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A COST-BENEFIT ANALYSIS OF HULL VANE® APPLICATION ON MOTOR YACHTS

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SUMMARY

The Hull Vane® is an energy-saving device that can result in significant fuel savings. It consists of a fixed hydrofoil that can be attached to the transom of a vessel. It is especially effective on medium to high speed displacement vessels, such as naval vessel, supply vessels, and motor yachts. Resistance reductions of up to 23% were found for the 42m motor yacht *Alive*.

How effective the Hull Vane® is at reducing overall costs will be elaborately discussed in this paper. Initial costs and running costs will be compared to the initial and running benefits. Additionally, the unquantifiable aspects of the Hull Vane®, such as its influence on the layout of the yacht, the seakeeping performance and the manoeuvrability will be discussed.

The main conclusion drawn is that the Hull Vane® is very effective at reducing the running costs of the vessel, especially by reducing the fuel costs. Incorporating the Hull Vane® already in the design phase will result in the most benefits, as the whole propulsion system can be adjusted to its new operation point.

1. INTRODUCTION

The patented Hull Vane® is a fixed hydrofoil that can be attached to the aft of a vessel. It uses the upward flow at this location to recuperate some of the energy that otherwise would be lost in the transom wave. The Hull Vane® has proven to be highly effective on motor yachts; application on the 42m motor yacht Alive showed a 23% reduction of resistance.

Due to the characteristics of yachts' operational profiles, the fuel reduction itself does often not offset the investment costs of the Hull Vane®. However, various other aspects of the Hull Vane® may prove valuable to yacht owners. A reduction of required power leads to a smaller main engine, with the resulting reduction of investment costs, and an increase of internal space for guests. Additionally, on a more intangible level, the pitch, roll, and heave motions are reduced.

This paper discusses research into the advantages and disadvantages of Hull Vane® application on motor yachts. All of the aforementioned aspects will be discussed: costs, fuel reduction, engine power reduction, internal space, and seakeeping considerations. This will all be substantiated with proven results from, among others, the 42 meter motor yacht *Alive*. First, a short history and the theoretical background of the Hull Vane® will be discussed. Subsequently, all costs and benefits of the Hull Vane® will be assessed, both quantifiable and unquantifiable. After this, there will be some comments regarding retrofitting the Hull Vane® to existing yachts. A conclusion is provided in the last chapter.

1.1 History

The early beginnings of the Hull Vane® can be traced back to 1992. The first full-scale application of the Hull Vane® was in 1997 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 followed.

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The next application of the Hull Vane® was on the sailing yacht Le Défi Areva, the French challenger for the 2003 America's Cup (Figure 1). During model tests a resistance reduction of 9% was found at model scale for a full-scale speed of 10 knots at 15 degrees of heel angle. Unfortunately, the America's Cup regulations allowed an appendage to be fixed only on centreline (with a single strut), which made it difficult to achieve sufficient strength.

Figure 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, naval vessels, containerships, cruise ships, and Ro-Ro vessels.

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 [1]. The second vessel that was launched with a Hull Vane® is the 42 metre displacement yacht *Alive*, 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%.

In the first part of 2016, contracts were signed for another six vessels to be fitted with a Hull Vane®, ranging in ship lengths between 19 and 90 meter. Interest in the Hull Vane® origins from a range of markets, and most of these orders are for motoryacht application.

1.2 Theoretical Background

This section will elaborate on the working principles of the Hull Vane®. Four distinct effects of the Hull Vane® can be found: a thrust force, the reduction of waves, a trim correction, and the reduction of motions in waves.

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. The vessel in the figure is displayed at zero trim.

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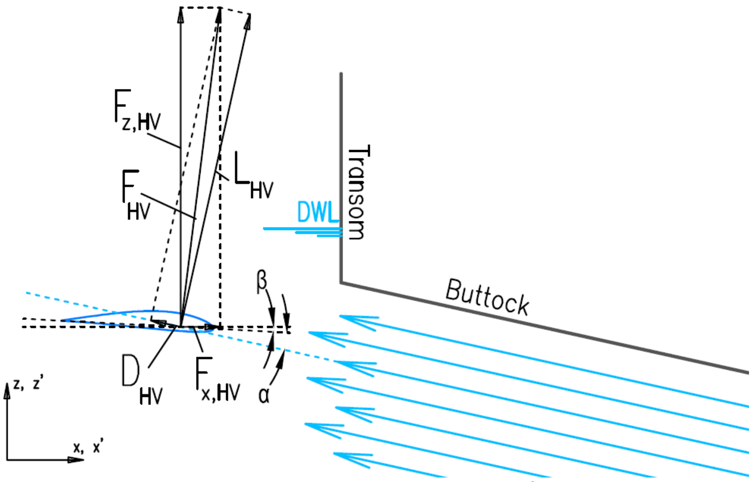

Figure 2. *Schematic overview of the forces on the Hull Vane® in a section view of the aft ship.*

The foil creates a lift force vector 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. 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 second 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®. When properly designed, 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 without Hull Vane® (top half of the figure) is compared to the same vessel with Hull Vane® (bottom half of the figure), at 20 knots. This also leads to less noise on the aft deck.

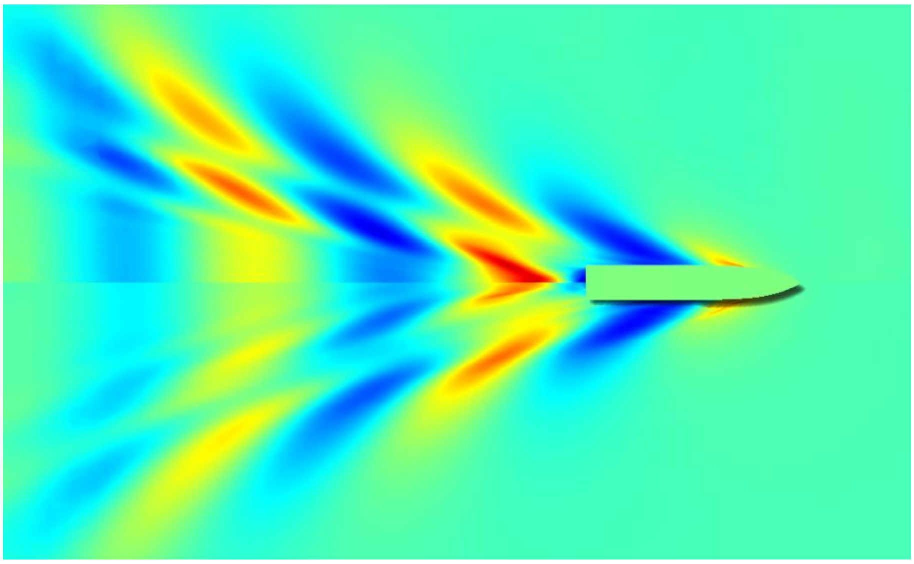

Figure 3. *Wave pattern on the 55 metre supply vessel without Hull Vane® (top) and with Hull Vane® (bottom) at 20 knots, as seen from above, from CFD computations (blue portrays a wave trough and red a wave crest).*

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 could also be achieved with interceptors, trim tabs, trim wedges or ballasting, but often these have a larger drag penalty at intermediate speeds than the Hull Vane® [2].

The final effect of the Hull Vane® is that it dampens the pitch and yaw motions of the vessel. When the vessel is pitching bow-down the angle of attack on the Hull Vane® is temporarily reduced (as the stern moves upwards), leading to reduction in lift at the stern of the vessel. 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.

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 at MARIN showed that the required propulsion power at 21 knots can be reduced by 10.2% in calm water and by 11.2% in waves [3].

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 vertical motions on the foredeck was reduced by approximately 10%, while that at the aft deck was reduced by approximately 20% in a typical wave condition (HW=1.0 m, TW=5.7 s).

1.3 Application on Motor Yachts

The Hull Vane® proves to be very effective on most motor yachts in terms of fuel saving, due to their relatively high speed and full displacement hull forms. Additionally, the extra comfort that the dampening of the pitch and yaw motions creates is an important benefit for yachts.

The Hull Vane® has already been applied on the 42 meter motor yacht *Alive* since 2014. The *Alive* is built by Heesen Yachts in the Netherlands, and the Hull Vane® was incorporated during the design phase. In the configuration used on this yacht, the Hull Vane® does not protrude the transom, as it is located below a recess in the aft of the vessel. This can be observed in Figure 4. This has various benefits: the aft can be fitted with a transom door, there is no risk of the Hull Vane® hitting anything during manoeuvring, and swimming is safer as one can't accidently dive onto the Hull Vane®.

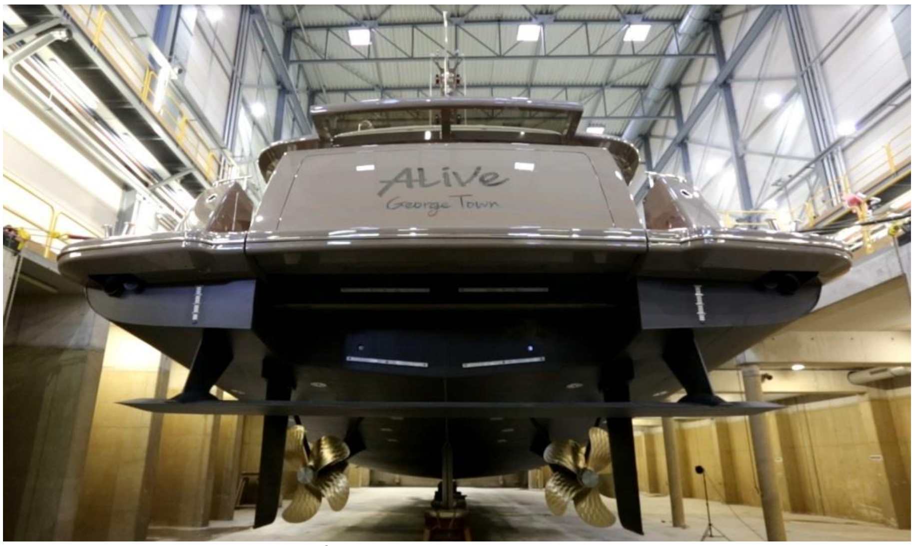

Figure 4. *Hull Vane® configuration on the Alive, with a recess.*

Incorporating the Hull Vane® during the design phase enabled the designers to optimise the combination hull-Hull Vane®, which resulted in a resistance reduction at 12.0 and 14.5 knots of 20% and 23%, respectively. For this application, that meant that the shipyard was able to opt for a 12V engine instead of a 16V, as will be further discussed in Section 2.1.

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The next motor yachts to be equipped with a Hull Vane® are a 36m motor yacht (retrofit in 2016), a 50m new construction (to be launched in 2018), and the 19 meter Jetten Beach 65, which is currently being built by Jetten Shipyards in the Netherlands. For the investor of this vessel, the positive effect on the seakeeping performance was an important reason for application of the Hull Vane®.

Experience gained with the different applications of the Hull Vane® on different types of vessels, is used in the assessment of all costs and benefits associated with Hull Vane® application.

2. COST-BENEFIT ANALYSIS OF THE HULL VANE®

In this section, all quantifiable costs and benefits that can be contributed to the Hull Vane® are assessed. All costs and benefits will be split in initial benefits and costs, and running benefits and costs.

2.1 Initial Benefits

While the most apparent benefit of the Hull Vane® is the more long-term fuel reduction, a number of initial cost reductions can be achieved by implementing the Hull Vane® already during the design phase of the vessel. For the 42m *Alive*, the resistance reduction of 20-23% enabled the shipyard to opt for 12V engines instead of 16V engines, reducing the installed power from 2600 kW to 2160 kW. This is a cost reduction in itself that has offset a major part of the initial investments in the Hull Vane®.

Additionally, many costs that are associated to installed engine power can be reduced as well. For instance, one can think of:

- Propeller size
- Shaft diameter
- Gearbox size
- Bearing and seal size
- Thrust block

A significant resistance reduction at cruising speed reduces the fuel required to reach the vessel's required range. This means that the tank size (or number of tanks) can be reduced. This reduces the complexity of the below-deck construction, e.g. by reducing the number of manholes required. Alternatively, the tank size can be kept to increase the vessel's range.

It can be said that the reduction of required engine power does not only reduce the size of the engine itself, but many items that are associated with required or installed power as well. The list above is based on a configuration with conventional diesel engines and is certainly not complete. For instance, on a hybrid powered vessel the battery pack might be reduced. Evidently, the extent to which these benefits apply depends on the resistance reduction that the Hull Vane® achieves.

2.2 Initial Costs

The initial costs of the Hull Vane® come from the engineering and building of the Hull Vane®. During the design and engineering of the Hull Vane®, many variables influence the size, configuration, position, and shape of the Hull Vane®. As the majority of yachts in the applicable size range are one-offs, the design of the Hull Vane® is often unique, which makes almost every Hull Vane® for yacht application a custom designed, engineered, and built Hull Vane®.

To make the design and engineering cost-efficient, CFD is used for optimisation. Physical model tests require expensive models and tank time, while making adjustments to the hull or Hull Vane® is costly. However, physical models might prove useful in a later stage, if clients require an elaborate insight in the seakeeping and

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manoeuvring characteristics of a vessel. However, the decision for a Hull Vane® is often made before this stage already.

When doing physical model tests, it needs to be noted that the boundary layer is not scaled properly between model and full scale, which causes the predicted resistance reduction from the Hull Vane® to be underestimated during model tests. Therefore, CFD calculations are often the preferred option.

In terms of construction, the Hull Vane® is not more complicated than for instance a rudder: a top plate, a bottom plate, and dependent on its size, a number of longitudinal and transversal girders. If the structural requirements permit, the building material is regular steel (SJ235), and otherwise S355J+N steel. Other materials such as aluminium (not enough strength) and composites (too costly) are in most cases not suitable for this application.

The struts can be directly welded onto the hull (as on *Alive*), or can be connected by a pinned or bolted construction (as on *Karina*). The construction inside the hull at these points needs to be reinforced as large forces are associated with the Hull Vane®. However, often these are relatively small adjustments, such as adding additional plate thickness or brackets are sufficient for this. Retrofitting the Hull Vane® to the transom of an existing yacht can often be done while the vessel is in the water.

2.3 Running Benefits

The main financial benefit of the Hull Vane® is its effect on the fuel use of the vessel. This benefit mainly depends on the resistance reduction and the operational profile of the yacht. In 2012, SuperyachtIntelligence.com[1] calculated that dependent on the yacht's use, fuel expenses summed up to be 24%-34% of the total monthly expenses for yachts of 24m and larger. Even though fuel prices have gone down since then, the fuel costs are still be a major contribution to the vessel's life cycle costs. This shows the potential savings that can be achieved if fuel use is reduced, even for yachts which are used less often than commercial vessels.

Due to Van Oossanen's background in yachts, a large number of motor yacht hulls have been tested for feasibility of the Hull Vane®, mainly with the use of Computational Fluid Dynamics (CFD). The obtained resistance reduction ranges between 0% and 27%, showing that not every vessel is equally suitable for Hull Vane® application. However, resistance reductions of over 10% are not uncommon for yachts, due to their suitable hull types and operational speed profiles.

A secondary benefit of the potential reduction of installed engine power is the reduction of maintenance involved. Less or smaller engines and/or engine parts reduce maintenance costs. A reduction of the size or number of fuel tanks also reduces maintenance costs, as e.g. less conservation is required.

2.4 Running Costs

Because the Hull Vane® is a fixed foil without any moving parts, there is little to no additional maintenance involved. The added maintenance can completely be included in the maintenance schedule of the yacht. The Hull Vane® requires maintenance on its antifouling system, and its cathodic protection, just like the hull. It can therefore be included in the hull's maintenance schedule, which significantly reduces the additional costs of maintenance.

[1] http://www.superyachtintelligence.com/economic_impact_survey/

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3. OTHER UNQUANTIFIABLE COSTS AND BENEFITS

Next to the costs and benefits mentioned above, there are many costs and benefits that cannot be expressed in monetary values, which will be elaborated upon in this chapter.

3.1 Yacht Layout

The potential reduction of the installed power also creates additional benefits. The space required inside the engine room is reduced, as smaller main engines are required, and the associated parts are reduced in size as well. The space gained can be attributed to the guest rooms, which are often found in front of the engine room, or to a beach club, which is often found behind the engine room. Additionally, the tanks might also be reduced in size, which can free up space for other purposes like storage as well. Besides the space and cost benefits, the weight of the whole propulsion system is reduced as well, although the weight of the Hull Vane® adds to the equation as well.

Smaller (or less loaded) engines and propellers radiate less noise and vibration, which makes the vessel more comfortable, especially in the areas directly adjacent to the engine room.

A potential downside of the Hull Vane® is its location. It can make life more difficult if stern doors, stern anchors, or stern thrusters are required. Earlier applications of the Hull Vane®, like on *Alive*, showed that an early inclusion of the Hull Vane® in the design process of the yacht can prevent many of these potential issues.

3.2 Seakeeping

One of the main benefits of the Hull Vane® for yachts is its influence on the pitch motions. Next to its influence on the fuel use of a yacht, it can be regarded a very effective passive pitch dampening device. A reduction of the pitching motion not only increases the comfort on board, it also reduced the added resistance due to waves, making the Hull Vane® more effective in waves than in flat water.

How effective the Hull Vane® can be in reducing the pitch amplitude and the added resistance due to waves, is shown in multiple studies published. The following table displays the reduction of pitch amplitude and added resistance in regular waves on a 19m Motor Yacht, a 50m Patrol Vessel, a 55m and a 88m Supply Vessel, a 108m Ocean-going Patrol Vessel, and a 167 ROPAX vessel after a Hull Vane® is added [4]. These results were obtained with the use of CFD computations.

Vessel	**Vs**	**Hw**	**Tw**	**dP**	**dRA**
	kn	*m*	*s*	-	-
18m MY	14.0	0.5	4.00	-16.3%	-21.7%
18m MY	14.0	1.0	4.00	-12.4%	-8.8%
50m PV	20.0	1.0	5.66	-20.5%	-39.2%
55m SV	20.0	1.0	5.66	-14.4%	-29.3%
88m SV	15.0	1.5	7.00	-6.6%	-4.8%
88m SV	15.0	1.5	7.75	-5.3%	-5.3%
88m SV	15.0	1.5	8.50	-2.3%	-4.6%
108m OPV	17.5	2.0	8.00	-8.2%	-4.9%
108m OPV	17.5	4.0	8.00	-6.5%	-5.7%
167m PAX	20.0	2.5	6.28	-4.9%	-4.5%

Table 1. *Reduction of pitch amplitude (dP) and added resistance (dRA) of various vessels in different regular wave systems. From Uithof et al., 2016b.*

In model tests performed at the Wolfson Unit in 2011, similar results were found for irregular waves. In 9 different conditions, the root-mean-square (RMS) of the pitch motion was on average decreased by 5% for a 42m yacht [5]

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The pitch motion has a large influence on the vertical accelerations on board, especially in the front and aft of the vessel. For the 108m OPV, the accelerations at the aft deck (where the helicopter platform is situated), are displayed in Figure 5. The results are displayed for the vessel without Hull Vane® (red) and with Hull Vane® (blue) in 4 meter waves [6].

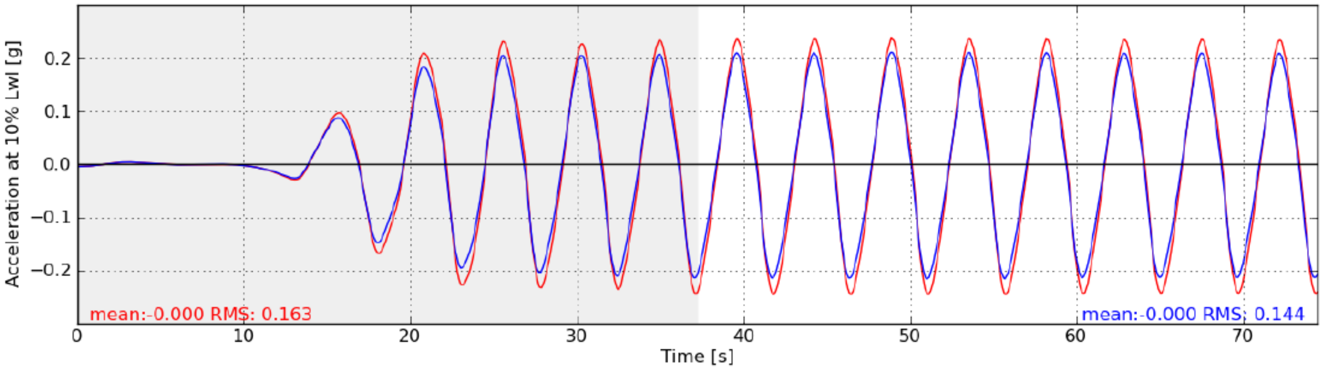

Figure 5. *Vertical accelerations at 10% of LWL for a 108m OPV with and without Hull Vane® (blue and red line, respectively).*

Sahoo et al. (2016) did an extensive study into the influence of the Hull Vane® on the pitch and heave response of a 50m generic hull shape in waves [7]. In Figure 6 a typical result from this research is displayed, in which it can be observed that both the response at the natural frequency of the pitch and heave motion are reduced.

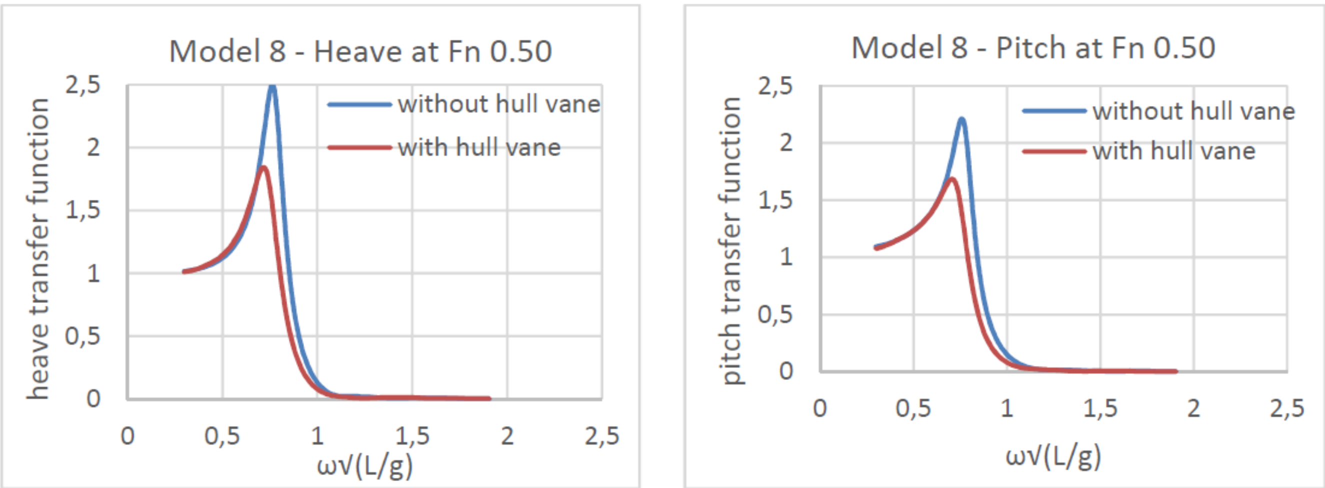

Figure 6. *Typical motion response functions of a 50m generic hull shape with and without Hull Vane®, from [7].*

Roll decay tests on a 108m OPV [5] showed that the roll motion was also slightly decreased after a Hull Vane® was fitted to the model. The dampening of the roll motion is especially important for comfort on board in beam or quartering waves.

3.3 Manoeuvrability

Not much data is available yet on the influence of the Hull Vane® on the manoeuvrability of vessels. Sea trials on the 55m Supply Vessel *Karina* showed an increase of directional stability: during the manoeuvrability tests, the diameter of the turning circle was increased by 4% while the overshoot of the vessel in the zig-zag tests was decreased from 3.5 degrees to 1.8 degrees.

The increased directional stability has a positive effect on the seakeeping of the vessel: yawing is reduced and especially in bow- and stern quartering waves this improves the comfort and operability of the ship, as 'corkscrewing' is reduced. The reduced yawing also means that less compensation is needed from the rudder, which further reduces the fuel use of the yacht slightly.

4. RETROFITTING

Some of the benefits (and costs) mentioned above are only valid if the Hull Vane® is incorporated during the design phase of the vessel. However, for retrofits the main running benefits still apply. The Hull Vane® on the 55m Karina was designed as a retrofit; its installation onto the transom can be observed in Figure 7. It needs to be noted that for motor yachts a more elegant solution can be designed, for instance one where the Hull Vane does not protrude aft of the hull.

Figure 7. *The installation of the Hull Vane® onto the transom of the 55m Supply Vessel Karina.*

Although generally less optimisation is possible on an existing vessel, the resistance reduction can still be significant. Although this leads to a reduction of the fuel use (and/or an increase of top speed), the lower resistance also results in a different operational point for e.g. the engines, the propellers, and subsystems, potentially resulting in lower fuel reductions as it would for new-builds (or an additional investment is required for a higher efficiency). Similar to for new-builds, the Hull Vane® for retrofits does not increase the maintenance budget of the yacht significantly, as only additional antifouling and cathodic protection is required.

The initial costs of the Hull Vane® are thus still in place, while the initial benefits of potentially smaller engines cannot be fully exploited. Because the fuel reduction still applies as well, it means that it will take some time before the Hull Vane® has paid back for its initial investment costs. While for the newbuilds the initial costs are often covered by the initial benefits, for retrofits a payback period of between 1-3 years is commonly found for commercial vessels. For yachts, an important parameter which defines the payback period is the operational profile of the yacht. If the vessel is used often the payback period can be short (e.g. if it is available for charter, or if it makes transatlantic journeys often). This means that for some yachts the Hull Vane® may never pay back for itself in terms of cost saving, but other benefits (e.g. comfort and operability) may still convince investors to make this investment.

Although generally the layout of the yacht cannot be dramatically altered anymore, the beneficial influence on the comfort, seakeeping, and manoeuvrability of the yacht will still apply after retrofitting the Hull Vane®. Because the engine and propeller will be less loaded, the noise and vibration will be decreased. The pitch, yaw, and roll motions will also still be reduced, leading to a more comfortable ride for owners, guests, and crew.

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5. CONCLUSION

It can be concluded that the Hull Vane® can lead to a significant reduction of both initial costs and running costs, given a suitable hull shape and operating profile. Especially if the resistance is reduced to such an extent that the installed power can be decreased, the initial investment costs of the Hull Vane® can be compensated by savings on the building costs of the yacht. This paper thus showed that it is best to include the Hull Vane® already during the design phase for maximum benefits, both on the short term and long term. On the short term, it is easier to prepare the planned propulsion system for the less required power, while on the long term the potential fuel savings are increased.

However, also for retrofit there are enough benefits left: Additionally to the fuel savings, the positive effect of the Hull Vane® reduction of pitch, yaw, and heave motions increases the comfort and operability on board. Although the initial costs may not be covered by the initial benefits as for new builds, the short payback periods make the Hull Vane® an interesting investment for commercial application from an economic point-of-view. For yachts the payback period is often longer due to their operational profile, but the unquantifiable benefits make it an interesting investment nonetheless.

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