AN UPDATE ON THE DEVELOPMENT OF THE HULL VANE®

K. Uithof[1], P. van Oossanen[1,2], N. Moerke[1,2], P.G. van Oossanen[1,2], and K.S. Zaaijer[2]

[1] Hull Vane B.V., Costerweg 1b, 6702 AA, Wageningen, Netherlands
[2] Van Oossanen Naval Architects B.V., Costerweg 1b, 6702 AA, Wageningen, Netherlands

ABSTRACT

Although the early beginnings of the Hull Vane® can be traced back to its application on a catamaran in 1992, the research has gathered pace since the first patent was applied for in 2002. The Hull Vane® is a fixed foil located below the waterline, near the stern of the vessel. The lift it creates can be decomposed 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. Resistance reductions of up to 26.5% have been found with the use of CFD computations, model tests and sea trials. For commercial applications, resistance reductions between 5 and 10% are common. 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. In this paper, the development process, the working principles, and the achieved results up to now are discussed.

NOMENCLATURE

A	Planform area	[m^2]
α	Hull Vane® inflow angle	[rad]
β	Hull Vane® angle	[rad]
C_D	Drag coefficient	[-]
C_L	Lift coefficient	[-]
D	Drag force	[N]
Δ	Displacement	[m^3]
ΔR_T	Change in total resistance	[%]
F	Force	[N]
Fn	Froude number	[-]
g	gravitational constant	[$kg*m/s^2$]
GM_L	Longitudinal metacentric high	[m]
H_W	Wave height	[m]

L	Lift force	[N]
R_T	Total resistance	[N]
ρ	Density	[kg/m^3]
T_W	Wave period	[s]
θ	Trim angle	[rad]
V	Hull Vane® inflow velocity	[m/s]
x, z	Inertial coordinate system	
x', z'	body-fixed coordinate system	

Subscripts

HV	Hull Vane®
x	x-direction (forward)
z	z-direction (up)

1. INTRODUCTION

The ongoing quest for fuel efficiency of ships is divided into four areas of research: engine efficiency, propulsion efficiency, alternative sustainable sources of power, and the lowering of the resistance of the hull.

As naval architects, Van Oossanen Naval Architects mainly focuses on the latter. Within this category they have developed the patented Fast Displacement Hull Form, and the Hull Vane®: a fixed, resistance-reducing foil situated below the waterline near the stern of the ship. Since Peter van Oossanen's invention of the Hull Vane® in 1992, and the first patent application in 2002, a significant amount of research has been performed aimed at the optimization of the concept. Throughout the following years various applications of the Hull Vane® have been analysed by means of model tests, Computational Fluid Dynamics (CFD), and full-scale trials. These include sailing yachts, motor yachts, various merchant ships, naval vessels, cruise ships, and more. Fuel reductions in excess of 20% were found for displacement motor yachts, while for other types of ships reductions of 5 to 10% were found to be common. Various examples are given in this paper.

Now that the first two vessels fitted with a Hull Vane®, a 42 m motor yacht and a 55 m supply vessel, have been launched it is appropriate to review the results that have been obtained. This paper provides an update on past, current and future developments in this respect.

2. THE DEVELOPMENT PROCESS

The early beginnings of the Hull Vane® can be traced back to 1992. The first full-scale application of the Hull Vane® was on a catamaran vessel not reaching its required speed due to excessive trim and wave generation. Placing a foil in the steepest part of the interacting wave system aft of the midship of the catamaran proved to reduce the bow-up trim and the resistance significantly. This result led to an increased interest in the device and the associated hydrodynamics, and more research would follow.

The next application of the Hull Vane® was on *Le Defi Areva*, the French challenger for the 2003 America's Cup (figure 1). During model tests a resistance reduction of 5% was found at model scale for a full-scale speed of 10 knots. Unfortunately, the application of the Hull Vane® during the races was disallowed by the America's Cup regulations as an appendage that would give an unfair advantage.

Fig. 1. The second application of the Hull Vane®, on the 2003 IACC yacht *Le Defi Areva*.

After these first applications, focus has been on further research of the working principles of the Hull Vane®. Numerous applications have been tested, mainly with the use of CFD computations. The models that have been tested range from sailing yachts and motor yachts to more commercial applications, such as supply vessels, containerships, cruise ships and Ro-Ro vessels. The found influence of from the Hull Vane® on the total resistance have varied between a resistance decrease of -26.5% and a resistance increase of +9.5%, showing that the fuel saving device is not suitable to all cases. A number of these results will be further discussed in section 4.

In 2014, two Hull Vane®-equipped ships were launched. Shipyard De Hoop in the Netherlands built the 55 metre supply vessel *Karina*, which saw its required engine power during sea trials reduced by 15% after a Hull Vane® was retrofitted to the transom. More on these sea trials can be found in section 4.

The second vessel that was launched with a Hull Vane® this year is a 42 metre displacement yacht, built by the Dutch yacht builder Heesen Yachts. For this vessel, the Hull Vane® was incorporated during the design phase, which allowed for resistance reductions of up to 23%.

3. WORKING PRINCIPLES

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. A discussion of the effectiveness of the Hull Vane® will conclude this section.

3.1 Thrust force

The first effect of the Hull Vane® is based on basic foil theory. In figure 2, 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.

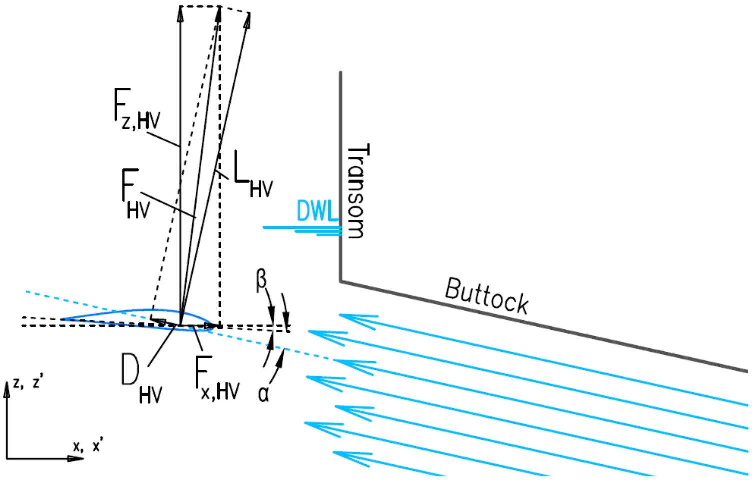

Fig. 2. Schematic overview of the forces on the Hull Vane® in a section view of the aft ship.

The foil creates a lift force vector $\vec{L}_{HV}$ which is by definition perpendicular to the direction of the flow of water, and a drag force vector $\vec{D}_{HV}$ in the direction of the flow. The sum of these vectors $\vec{F}_{HV}$ 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, C_L and C_D are not only dependent on the shape of the Hull Vane®, but also on other factors, such as the vicinity of the free surface.

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

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

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.

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

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:

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

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

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

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®.

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 3, 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.

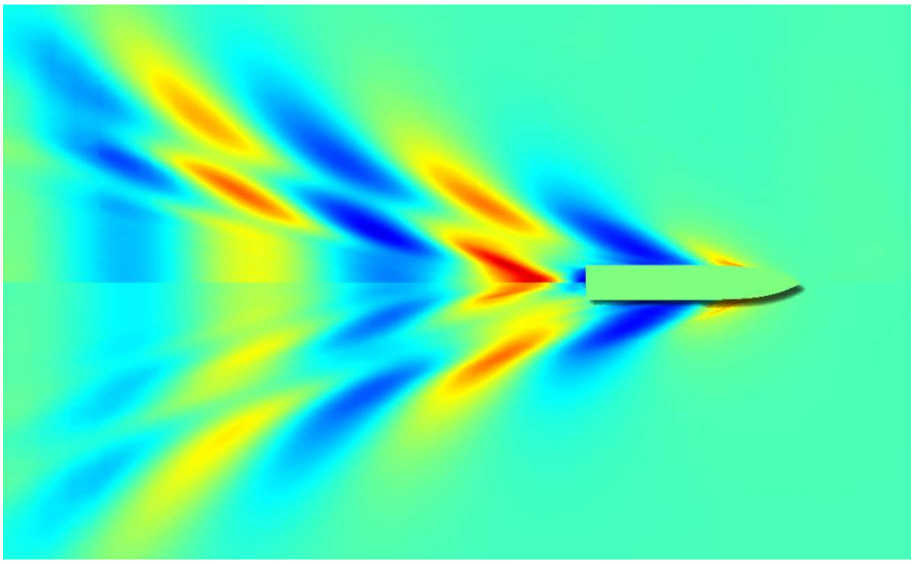

Fig. 3. Wave pattern on the 55 metre supply vessel without Hull Vane® (top) and with Hull Vane® (bottom) at 20 knots, as seen from above, from CFD computations (blue portrays a wave trough and red a wave crest).

The wave reduction is so significant, that it can be observed by eye. In figure 4, 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. 4. Comparison of the wave profile of the 55 metre supply vessel without Hull Vane® (left) and with Hull Vane® (right) at 13 knots, as seen from the aft deck during sea trials.

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 metre container ship *Rijnborg*, model tests 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 (H_W=1.0 m, T_W=5.7 s).

3.5 Influence of Hull Vane® location

During the last 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. His CFD analysis 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 reflected on to the hull, creating an additional pressure resistance on the hull. 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.

The second consideration in the positioning of the Hull Vane® is the angle of the water flow near the stern of the vessel. When not changing the orientation of the Hull Vane® itself, the largest angle of attack can be achieved by placing the Hull Vane® in the steepest part of the transom wave. Unfortunately, especially at higher speeds, this location is too far aft of the hull which creates difficulties for the attachment of the Hull Vane® to the hull. An additional complication is that this optimal location is very dependent on wave length, and thus on ship speed. In vertical direction, a higher angle of attack can be achieved by placing the Hull Vane® closer to the hull. This is however limited by the free surface effect on Hull Vane® lift, and possibly by slamming in waves and the pitching motions if the Hull Vane® is placed too close to the water surface.

3.6 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 169m 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.

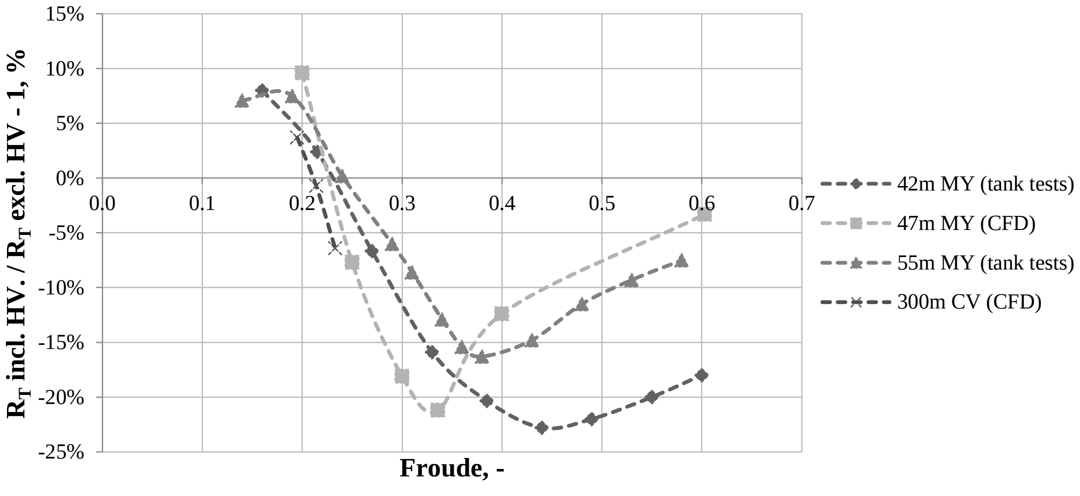

Fig. 5. Measured resistance reduction for a 42m, a 47m and a 55m motor yacht and a 300m container vessel, fitted with a Hull Vane® compared to the same vessels without a Hull Vane®, as functions of Froude number.

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 unbeneficial 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.

In 2009, Zaaijer and Moerke performed a systematic study into the performance of the Hull Vane®. They found that buttock angle and transom submergence are key factors. The influence of the buttock angle is clear when looking at figure 2: 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 suboptimal for this reason, and significant gains from Hull Vane® application are more difficult to obtain for this kind of ship types.

3.7 Effectiveness

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. For small vessels (below 30 metre) 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.

4. RESULTS AND DISCUSSION

As can be expected, 12 years of research and development into the performance of the Hull Vane® has generated a vast amount of data. Some interesting results will be presented below. This section is divided into three parts. In the first part, results from CFD computations will be discussed. Some of the model tests will be discussed in 4.2. The last part of this section is devoted to the results of the first systematically performed sea trials on a Hull Vane® equipped vessel: a 55 metre supply vessel.

4.1 CFD computations

Van Oossanen Naval Architects has built up a vast experience in hydrodynamic consultancy in CFD. It is therefore no surprise that a majority of the research into Hull Vane® performance has been carried out with the use of CFD. For this, the FINE/Marine CFD package is used, developed by École Centrale de Nantes and NUMECA International, specifically for hydrodynamic application in ship design. Throughout the years this research has produced detailed insight in how the Hull Vane® works, and how it can be optimized for various applications.

The first systematic series of CFD computations were performed by Moerke. He tested the Hull Vane® in several positions under the stern of a full-block dredger, in 2D. He found that in the configuration as pictured in figure 6, the Hull Vane® caused an increase of pressure resistance on the hull. The increase in pressure resistance on the hull was a slightly larger component than the thrust force generated by the Hull Vane®, and therefore an increase of the total resistance was found. In figure 6, the dynamic pressure on the stern is shown. It can be observed that the low-pressure region above the Hull Vane® is indeed reflected on to the hull. The benefit from the lift force created by the Hull Vane® is thus undone by the increased resistance of the hull.

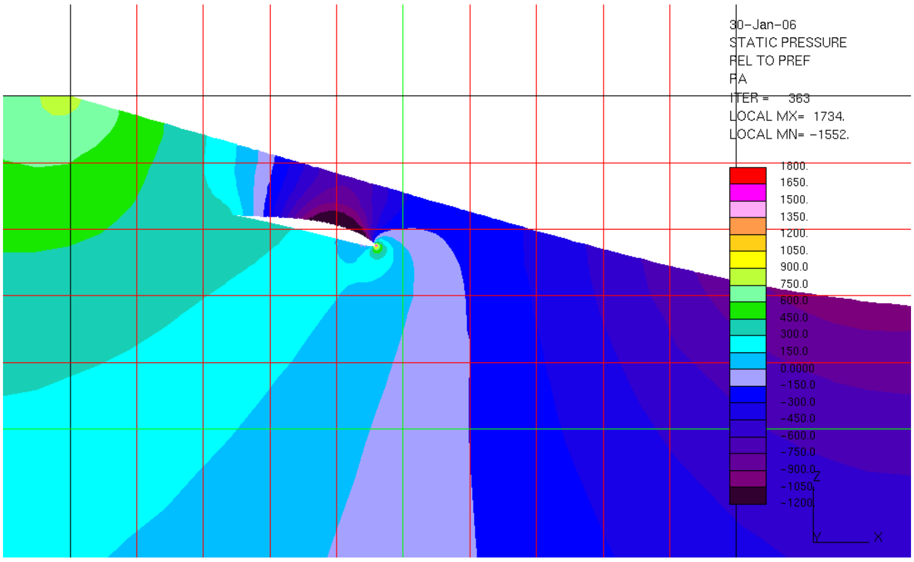

Fig. 6. Dynamic pressure around the stern of a full-block dredger equipped with a Hull Vane®.

Many variations of hull shape, Hull Vane® profile and Hull Vane® location were tested, but the increase in pressure resistance associated with the reflection of the low-pressure region on the hull always remained. Only by positioning the Hull Vane® aft of the transom can this phenomenon be sufficiently reduced. This was confirmed in the 2009 systematic 2D study by Zaaijer and Moerke, who found that the total resistance is reduced when the Hull Vane® is placed aft of the transom and not too close to the free surface.

After these 2D studies, a range of different ship types have been analysed. Most of these have been tested at different speeds, with different positions, and different shapes for the Hull Vane®. An (incomplete) overview of ship types, lengths, tested speeds and achieved resistance reductions is displayed in table 1. It can be seen that the Hull Vane® offers resistance reductions on a wide range of vessels, but is unfortunately unable to offer this for all ships. Additionally it shows that the gains are dependent on ship speed. Those ships in table 1 for which no resistance reduction was achieved, had either a speed near or below the critical level (Fn 0.2), or a complex (e.g. trawler) hull shape, involving reverse flow around the aft-end of the vessel.

Table 1. Resistance reductions achieved, from CFD computations.

Ship type	Tested speeds	ΔR_T
47m motor yacht	7.7 kn / Fn 0.20	+9.6%
	13 kn / Fn 0.34	-21.2%
	23.3kn / Fn 0.60	-3.3%
169m container vessel	17 kn / Fn 0.21	-10.1%
	21 kn / Fn 0.27	-15.5%
152m container vessel	15.5 kn / Fn 0.21	+1.2%
179m ro-ro vessel	18 kn / Fn 0.22	-2.7%
176m paper carrier	17 kn / Fn 0.21	+6.6%
285m container vessel	20 kn / Fn 0.19	+3.7%
	22 kn / Fn 0.21	-0.7%
	24 kn / Fn 0.23	-6.4%
64m motor yacht	15.9 kn / Fn 0.33	-26.5%
350m container vessel	24 kn / Fn 0.21	-7.2%
55m supply vessel	20 kn / Fn 0.46	-6.5%
142m navy vessel	18 kn / Fn 0.25	-6.7%
	24 kn / Fn 0.33	-7.5%
	30 kn / Fn 0.41	-6.2%
126m cruise liner	15 kn / Fn 0.22	-9.6%
33m fishing trawler	11 kn / Fn 0.31	+1.3%

4.2 Model tests

The first two sets of model tests have been performed on an America’s Cup sailing yacht and a dredger. The sailing yacht was tested over a range of speeds in excess of 6 knots, for Froude number values higher than 0.22. For the dredger the longitudinal position of the Hull Vane® was varied. These tests revealed that the optimal longitudinal position of the Hull Vane® is one where a positive interaction between the hull’s wave system and that of the Hull Vane® can be realized.

This first research also looked into the vertical positioning of the Hull Vane®, and it was found that the Hull Vane® should not be placed too close to the hull. On the other hand, it should not be placed too far below the hull, as the angle of attack from the water flow is then decreased. Additionally, this research showed that the hull shape of the tested vessel has a major impact on the performance of the Hull Vane®: The vicinity of the Hull Vane® below the steep buttocks of the dredger creates a pressure reflection cancelling the benefits of the Hull Vane® itself. The Hull Vane® only had a beneficial contribution to the system when placed behind the transom.

After the model tests for the sailing yacht and the dredger, two container vessels (137 and 169 metre) from Wagenborg were tested in the towing tank for Hull Vane® suitability (figure 7). These tests have provided further insight into the performance of the Hull Vane®, as these tests included dynamometers fitted to the Hull Vane®. With these dynamometers, it became possible to measure the F_x and F_z forces that are generated by the Hull Vane®. Again, the Hull Vane® was tested for different positions relative to the hull, for different angles, and different ship speeds. This again confirmed the working principles of the Hull Vane®, and showed that the Hull Vane® is able to provide resistance reduction if positioned and designed well. Additionally, the performance in waves was determined, and this showed that the Hull Vane® provides heave and pitch motion damping, leading to a lower added resistance in waves.

Fig 7. One of three Hull Vanes® as tested on a model of a 169 metre container vessel.

The reduced motions in waves and the subsequent reduction of the added wave resistance was later confirmed in tests on a 42 metre motor yacht which was tested at different speeds in different wave conditions. The effects on model scale in this case were relatively small however, and full-scale simulations in CFD have provided a clearer difference.

4.3 Full-scale sea trials

At this time, four full-scale applications of the Hull Vane® have been tested. The first two applications were described in section 2; the third one will be discussed below. The fourth full-scale application of the Hull Vane®, on a 42 metre motor yacht, was tested in October 2014, and the results were not available at the time of writing this paper.

The *Karina* was launched during the summer of 2014. She is a 55 metre Fast Supply Intervention Vessel (FSIV) built by Shipyard De Hoop in the Netherlands. During sea trials, she was retrofitted with the Hull Vane®, so that it was possible to compare the performance with and without Hull Vane®. As she left port, the lower stern wave system was readily visible (figure 4). Measurements were taken by a third party of shaft power, speed and manoeuvrability. The results are corrected for water depth and are displayed in figure 8.

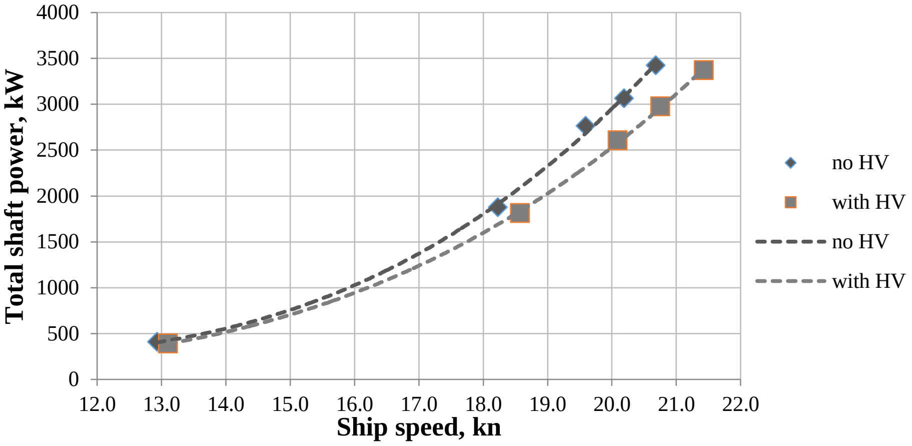

Fig. 8. The results from sea trials of a 55m FSIV, equipped without and with a Hull Vane®.

The manoeuvrability tests show that the turning circle was slightly increased due to the increased directional stability created by the struts that connect the Hull Vane® to the hull. This gain in directional stability reduces the chance of broaching in stern-quartering waves.

The newest application of the Hull Vane®, on a 42 metre motor yacht, is pictured in figure 9. Unfortunately the results of the sea trials of this vessel were not available at the time of preparing this paper.

Fig. 11. The latest application of the Hull Vane®: a 42 metre motor yacht.

5. CONCLUSION AND FUTURE RESEARCH

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.

Now that the first commercial applications have been launched it is not the time to sit back and relax. To improve the concept and to further explore the possibilities of the Hull Vane®, more research is needed. Such research has commenced with the investigation of a 50 metre trimaran platform concept, in which the Hull Vane® is attached to the outriggers, which are positioned partly aft of the main hull. The first results have been promising, outperforming equivalent monohulls in resistance, comfort and deck space.

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