evaluating the capabilities of some ESDs for particular candidate vessels. To this end, a device from each group of ESD is selected and its performance on two candidate vessels is assessed.

2 Methodology

Two vessels representing different ship types were selected as the test vessels: a gas carrier and a container ship. The main particulars of the vessels are given in Table 2 and a schematic view is shown in Figure 1. The vessels were chosen based on the availability of test data for validation of the computational model.

Based on the current practice, many studies rely on physical modelling in test tanks (Hoshino et al., 2004, Korkut, 2006). The key challenge with physical modelling is that many ESDs are relatively small compared to the vessel and it is very difficult to extrapolate their performance at full scale reliably using model scale data, especially in cases in which the ESDs operate wholly or largely within the full-scale ship boundary layer. Many of these shortcomings would be resolved through a physical test at ship scale.

However the purpose of the study is to evaluate the performance of a device without incurring the substantial costs associated with full-scale installation and testing. Furthermore, physical trials at full scale are obviously not feasible for optimisation purposes. The only remaining approach is thus to use a computational model at full scale although there are also some limitations in computational models.

Table 2: Main particulars of the test vessels.

Parameter	Gas Carrier	Container Ship	Unit
LBP	276	230	m
Draught – Laden	11.0	10.8	m
Draught – Ballast	9.05	---	m
Cb	0.717	0.651	---
Speed (trial max)	19.84	24.0	knots
Propeller Diameter	8.8	7.9	m

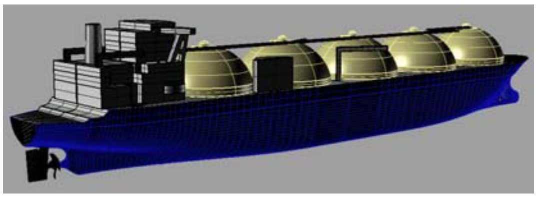

Figure 1: Schematic view of the gas carrier.

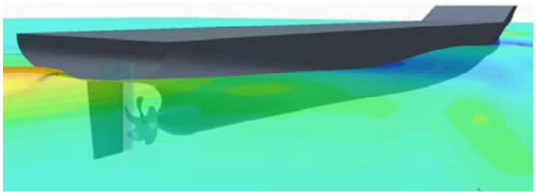

Figure 2: Schematic view of the container ship.

In addition to errors and uncertainties inherent in the use of RANS CFD in a general sense, there are some specific features in the application to flows around ships which may be included at an additional computational cost or can be neglected, based on the adoption of some simplifying assumptions. In the specific cases addressed here the key simplifications to be considered are simulation of free surface and choice of method of representing the propeller. A wide spectrum of theoretical methods has been developed to include the effect of propeller on the flow around the ship hull. The simplest plausible approach is the momentum source method in which the reaction of thrust and torque are applied on the fluid over the propeller disk and distributed circumferentially or radially according to calculations of the open-water propeller performance (Sparenberg, 1972, Sparenberg, 1974). A more complete approach is to couple the RANS simulation of viscous flow around hull with an inviscid solution of propeller. The RANS simulation determines the propeller inflow that is used by inviscid solution to find the propeller forces. These forces will be fed back to the momentum source representing the propeller in the RANS solution. This two-way coupling approach was firstly reported by Stern et al. (Stern et al., 1988). Computations were carried out for a steady-state case and the propeller was modelled by a vortex-lattice lifting surface method. This method has been later enhanced to incorporate different levels of complexity. Phillips et al (2009) used blade element momentum theory (BEMT) to model the propeller forces. Greve et al. (2012) reported a coupling procedure between RANS method and boundary element method (BEM) to model unsteady behaviour of the propeller thrust and torque due to large amplitude ship motions without any circumferential or radial averaging. At the other end of the spectrum is the most accurate and most computationally expensive approach of rotating/sliding mesh in which the rotation of blade is taken into account (Çelik and Güner, 2007, Castro et al., 2011, Carrica et al., 2013).

The study reported in this paper is based on the use of the RANS CFD approach to analyse the performance of the vessel at full scale in two scenarios: firstly the vessel as it was built and secondly the vessel fitted with an ESD. This will show the overall savings in the delivered power. The computational model was carried out by using the commercial code Starccm+ in a model including sliding mesh technique for propeller representation and the self-propulsion approach. The effect of free surface was taken into account in simulation of container ship whereas it was not considered in the analysis of the gas carrier. The mesh size varies between 6.4M cells for the base ship and 8.9M cells for the ship with ESDs. The computational models were verified against model and the sea trial data for the gas carrier and large-scale model test data for the container ship.

3 Results

This study considers four retrofitting technologies designed either to reduce resistance or to improve the propulsive efficiency through devices located before, at and aft of the propeller.

3.1 Resistance reduction

Large openings on the hull, such as the bow thruster tunnel, disturb the streamlined flow and can increase the ship resistance. Since the thruster is far removed longitudinally from the propeller it is reasonable to assume that modification to flow in this vicinity will not greatly impact the propulsive efficiency; hence the success of the modification can reasonably be judged by measuring the resistance of the ship at a constant speed.

To quantify the level of increased resistance due to openings on the hull, the bare-hull of the gas carrier was modelled at laden condition (draught 11.0 m) and speed of 19.8 knots. The model consists of hull, rudder and open thruster tunnel. The computational mesh was then modified so that the thruster tunnel was fully closed and the computations were repeated in the same conditions. The comparison of two cases shows that the full closure of thruster tunnel can lead to 1-2 per cent saving in fuel consumption due to reduced resistance.

In the illustration of dynamic pressure near the thruster tunnel (Figure 3), the flow separation near the back edge at 30 degrees is highlighted by dark blue which indicates the low speed region. On the other hand, the light colour in the inner side of the back wall indicates the high speed flow entering the thruster tunnel and creating vortices (Figure 4).

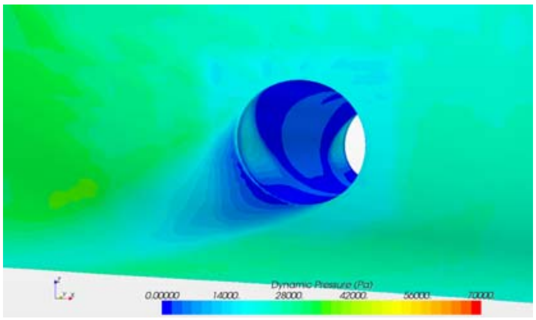

Figure 3 Dynamic Pressure, open thruster tunnel.

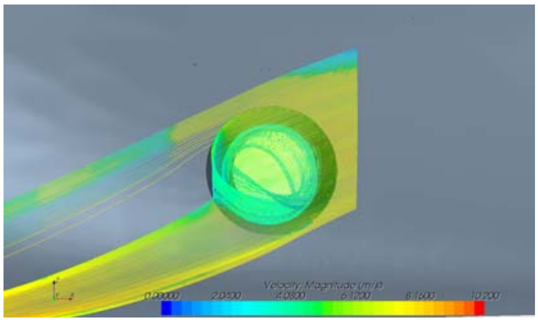

Figure 4 Streamlines, open thruster tunnel.

However the full closure of thruster tunnel is the ideal scenario; this solution is not considered to be feasible in vessels requiring a bow thruster due to practical concerns such as long-term reliability of mechanism of opening and closing the thruster tunnel cover. Thus, four alternative solutions to reduce resistance due to openings that require no moving parts were assessed.

The first technology is to mount three vortex generators forward of the opening to manipulate the flow and to prevent flow impact on the back wall (Figure 5). The second technology contains a wedge (or “eyebrow shield”) forward of the opening to regulate the flow and change its direction in order to prevent fluid particles from hitting the back wall of the opening (Figure 6). It was observed in the initial analysis of the existing ship that the flow direction in the vicinity of thruster tunnel is at 30 degrees to the horizontal. Therefore, this wedge is aligned to the flow direction to minimise the generated resistance. The third technology is to install a plate in the middle of the opening. This plate will cut the vortices formed in the thruster tunnel and reduce their size (Figure 7). This idea has previously been proposed for reducing resistance in empty wagons of cargo trains (Saunders et al., 1993). The last technology consists of a grid with different spacing in two directions (Jang et al., 2009). Similar to the eyebrow shield, the grid was rotated 30 degrees to align with the flow direction (Figure 8). It has nine segments in the flow direction and five segments in the cross flow direction.

All the technologies described above were modelled through modifications to the base ship mesh, and simulated at the same conditions. Most of the proposed technologies slightly increased the resistance. It appears that the additional structure required to divert the flow away from the tunnel generates drag which is comparable to the drag generated by the tunnel itself. It was only the grid cap which showed the potential of reducing resistance. However, this saving was very small and this technology needs to be optimised further.

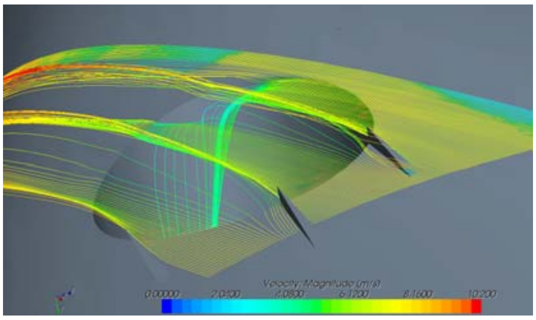
Figure 5 Streamlines, Vortex Generators.

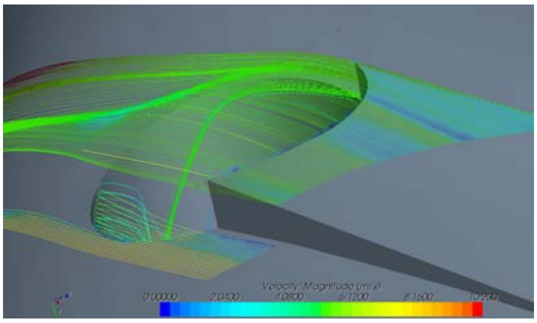
Figure 6 Streamlines, eyebrow shield.

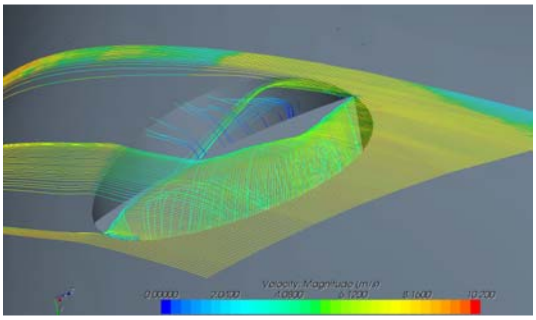
Figure 7 Streamlines, splitter plate.

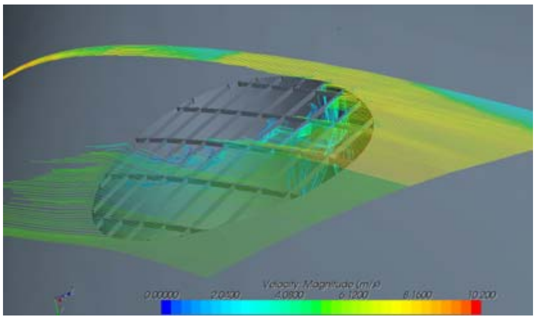
Figure 8 Streamlines, grid cap.

3.2 Pre-swirl device

Pre-swirl ESDs are located upstream of the propeller and are designed to improve the propulsive efficiency through the manipulation of propeller inflow. Among the more well-known technologies are the wake equalising duct (WED), preswirl fins and combinations of the two. Pre-swirl fins are designed to improve the propulsive efficiency through pre-rotating the propeller inflow. Their advantages include simple design, relatively low cost to install, and easy maintenance.

One challenge often faced by ship owners in assessing energy saving devices is the unwillingness of manufacturers to supply appropriate details of their device geometry for an independent investigation. In the present case, designs of preswirl fins were not available, and instead the fins were designed as part of the study based on observations of streamlines in the wake and before the propeller. A four-blade technology was considered as a typical design of preswirl fins. For the right-hand rotating propellers, three fins are located on the portside and one fin is placed in the starboard side. All fins were built based on a NACA profile with a taper shape along the fin; several iterations of the design were carried out before the final version was adopted.

This technology was designed for the container ship (Figure 9) and the gas carrier (Figure 10) independently. Next the performance of vessels was simulated by using the sliding mesh method to model the propeller and adjusting the shaft speed to find the self-propulsion condition. The delivered power was computed as the metric for comparison.

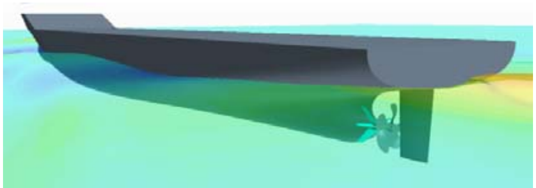

Figure 9 Preswirl technology, container ship.

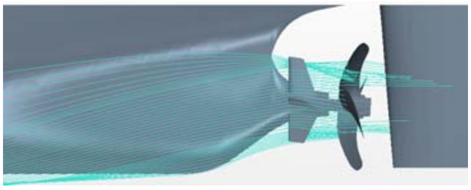

Figure 10 Preswirl technology, gas carrier.

The results confirm that the installation of fins ahead of a propeller leads to generation of a greater thrust at a fixed RPM. However, with the pre-swirl fins in place the propeller requires more torque to reach the same shaft speed. In other words, this technology increases the generated thrust at the price of requiring higher torque. The effect of pre-swirl fins upon propulsion parameters at self-propulsion point is presented in Table 3 in the form of change in these parameters. A positive number indicates an increase in power requirement and a negative indicates a reduction.

Change (%) = (ship with ESD – original ship) / (original ship) x 100

It is observed that the fins affect propulsion by increasing the thrust and torque. Since the increase of thrust is higher than the increase of total resistance, the ships with the fins reach the self-propulsion point at a lower RPM. However, propulsive efficiency and the delivered power which are influenced by both RPM and torque may have different behaviours. The design of pre-swirl fins technology on the gas carrier had a poor performance and could not reduce the delivered power and fuel consumption; whereas it was found that the fins designed for the container ship could improve the performance by just over 1 per cent at higher speeds (Table 3).

Table 3: Propulsion parameters at self-propulsion point.

		Change		
Vessel	Speed (Knots)	Thrust (%)	Torque (%)	Power (%)
Gas carrier	17	14.6	6.8	0.81
Container ship	19	6.65	4.30	0.40
Container ship	24	5.62	3.18	- 0.79
Container ship	29	4.36	2.28	- 1.19

3.3 Propeller

The New Propeller Type (NPT) propeller is a new propeller design incorporating cavitation friendly section profiles to reduce the blade surface area and increase propeller efficiency. Additional benefits include reduced propeller weight and inertia, which can lead to further savings.

The performance of the new propeller and the original propeller was investigated in open water conditions in order to remove the effect of hull on their performance. Similarly, to prevent any computational influence from mesh generation on the results, the NPT propeller was modelled with the same mesh as the original propeller with the exception of the zone in the vicinity of propeller. Figure 11 shows a schematic comparison between NPT propeller and the original propeller.

Both propellers were investigated at two scales, 1:20 and 1:4. The two sets of results showed good consistency with respect to Kt, Kq and open water efficiency.

The performance of the NPT propeller was compared with the original propeller and also the Wageningen B4 series with similar pitch to diameter (P/D) ratio. With respect to efficiency, it was concluded that the NPT propeller with P/D ratio 0.95 (measured at 0.7R) shows a similar behaviour to Wageningen with P/D ratio 1.0. On the other hand, the original propeller with P/D ratio 0.86 has a similar performance in comparison with Wageningen with P/D ratio 0.8.

In terms of the water speed, the new NPT propeller has better efficiency than the original propeller and could result in up to 4% savings in power and fuel consumption.

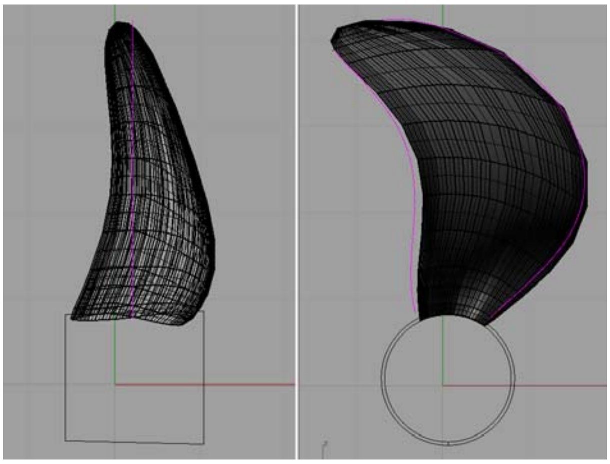

Figure 11: NPT propeller geometry.

3.4 Post-swirl device

Post-swirl ESDs are located behind the propeller and usually aim to recover the energy associated with fluid swirl in the wake which would be otherwise lost in the flow. In the current study, the rudder of the gas carrier was replaced by a twisted rudder specifically designed by a manufacturer for this vessel (Figure 12).

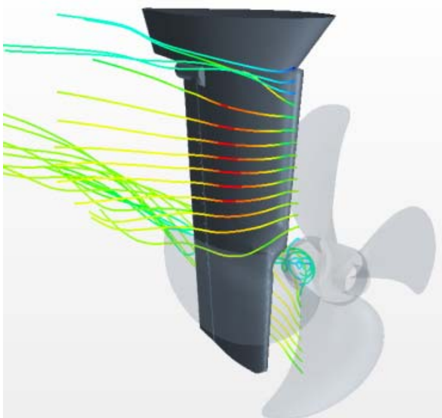

Figure 12 Streamlines in vicinity of the twisted rudder on the gas carrier.

The first set of computations was based on the manufacturer's approach to the evaluation of the device. The vessel with the twisted rudder was first simulated at a fixed ship speed and propeller RPM. Next, the base ship was simulated at the same ship speed and shaft RPM; the ship resistance of the two cases were compared and it was observed that the twisted rudder reduced the resistance by 1.25%. In the specified speed/RPM condition however, it was found in both cases that the propeller thrust and ship resistance were not in equilibrium, and thus the vessel was not in self-propulsion conditions.

In addition to the imbalance of thrust and resistance, the preliminary results showed that replacing the rudder influences the propeller behaviour. In this particular case, the generated thrust and required torque both decreased. Therefore, it was concluded that the approach was not appropriate and that resistance at a constant forward speed and propeller speed is not a suitable criterion for comparison in this case. The resistance, generated thrust and delivered torque all interact, and consequently, the resistance on its own does not deliver a clear picture of the overall performance of the ship. As with the other technologies applied in the vicinity of the propeller, a more appropriate measure to evaluate performance is the power at the self-propulsion point. Of course, this measure requires more computational effort than the original approach, as the model has to be computed with several propeller speeds.

The computations for the two test cases were then repeated for a given ship speed and the propeller speed was adjusted to find the self-propulsion point. In line with results from the previous analysis, the twisted rudder reduced the resistance at self-propulsion point; however results showed that the twisted rudder had a poor performance with respect to the delivered power, as the vessel with the twisted rudder required 1.5% more power to achieve the target speed.

Table 4: Change in total resistance & power, due to twisted rudder.

RPM	Resistance (%)	Power (%)
Given	-1.25	-2.3
Self-PP	-0.38	1.5

4 Conclusions

The study investigated four retrofitting technologies from different groups of ESDs. A full scale computational approach was adopted and the most accurate method of representing the propeller was deployed. In general, the levels of savings obtained from some of the technologies were not as promising as those published in the literature.

The study shows that choice of the correct measure of performance is crucial in evaluating technologies to be applied near the propeller due to the complex interaction between resistance, torque and thrust. In one particular case, it could be seen that the device could reduce the resistance at a given ship speed and the shaft RPM; in contrast, when the device was evaluated in terms of effective power at self-propulsion point, based on the procedure and metric proposed in this study, the vessel with the ESD had a poor performance with respect to the delivered power and needed more fuel to achieve the target speed.

There are several possible reasons as to why the devices examined here did not deliver the levels of savings published in the literature. It is possible that an over-simplified metric (such as resistance) was used; it is possible that studies were carried out at model-scale (either in model tests or CFD) leading to inaccurate extrapolation to full-scale. It is also possible that the issue relates to the design of either the ship or the device; the device may yield larger savings in mitigating the impact of a poorly-designed stern, or finally, the devices adopted in this study may not be suitable optimised for the ships at the operating conditions studied. However, it should be noted that if the devices must be optimised for a specific operational conditions on a particular ship, then further questions arise as to how these ESDs behave when the vessel is not operating in the optimum conditions.

In summary, it was observed that the results from the evaluation of ESDs are very sensitive to the procedure used. Hence, the shipping industry may need to assess the performance of ESDs more carefully and potentially revise its expectations of savings from hydrodynamic energy saving devices.

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