Hull Vane: Reducing Total Resistance and Trim by Modifying Ship Design

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Abstract- Hull Vane is a fixed foil located below the waterline, near the stern of the vessel. The lift created by it can be divided into a force in x-direction, reducing the total resistance of the vessel, and in z-direction, influencing the trim and thus the total resistance. Additionally, the Hull Vane reduces the generation of waves and the vessel's motions in waves. Model tests and sea trials have shown significant reduction in resistance. The Hull Vane is especially applicable on ships sailing at moderate to high non-planing speeds, with Froude numbers between 0.2 and 0.7.

Keywords: Hull Vane, Froude Number, CFD.

1. Introduction

The oceans have been exploited by mankind since time unknown, along with that the fossil fuels shall soon be depleted. Keeping in mind that maritime industry contributes to 90% of transportation of goods, the amount of pollution it causes is also quite alarming.

As international shipping started to sail into a world of greener ships with lower carbon emission and better fuel efficiency, steps are taken in the form of new technologies and new designs to improve the hydrodynamic efficiency of ships. In order to make the existing ships more fuel efficient, research is being carried all around the world to improve the hull form by modifying the forward and aft regions of the hull.

1.1. *Background*

Considerable amount of research has been conducted in the past on stern appendages such as trim tabs, stern wedges, stern flaps, interceptors and transom wedges. All of these have proved to be able to reduce the overall resistance of a vessel by reducing its running trim. In a study conducted on stern wedges by Karafiath and Fisher (1987), it was shown that a reduction of running trim of up to 2.0 degrees could result in a 2% of saving in fuel consumption. Cusanelli and Cave (1993) investigated the application of stern flaps as a retrofit on US Navy vessels and found a reduction in power which resulted in reduced fuel consumption and increased top speed. In a later study by

Karafiath and Cusanelli (1997) on integrated wedge-flap design, a reduction in power of 11.6% was observed, while a wedge-only configuration lead to a power reduction of 6.2%. Tsai and Hwang (2004) studied interceptors and found that these can be used to reduce the resistance of planning hulls. In line with the above research, van Oossanen (1992) invented the Hull Vane, a fixed, resistance-reducing foil situated below the water line, aft of the stern of the ship. After extensive research using CFD computations, model tests and sea trials were conducted and found that the reduction in resistance can be up to 26.5% on ships running at Froude number between 0.2 and 0.7.

2. Theory

A Hull Vane is a wing structure horizontally placed below the stern of the vessel. The flow around the vane develops a lift force as well as a forward thrust force. This reduces the resistance which results in fuel savings. It has four different effects on the vessel which are thrust force, trim correction, reduction of stern waves and reduction of motions.

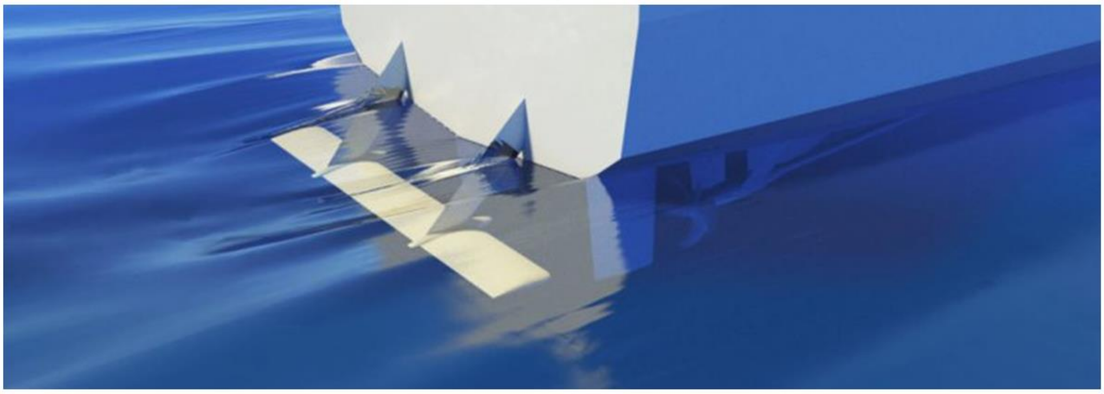

Fig. 1: Pictorial representation of hull vane

The Hull Vane was found to be most effective in the non-planning regime, at Froude numbers between 0.2 and 0.7. Since the frictional resistance is more dominant below the Froude number 0.2, addition of a Hull Vane to a vessel which increases the wetted surface area also increases the frictional resistance compared to the vessel without Hull Vane. Beyond Froude number of 0.2, the pressure resistance becomes a dominant component. Since the Hull Vane decreases pressure resistance, likely gains are obtained in the Froude number range of 0.2 to 0.7. At higher Froude numbers, the lift force of the Hull Vane creates a bow-down trim which is not desirable.The Hull Vane is generally designed and optimized for the cruising speed or maximum speed depending on the vessel’s operating profile. Also, the shape of the stern of vessels which have flat buttocks are ideal for fitting the Hull Vane ensuring a uniform flow to it.

2.1. Design process

Just like a bulbous bow, each Hull Vane is different and custom designed for a specific ship. An optimisation of the Hull Vane using Computational Fluid Dynamics (CFD) is the starting point. Such a Hull Vane study indicates how much the ship’s resistance is reduced with the addition of a Hull Vane – either for a single speed or for a wider operational profile.

Based on the results of this study, a cost-benefit analysis can be made and a go or no-go can be given for the further development of a Hull Vane for this ship. In the following phase, Finite Element Analysis and vibration analysis is conducted to ensure sufficient strength of the Hull Vane for a lifetime of trouble-free operations.

3. Working Priciple

This section will elaborate on the working principles of the Hull Vane. Four interrelated effects of the Hull Vane can be found: a thrust force, a trim correction, the reduction of waves, and the reduction of motions in waves. These effects will be discussed below. After this, the influence of the location of the Hull Vane and the influence of ship speed and hull shape are discussed.

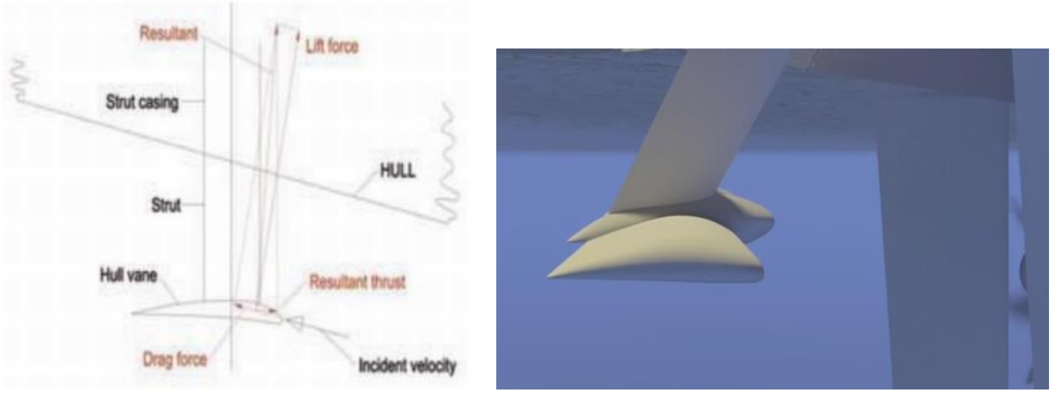

Fig 2. Components of Hull Vane

The reduction in fuel consumption that the Hull Vane generates can be contributed to various factors. Placing the foil in the inclined part of the transom wave creates a lift force which is tilted forward. This force can be decomposed into a resistance reducing force in x-direction, and a force in z-direction. This force in z-direction has a direct influence on the trim, and therefore also on the resistance of the vessel.Furthermore, because the flow is redirected to a more horizontal direction, the transom wave is reduced. This is for instance important for inland vessels, which do not want to damage coastlines or disturb vessels nearby, and for naval vessels where the transom wave is a significant part of the ship’s signature. The last effect is related to the foil’s behaviour in waves. Moving a flat plate up and down is hindered by the water surrounding it. The same applies to the Hull Vane, when the vessel is pitching in waves. The Hull Vane is then forced up and down, and the resulting dampening effect of the water on the movement of the Hull Vane also dampens the pitching motion of the vessel. This not only results in lower accelerations on board of the vessel, it also lowers the added resistance due to waves.

3.1. Thrust Force

The first effect of the Hull Vane is based on basic foil theory. In figure 3, a schematic overview of the forces on the Hull Vane is given. In this figure, α is defined as the Hull Vane inflow angle (the angle between the inflow and the chord line), β is defined as the Hull Vane angle (the angle between the chord line and the body-fixed x’-axis). The vessel in the figure is displayed at zero trim.

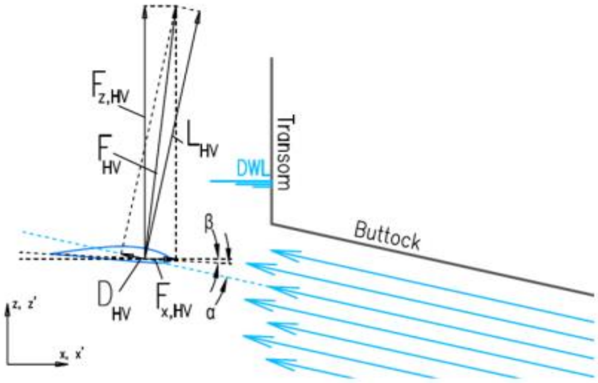

Fig. 3: Force distribution

The foil creates a lift force vector L□ HV which is by definition perpendicular to the direction of the flow of water, and a drag force vector D□ HV in the direction of the flow. The sum of these vectors F □ HV can be decomposed into an x-component and a z-component:

$$\vec{L}_{HV} + \vec{D}_{HV} = \vec{F}_{HV} = \vec{F}_{x,HV} + \vec{F}_{z,HV} \tag{1}$$

If the x-component of the lift vector is larger than the x-component of the drag vector, the resulting force in x-direction provides a thrust force. The lift and drag forces can be estimated by equation 2 and 3. In these formulae, CL and CD are not only dependent on the shape of the Hull Vane, but also on other factors, such as the vicinity of the free surface:

$$L_{HV} = C_L * \frac{1}{2}\rho V^2 A \qquad (2)$$

$$D_{HV} = C_D * \frac{1}{2}\rho V^2 A \qquad (3)$$

If θ is defined as the trim angle (the angle between the body-fixed x-axis and the inertial x-axis), the thrust force that is generated by the Hull Vane can be derived by equation 4.

$$F_{x,HV} = \sin(\alpha + \beta + \theta) * L_{HV} - \cos(\alpha + \beta + \theta) * D_{HV} \qquad (4)$$

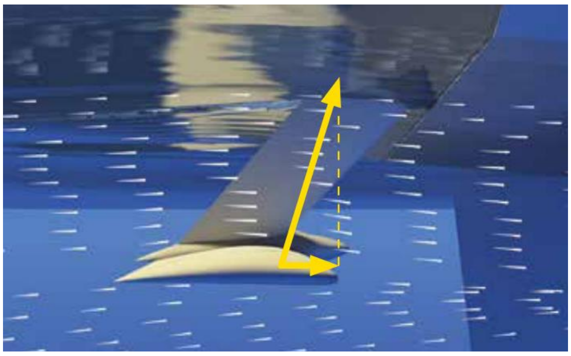

Fig. 4: Forward thrust representation

3.2. Trim Correction:

It must be noted that not only the resulting force in x-direction has an influence on the performance of the vessel. The force in z-direction affects the trim, and especially at higher speeds, this trim reduction proves to have a large influence on the total resistance of the vessel. This effect can also be achieved with interceptors, trim tabs, trim wedges or ballasting. Similarly to the force in x-direction, the force in z-direction can be estimated by equation 5:

$$F_{z,HV} = \cos(\alpha + \beta + \theta) * L_{HV} + \sin(\alpha + \beta + \theta) * D_{HV} \qquad (5)$$

With this, the influence of the Hull Vane on the running trim can be derived with equation 6:

$$\delta\theta = \frac{trimming\ moment}{righting\ moment\ per\ degree\ of\ trim} \approx \frac{F_z * arm}{GM_L * \Delta * g * \sin(1^\circ)} \qquad (6)$$

Not only the trim reduction itself has a positive influence on the hull's performance, but the trim also affects the angle of attack of the water flow on the Hull Vane. In equation 4 it can be seen that this has an important influence on the thrust force generated by the Hull Vane.

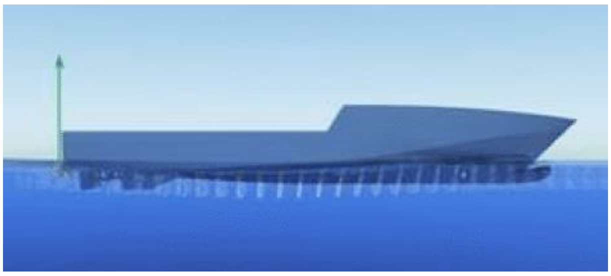

Fig. 5: Trim Correction

3.3. Reduction of Waves:

The third effect of the Hull Vane is related to the reduction of the wave system of the ship. The flow along the Hull Vane creates a low pressure region on the top surface of the Hull Vane. This low pressure region interferes favourably with the transom wave, resulting in a significantly lower wave profile. This result can be seen in figure 6, in which the wave pattern of the 55 metre supply vessel with Hull Vane (bottom figure) is compared to the same vessel without Hull Vane (top figure), at 20 knots. The blue area portrays a wave trough whereas as a red area portrays a wave crest.

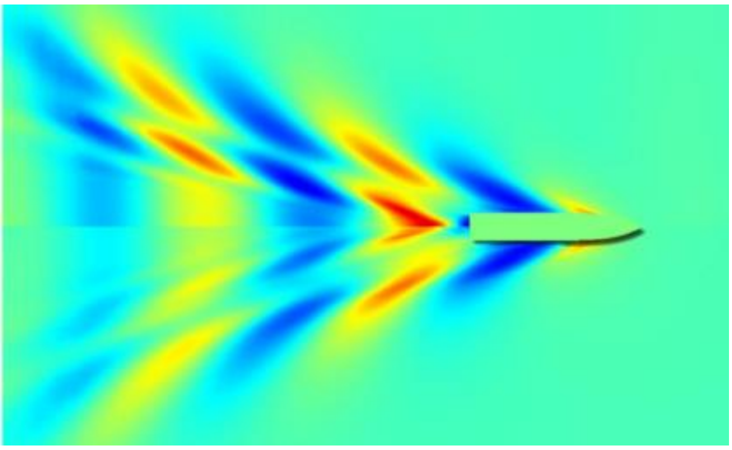

Fig. 6: Wave pattern on a supply vessel without Hull Vane (top) and with Hull Vane (bottom) at 20 knots as seen from above, from CFD computations

The wave reduction is so significant, that it can be observed by eye. In figure 7, photographs of the wave pattern of the same supply vessel during sea trials are shown. Both photographs were taken at a ship speed of 13 knots. The wake is clearly reduced with the attachment of the Hull Vane, pictured on the right.

Fig. 7: Comparison of the wave profile of the 55 metre supply vessel without Hull Vane (lefthand) with Hull Vane(right).

The reduction of waves not only leads to a more beneficial resistance, it also leads to less noise on the aft deck, and to a lower wake. The first is mainly beneficial for yachts, the latter is important for inland shipping, where wake restrictions limit ship speeds in ports or other enclosed areas.

3.4. Reduction of motions in Waves

The final effect the Hull Vane produces is that it dampens the heave and pitch motions of the vessel. When the vessel is pitching bow-down the stern of the vessel is lifted and the vertical lift on the Hull Vane is reduced by the reduced angle of attack of the flow. This counteracts the pitching motion. Similarly, during the part of the pitching motion in which the stern is depressed into the water, the vertical lift on the Hull Vane is increased. This again counteracts the pitching motions. Similar reasoning exists for the heave motions.

The reduction of the motions reduces the added resistance due to waves, which makes the Hull Vane even more effective in waves then it is in calm water. For instance, on the 169 meter container ship Rijnborg, model tests conducted by Hull Vane BV showed that the required propulsion power at 21 knots can be reduced by 10.2% in calm water and by 11.2% in waves.

The second benefit of the reduced motions is that it increases comfort, safety and the range of operability. For the 55 metre supply vessel, a CFD analysis showed that the root mean square of the vertical motions on the foredeck was reduced by approximately 10%, while that at the aft deck was reduced by approximately 20% in typical wave conditions (HW=1.0 m, TW=5.7 s).

3.5. Influence of ship speed and hull shape

In his research, Moerke also noted that the results of the Hull Vane improve with increasing speed.This was confirmed a few years later during model tests carried out at MARIN. A 169 m container vessel was equipped with a Hull Vane, and power reductions of 3.3% at 17 knots (Fn 0.21) up to 10.2% at 21 knots (Fn 0.27) were achieved on model scale.Higher savings can be achieved at higher Froude numbers. During tank tests for a 42 metre motor yacht, maximum resistance reductions of 23% were found at Fn 0.44. The dependency of the resistance reduction on Froude number for this particular yacht is shown in figure 5, alongside the results of a 55 metre yacht from tank tests, the results of a 47 metre motor yacht from CFD computations, and the results for a 300 metre container vessel from CFD computations. The Hull Vane seems to be most favourable at moderate to high Froude numbers in the non-planing region, approximately between 0.2 and 0.7.

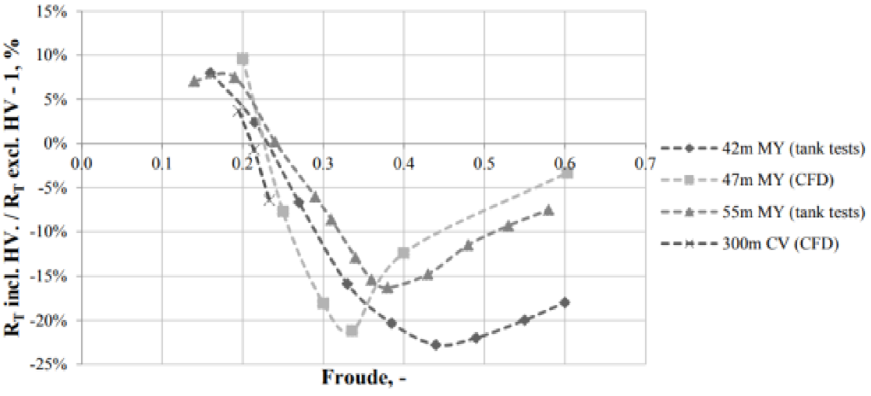

Fig. 8:Measured resistance reduction for a motor yacht and a 300m container vessel, fitted with a Hull Vane compared to the same vessels without a Hull Vane, as functions of Froude number.

These results can be explained by the dominance of frictional resistance below Froude numbers of 0.2. The addition of a Hull Vane to a vessel adds to the wetted surface area. Therefore, the frictional resistance is increased compared to the vessel without Hull Vane. Above Froude numbers of 0.2, the pressure resistance becomes a more dominant resistance component. As the Hull Vane decreases pressure resistance, most gains are found in the region of Froude numbers between 0.2 and 0.7.At higher Froude numbers, the force generated by the Hull Vane creates an un-beneficial bow-down trim.

The Hull Vane can be specifically designed for the cruising speed or maximum speed of a vessel, or for its operating profile. In most cases the operating profile is such that a loss in the low Froude number region is acceptable since these speeds are only sailed while manoeuvring. In absolute terms, a resistance increase at the low Froude numbers is negligible compared to the potential fuel savings at higher speeds.

The buttock angle and transom submergence are key factors. If the buttock angle is increased, the angle of attack of the flow to the Hull Vane is increased, and the lift vector is directed more forward, increasing the resulting decomposed force in x-direction. If the water column near the transom is maintained as much as possible, and the effect of pressure reflection on the hull is minimized, the overall resistance is reduced most The horizontal buoyancy force on the Hull Vane contributes to the overall performance as well: the leading edge region of the Hull Vane experiences a lower hydrostatic pressure than the trailing edge region when the Hull Vane is positioned below the front of the transom wave.

Additionally, the shape of the stern of the ship is important. Flat buttocks, ensuring a uniform flow to the Hull Vane are ideal. Trawler-type fishing vessels are sub-optimal for this reason, and significant gains from Hull Vane application are more difficult to obtain for this kind of ship types.

3.6. *Influence on Hull Vane location:*

In the last few years, much of the research has been focused on the optimal position of the Hull Vane relative to the ship's hull. One of the main considerations was found by Moerke. CFD analysis conducted by him showed that if the Hull Vane is fitted too close to the hull, it might be positioned in the boundary layer reducing the lift it creates. Additionally, the low pressure region on the upper side of the Hull Vane is fitted too close to the hull, it might be positioned in the boundary layer reducing the lift it creates. Additionally, the low pressure region on the upper side of the Hull Vane. Because of this 'pressure reflection', the resistance of the combination hull and Hull Vane is increased when the Hull Vane. is situated fully below the hull. Moerke investigated various modifications with the aim to reduce the pressure reflection, but was unable to fully solve this problem with the Hull Vane underneath the hull. Only by placing the Hull Vane behind the transom of the vessel can the pressure reflection problem be solved, with a slight reduction in Hull Vane thrust as a consequence.

4. Results and Discussions

4.1. Advantages of Hull Vane:

4.1.1. *Fuel Consumption*

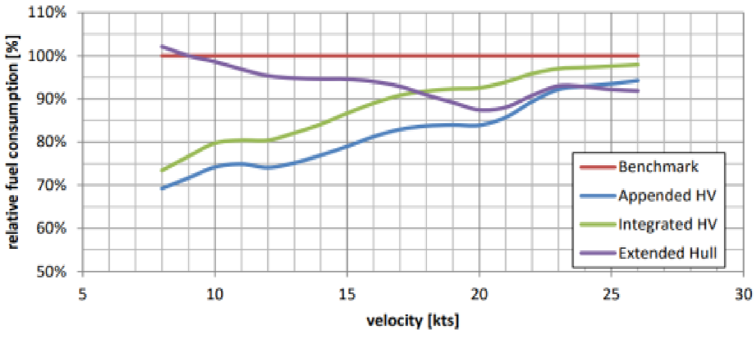

Fig. 9: Relative Fuel Consumption

From Fig. 9 we can interpret that there is a relative decrease in fuel consumption on application of a Hull vane.

4.1.2. Sea-keeping

The reduction of pitching, heaving, rolling and yawing is not only a matter of fuel saving. This effect has gained a lot of attention from owners with vessels operating in severe weather. Both the vertical and horizontal accelerations are reduced, which not only reduces the likeliness of seasickness – particularly important to passenger vessels and superyachts – but it also makes certain operations on deck safer. For example navies and coastguards often use helicopters from the aft deck, whereby the operational limits are dictated by the measurements of an accelerometer on deck.

4.1.2. Applicability

These are incidentally also the ship types on which the Hull Vane is most applicable, as they combine a steel or aluminium hull and significant displacement (for seakeeping) with a relatively high service speed. While many large container vessels have resorted to slow steaming, the ships transporting high-valued goods and passengers still maintain a high service speed. This includes roro-ships, ferries, naval ships, patrol vessels, superyachts, medium-sized cruise ships and certain offshore vessels. The lower limit for application of the Hull Vane is defined by a Froude number of about 0.2, which corresponds with a speed of 9 knots for a 50-metre vessel, 12 knots for a 100-metre and 17 knots for a 200-metre ship. Apart from the speed, the hull shape is also important. A wide, U-shaped stern is preferable to a very narrow V-shaped stern. The Hull Vane and its savings percentage are different for each ship. The design requires a CFD study, which gives a very accurate performance prediction, as has been confirmed both by model tests and full scale trials.

4.1.3. *Adaptability*

The Hull Vane can be easily retrofitted to an existing ship, as it requires only a minor amount of internal reinforcements. The biggest benefits can be obtained on a new building, as the hull lines can be optimized in conjunction with the Hull Vane , leading to a better overall result. The advantage is also that the propulsion power and shaft lines can be adjusted to the lower power requirement. On large, high-powered ships the saving on propulsion power often exceeds the investment cost in the Hull Vane. For typical retrofit installations the payback is often in the range of 1 to 3 years at current (low) bunker costs, depending of the savings percentage, the amount of sailing time per year and the type of fuel used. Because the resistance is reduced, the Hull Vane is a future-proof investment. Regardless of the fuel used – whether it’s HFO, MGO or LNG, the savings percentage will still be the same. For newbuildings, the Hull Vane can usually be incorporated within the length of the vessel, but for retrofit installations, some protection above the waterline is advisable. This can be for example a simple bulbar construction or a small platform on the transom.

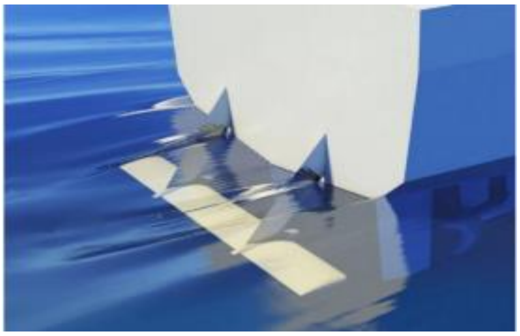

Fig. 10: Appended Hull Vane

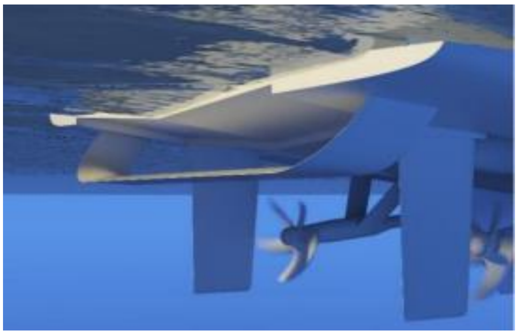

Fig. 11: Integrated Hull Vane

Conclusion

While most fuel saving devices focus on a reduction of the frictional resistance (e.g. air lubrication) or propulsive efficiency (e.g. Mevis ducts, propeller boss cap fins), the Hull Vane is one of the few fuel saving devices (along with the bulbous bow) that aim to lower the pressure resistance, which is the dominant component of the resistance at higher speeds. Therefore the Hull Vane proves to be one of the most promising fuel saving devices available today. CFD computations, model tests and sea trials have shown potential resistance reductions of more than 20% depending on ship speed and hull shape. On merchant ships, potential resistance reductions between 5% and 10% are common. The Hull Vane is especially interesting for vessels that operate at a moderate to high non-planing speed (Froude numbers between 0.2 and 0.7), such as ferries, supply vessels, cruise ships, patrol- and naval vessels, motor yachts, reefer ships, Ro-Ro vessels, car carriers, and container vessels.

The fact that the results are dependent on ship speed and hull shape makes it clear that not every ship type is suitable for fitting a Hull Vane . For bulk carriers and crude oil carriers the Hull Vane will not bring much gain. Not only is their speed too low, but the difference in draft between loaded and ballast condition makes it nearly impossible to achieve gains in both conditions, but every percentage of savings is significant and thus future research can be conducted in order to optimize the results. For small vessels (below 30 meter) the investment costs are often too high relatively to the fuel savings to recoup these costs.

The ideal candidates for Hull Vane application are medium and large-sized vessels operating at moderate or high non-planing speeds. Examples are ferries, supply vessels, cruise ships, patrol and naval vessels, motor yachts, reefer ships, Ro-Ro vessels, car carriers, and container vessels.

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References:

1. K. Uithof, N. Hagemeister, B. Bouckaert, P. G. van Oossanen and N. Moerke, "A Systematic Comparison of The Influence of the Hull Vane, In-interceptor, Trim Wedges and Ballasting on the Performance of the 50M AMECRC Series #13 Patrol Vessel," in Warship 2016: Advanced Technologies in Naval Design, Construction, & Operation, Bath, UK, 2016.

2. J. A. Keuning, J. Pinkster, "Further Design and Seakeeping Investigations into the Enlarged Ship Concept"," in FAST Conference Proceedings 1997, Sydney, Australia, 1997.

3. Uithof, K., P. van Oossanen, N. Moerke, van Oossanen P.G., and Zaaijer K.S., ‘An update on the Development of the Hull Vane®,” HIPER 2014, High Performance Marine Vehicles, Athens, December 2014.

4. https://www.hullvane.com/

5. https://www.oossanen.nl/the-hull-vane/