A SYSTEMATIC COMPARISON OF THE INFLUENCE OF THE HULL VANE®, INTERCEPTORS, TRIM WEDGES, AND BALLASTING ON THE PERFORMACE OF THE 50M AMECRC SERIES #13 PATROL VESSEL

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SUMMARY

The patented Hull Vane® is a fixed hydrofoil that can be attached to the transom of the vessel. It uses the upward flow at this location to recuperate some of the energy that otherwise would be lost in the transom wave. For naval vessels high fuel savings have been found, e.g. 12.5% of annual fuel savings for the 108m Holland Class OPVs of the Royal Netherlands Navy [1].

Part of the resistance reduction of the Hull Vane® lies in the alteration of the vessel's trim. This paper discusses a comparison between the Hull Vane® and other trim correction methods: interceptors, trim wedges, and ballasting. With the use of a systematic CFD study, the 50m Patrol Vessel from the AMECRC series #13 is analysed to quantify which trim correction method is most suitable for this round-bilged fast displacement hull at speeds between 8.6 and 34.4 knots. The results show that although for all trim correction methods resistance reductions were found, the Hull Vane® achieves the highest resistance reduction over the major part of the speed range, with resistance reductions up to 32.4%. The influence of the different trim correction devices on the performance in waves is also assessed, and the Hull Vane® effectively reduces the pitching motion and the added resistance in waves, more than e.g. an interceptor.

1. INTRODUCTION

Trim correction devices such as (variable) interceptors and trim wedges have been used on medium to high speed crafts with great success. They are designed to reduce the running trim and reduce the vessel's resistance, often with the goal to obtain a higher top speed.

Relatively new to the market is the patented Hull Vane®, a fixed hydrofoil (see Figure 1) which can be attached to the transom. Like interceptors and trim wedges, it effectively reduces the running trim of the vessel. But besides that, it also produces an additional thrust force, it reduces the transom wave, and reduces the pitching and added resistance in waves.

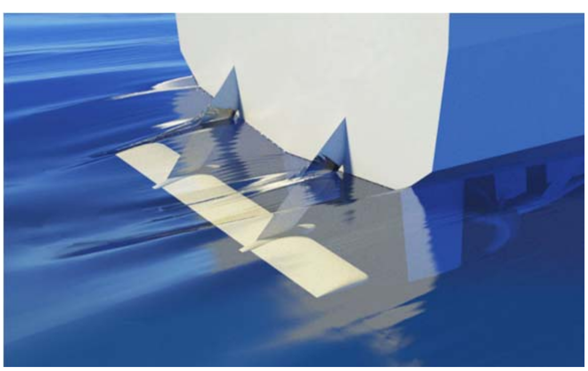

Figure 1. Render of a typical Hull Vane configuration.

In this paper, the benefits of the Hull Vane® in terms of resistance are compared to those of variable interceptors, trim wedges, and ballasting. In a systematic study using Computational Fluid Dynamics (CFD), a 50m patrol vessel is analysed with all these trim correction methods for the speed range between 8.6 and 34.4 knots. First, a short explanation of the working principles of the trim correction devices will be given. Subsequently, the method and results of the research will be elaborated upon. The paper will be concluded with a discussion on the results, followed by the conclusion.

2. THEORETICAL BACKGROUND

2.1. The Hull Vane®

Although the working principles of the Hull Vane® have been extensively described in earlier work [2], a short recapitulation will be provided in this section.

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.

Earlier research which is relevant for naval vessels are two papers on the Holland Class OPV of the Dutch Navy [1,3], which include a cost-benefit analysis and a sea-keeping analysis for the Hull Vane® on these 108m naval vessels.

2.2. Interceptors and trim wedges

Interceptors and trim wedges have been broadly adopted in the faster ship segments, such as naval vessels and yachts. Both devices are based on the same principle: they are designed to slow down and redirect the flow near the aft ship, such that a high pressure region is created under the aft ship. This pressure region pushes the aft of the vessel up, causing a trim more bow-down. This influence on the trim proves to be beneficial for the resistance of the vessel, especially at the higher speeds.

3. METHOD

3.1. AMECRC #13

For this study, it was opted to make use of the AMECRC series of high speed displacement monohulls, which is based on the MARIN HSDHF series. This series consists of 14 round-bilge hull forms with submerged transoms, which are suitable for naval application. The *L/B* ratio varies between 4 and 8, while the *B/T* ratio varies between 2.5 and 4. The chosen geometry #13 has an *L/B* ratio of 6, and a *B/T* ratio of 3.33, making it the 'most average' geometry of the available hulls. This model has the ship parameters as given in Table 1, and the sections as in Figure 2.

Table 1. Ship parameters of AMECRC #13.

Main parameters	
Lwl	50.000 m
Bwl	8.333 m
T	2.500 m
Δ	481.4 m^3
LCB	22.279 m

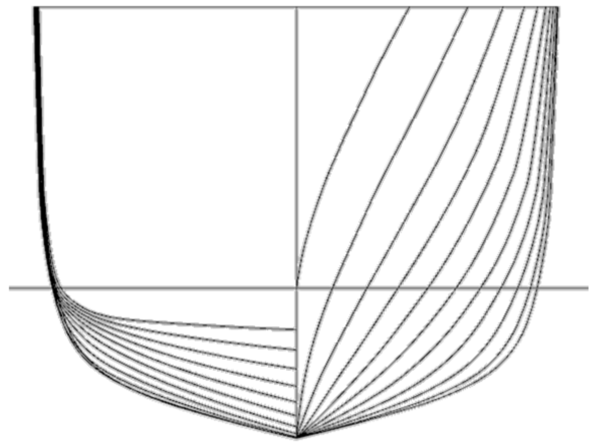

Figure 2. Sections of AMECRC #13.

Various trim correcting devices were tested on this hull with the use of FINE/Marine, a RANS-based CFD code developed especially for marine application by Numeca and the University of Nantes: a Hull Vane®, an interceptor, a trim wedge, and ballasting. All these devices have been tested in flat water, and the best performing ones have been tested in a single regular wave condition as well.

3.1. FLAT WATER

In flat water, all geometries are tested at 9 different ship speeds, ranging from *Fn* 0.20 and *Fn* 0.80. For a 50m vessel, this corresponds to ship speeds between 8.6 knots and 34.4 knots.

3.1.1. Hull Vanes

Because there are many parameters that influence Hull Vane® performance, a total of five Hull Vane® configurations have been tested, varying in vertical and longitudinal position. The span of each Hull Vane® is kept constant. The Hull Vanes were tested without the struts connecting it to the hull. The influence of the struts on the total resistance is often found to be negligible; the resistance of the struts itself is often (partly) offset by the increased performance of the foil part between the struts. The Hull Vane® variations are displayed in Figure 3.

3.1.2. Interceptors and trim wedges

Two different interceptor heights were tested. One interceptor has a height of 30 mm, the other has a rather extreme height (for this ship length) of 60 mm. This way, for each speed the best interceptor height can be estimated, and the performance of a variable interceptor can be assessed. The width of both interceptors is 7.0 meter. The interceptors are displayed in Figure 3.

Equivalently to the interceptors, two trim wedges are analysed. They have a length of 1.5% of the *Lwl* of the model (750 mm), and have a 4 and 10 degree angle. These analysed trim correction devices are displayed in Figure 3.

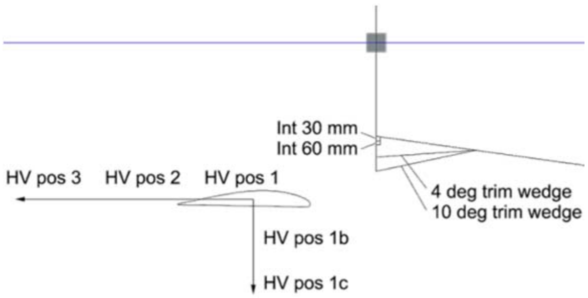

Figure 3. Overview of Hull Vane® positions, interceptor heights and trim wedge geometries.

3.1.3. Ballasting

Because the interceptor's and trim wedge's effectiveness are dependent on their influence on the trim, and that of the Hull Vane® partly, it was opted to add a fourth trim correction method: ballasting. Two methods were tested:

- To ballast the vessel as to obtain the same dynamic trim as the optimal Hull Vane® geometry. With this method, it can be seen whether the Hull Vane® achieves its resistance reduction from its influence on the trim, its influence on the rise, or the thrust force it generates.
- To ballast the vessel to its optimum trim. A maximum *LCG* shift of ±2 meter was assumed, which corresponds to moving approximately 20 tons of ballast from 10% *Lwl* to 90% *Lwl* or vice versa. No extra displacement was added.

3.2. WAVES

As an additional analysis, the best performing trim correction devices are compared to the bare hull in waves. The models are analysed in regular waves, with a wave length of 50 meter and wave height of 1 meter, at 25.8 knots (*Fn* 0.60).

4. RESULTS

4.1. FLAT WATER

4.1.1. Hull Vane®

The Hull Vane® was tested in 5 different positions, varying in horizontal and vertical positions (See Figure 3). In Figure 4 a typical result of the rise (vertical motion at LCG) and trim (defined positive bow-up) as a function of ship speed is compared to that of the model without Hull Vane®.

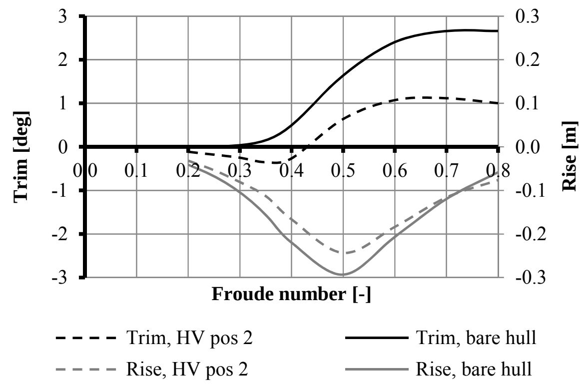

Figure 4. Trim and rise of the bare hull geometry, and the geometry with Hull Vane® in position 2.

It can be noted that the Hull Vane® indeed influences the trim. The change in trim due to the Hull Vane® peaks at 1.7 degrees at the highest speed. The Hull Vane® also reduces the sinkage over the major part of the speed range. Only at the highest speed, the lift that is created on the hull due to the trim causes the vessel without Hull Vane® to rise more.

The results in terms of bare hull resistance are displayed in Figure 5, in which the results are displayed as the change in resistance relative to the bare hull. No correction for surface roughness or wind resistance has been applied to these results.

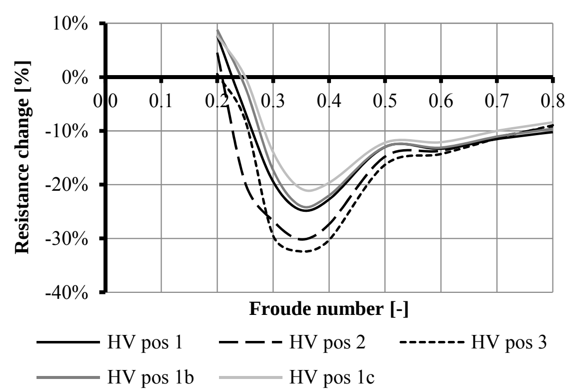

Figure 5. Resistance change relative to bare hull, for the five different Hull Vane® positions, as a function of ship speed.

It can be observed that the Hull Vane® reduces the resistance above *Fn* 0.2, by a maximum of 32.4% for position 3 at *Fn* 0.35. The results also show that an optimal horizontal positioning of the Hull Vane® is essential, as the difference in resistance reduction between these position can be as high as 13%. The vertical position does not have the same degree of influence: the maximum difference between position 1 and 1c is 7%. At the higher speeds (*Fn* 0.6 – 0.8), the difference between the positions of the Hull Vane becomes small (<2%). This is because the flow of the water behind the transom becomes more uniform, such that the influence of the position of the Hull Vane becomes less significant.

4.1.2. Interceptors and trim wedges

Two different interceptor heights and two different sizes of trim wedge were analysed and compared to the bare hull. The resistance change due to these trim correction devices as a function of speed is given in Figure 6.

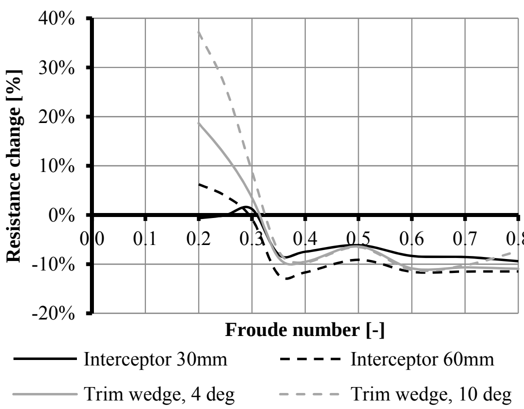

Figure 6. Resistance change relative to bare hull, for two interceptor heights and two trim wedges, as a function of ship speed.

The interceptor and trim wedge give a resistance reduction at ship speeds above *Fn* 0.3 of between 7 and 12%. However, at ship speeds of *Fn* 0.3 or lower, the influence on the resistance is negative. Especially the trim wedge solution increases the resistance at these lower speeds significantly, up to 37.2%. In Figure 7 can be seen how the stream lines around the aftship are influenced by the trim wedge.

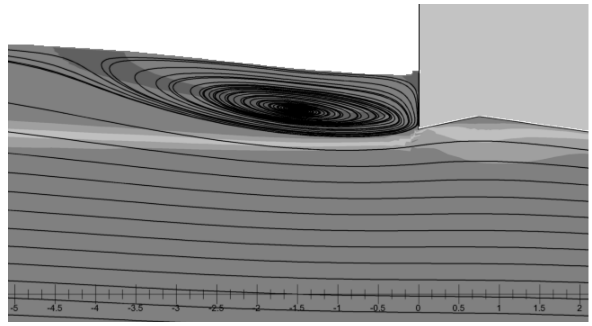

Figure 7. Stream lines around the transom for the large trim wedge, at *Fn* 0.2.

It can be observed that there is a large part of 'dead water' being dragged by the vessel, due to the increased transom depth. This significantly increases the resistance of the hull. The smaller trim wedge and the interceptors also cause an increased transom, although to a lesser extent, resulting in lower resistance increments at lower speeds.

4.1.3. Ballasting

To simulate ballasting, the longitudinal center of gravity of the vessel was moved. It was chosen to not move the LCG by more than ±2 meter. As can be seen in Figure 8, moving LCG forward by 2 meter proved to be the best ballasting condition within these boundary conditions at the lower speeds.

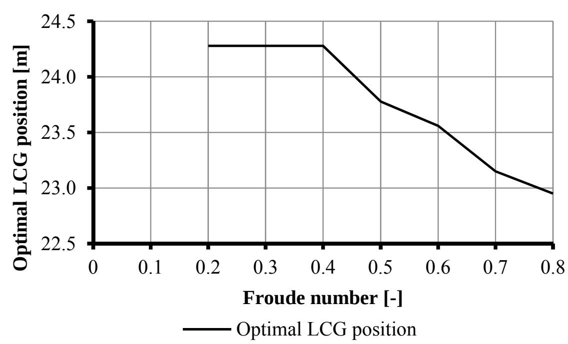

Figure 8. Optimal LCG position as a function of ship speed.

The fact that LCG needs to be moved forward is related to the phenomenon visualised in Figure 7. Moving LCG forward will lift the transom out of the water, such that at lower speeds there is less dead water dragged along with the ship.

It can also be noted in Figure 8 that at higher speeds, it proves to be useful to move the LCG more aft, although at the highest speed the optimal LCG is still forward of the original LCG of 22.279 meter. Figure 9 shows the resulting reductions in resistance due to the shifting of the LCG.

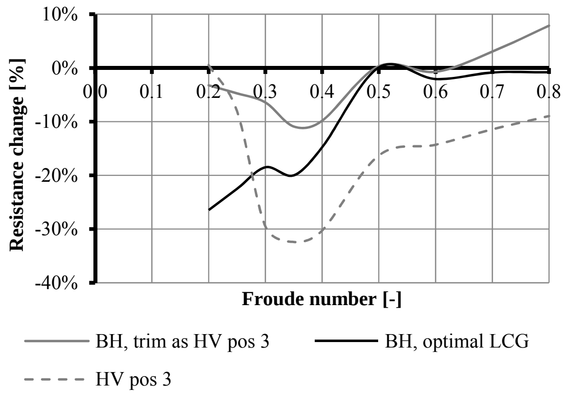

Figure 9. Resistance change relative to bare hull, for optimal ballasting and ballasting to the trim obtained with Hull Vane®.

At the lower speeds, the resistance reduction is most significant, up to 26.5% at the lowest speed, due to the transom being trimmed out of the water. It can also be seen that only trimming the vessel to the trim of the vessel with Hull Vane® does not achieve the same benefits as actually applying the Hull Vane®.

4.1.4. Combined results

Now that all configurations are tested a comparison can be made between the best performing ones. For the Hull Vane®, it was opted to choose position 2, as it seems to be giving the best results over the whole speed range, especially at the lower speeds (*Fn* 0.2 – 0.3).

For the interceptor heights, the best result at each speed was chosen, as would be possible with a variable interceptor. In the decision between the trim wedges, the small trim wedge was opted for, because its results were equal to, or better than, the results of the large trim wedge over the entire speed range. For the results of ballasting, the optimal ballasting condition for each separate speed is used. The results in terms of trim, rise, and change in resistance relative to the original bare hull are given in Figures 10, 11, and 12, respectively.

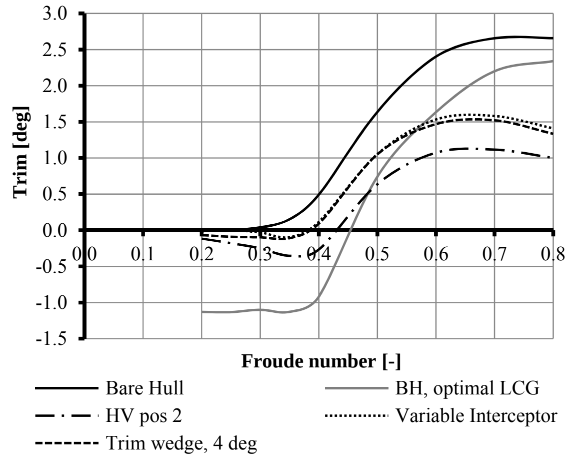

Figure 10. Trim as a function of ship speed, for different configurations.

At the lower speeds, the trim can only be significantly altered by the LCG shift of 2 meter, resulting in a trim of 1.1 degrees bow-down. At the higher speeds, the trim correction devices start doing what they are intended to do: the difference in trim between the bare hull and the geometry with Hull Vane® is 1.7 degrees at the highest speed.

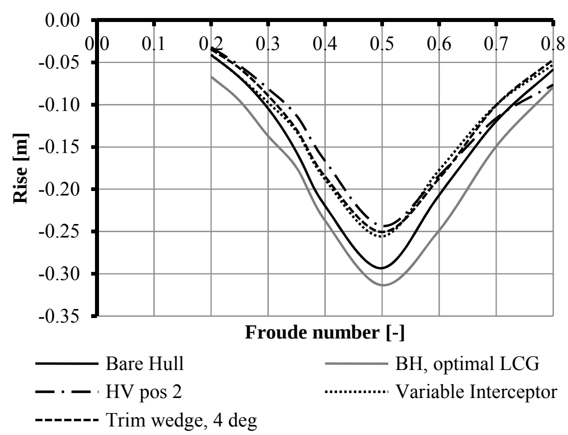

Figure 11. Rise as a function of ship speed, for different configurations.

From the results in terms of rise can be observed that the lift that is generated by the Hull Vane®, interceptors and trim wedges also have their influence on the rise: Especially in the mid-speed segment the vessel lies higher than without these devices. At the higher speed, the excessive trim of the bare hull model causes the boat to rise higher between *Fn* 0.6 and *Fn* 0.8.

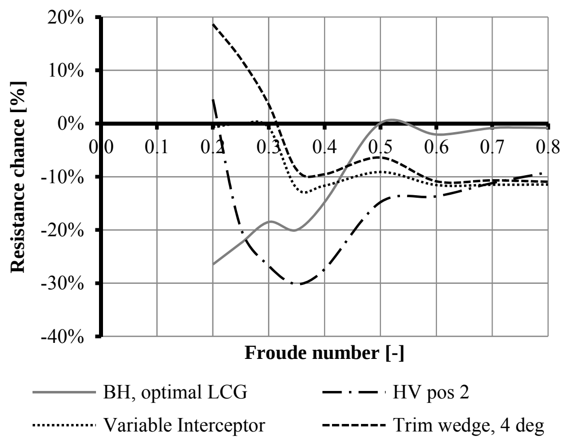

Figure 12. Resistance change relative to bare hull, for optimal ballasting and the best configurations of the Hull Vane®, the interceptor, and the trim wedge.

The results show that at the lowest speeds, under *Fn* 0.25, the right ballasting reduces resistance the most for this hull shape. In the speed range between *Fn* 0.25 and *Fn* 0.7, the Hull Vane® proves to be most beneficial in terms of resistance. Only at the highest speed of *Fn* 0.8 the interceptor and the trim wedge are slightly better than the Hull Vane®.

To illustrate the difference in resistance for intermediate Froude numbers, Figure 13 shows the wave profile of the ship equipped with variable interceptor (on the top half of the figure) and with Hull Vane pos. 2 (on the lower half of the figure). It can be clearly observed that the depth of the wave through and the height of the wave top behind the transom are smaller on the vessel with Hull Vane. In spite of a higher frictional resistance, the reduction in pressure (or wavemaking) resistance is such that the overall resistance is 18% lower for the vessel with Hull Vane than for the vessel with interceptor.

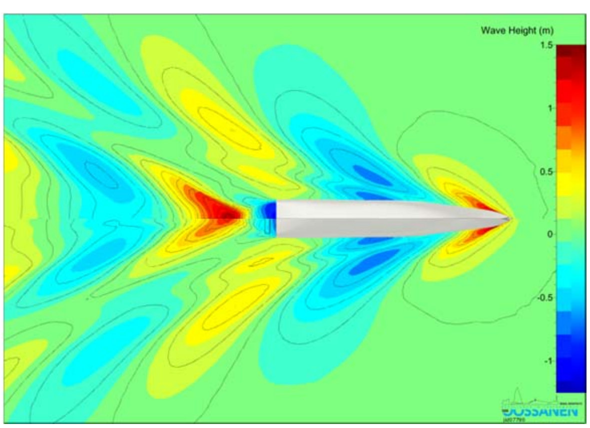

Figure 13. Comparison of wave profiles at Fn 0.4 with interceptor (upper half) and Hull Vane® (lower half).

4.2. WAVES

For the computations in waves, it was opted to compare both the geometry with Hull Vane® and the geometry with the 60 mm interceptor to the bare hull. *Fn* 0.6 was chosen as the ship speed, as the results of the interceptor and Hull Vane® at this speed are not that much different. A wave length of 50 meter was chosen, which is equal to the ship length. A wave height of 1 meter was chosen for this analysis. The resulting pitch signals of the three geometries as a function of time are displayed in Figure 14.

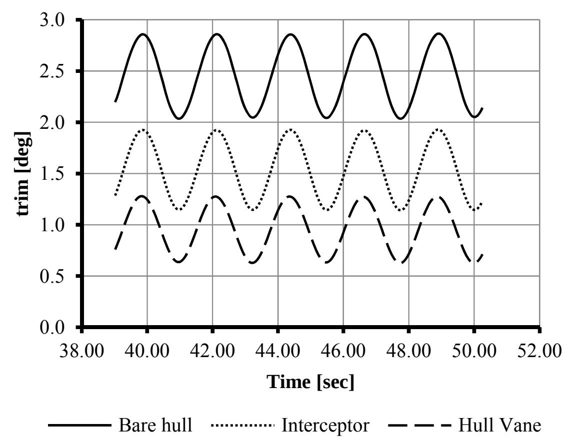

Figure 14. Trim signal in waves of the three geometries.

The influence of the Hull Vane® and the interceptor on the average trim is clearly visible, as it was in flat water. However, the influence of the devices on the pitch motion is interesting: The pitch amplitude is reduced by 4.5% from 0.82 to 0.78 degrees after the interceptor was added to the model. When the Hull Vane® is used, the amplitude is reduced to 0.65 meter, which is a reduction of 20.9% compared to the bare hull.

This reduction of the pitch motion also influences the resistance of the vessel. Whereas in flat water the interceptor and Hull Vane® decrease resistance by 11.6% and 13.7% respectively, in waves these percentages change to 10.4% and 14.7%, showing that the Hull Vane® effectively reduces the added resistance of the vessel due to waves.

5. DISCUSSION

The resistance reductions found with the Hull Vane® on this 50m Patrol Vessel are remarkable. In comparison to the original bare hull, resistance reductions up to 32.4% were found. The variation of Hull Vane® position showed that at different speeds, different positions gave different results. At the higher speeds however, the results lie closer to each other, as the flow around the aft ship becomes more uniform.

Although the Hull Vane®'s influence on the running trim can be as high as 1.7 degrees at the highest tested speed, the computations with ballasting to the same running trim show that this trim correction is not the sole reason for the resistance reductions from the Hull Vane®.

Furthermore, ballasting with a maximum LCG shift of 2 meter (or moving 20 tons of ballast from the aft of the vessel to the front) can improve the vessel's flat water performance at lower speeds significantly. The reason behind this is that a bow-down trim raises the wet transom out of the water, such that less dead water is dragged along with the vessel.

Dragging along dead water is also the main reason why the interceptors and especially the trim wedges increase the vessel's resistance at the lower speeds, as they increase the vessel's transom submergence. Above *Fn* 0.3 (13 knots), these devices start paying off, although the resistance reduction they generate never increases over 12%. Only at the highest tested speed of *Fn* 0.8 (34.4 knots), they outperform the Hull Vane® by 2%.

When assessing which trim correction device is most suitable for a certain vessel, it is important to look at the whole operating profile. Although only a small portion of time is sailed at the higher speeds, the fuel consumption at these speeds can still be a significant portion of the vessel's total fuel consumption. Applying this design philosophy to the vessel used for this research would make a strong case for the Hull Vane®, as it is the most effective at the speeds between *Fn* 0.25 and 0.70. A combination with ballasting (if possible) for sailing at low speeds would mean that almost the entire tested speed range is covered.

When assessing the whole operating profile of a vessel, waves are important as well. Although only one wave condition was tested for the current paper, the results (reduced pitching and reduced added resistance due to the Hull Vane®) are in line with results from earlier publications on the influence of the Hull Vane® on seakeeping performance ([3],[4]).

Lastly, it needs to be noted that all devices could be further optimized, especially if an operating profile is defined. However, the current research does cover a large part of the relevant speed range (8.6 – 34.4 knots for a 50m vessel), it uses a typical, generic, and publicly available hull shape, and everything has been set to work to make this a fair comparison.

6. CONCLUSION

This paper discussed a systematic comparison between different trim correction methods: The Hull Vane®, a variable interceptor, trim wedges, and ballasting. All these methods were tested on a 50m Patrol Vessel at speeds between 8.6 and 34.4 knots (*Fn* 0.2 – 0.8).

The research has shown that the Hull Vane® is the most efficient in reducing the resistance of this vessel for the largest part of the speed range. Only at the lower speeds ballasting proves to be more efficient, as it prevents dead water to be dragged along with the ship by lifting the transom out of the water. At the highest speed, the differences between the variable interceptor, trim wedge and Hull Vane® are small.

This research has not investigated the option of combining ballasting for the lowest speed with the Hull Vane® for the medium to high speeds. Combining these solutions could prove to get the best of both worlds.

In comparison to the interceptor, the Hull Vane also significantly reduces the pitching motion of the vessel. The amplitude in regular waves with a wave length of 50m and a wave height of 1m was reduced by 20.9%, which will significantly increase the comfort for the crew, and operability of the vessel.

Naval and coastguard vessels such as OPVs, corvettes, frigates and destroyers are designed for high Froude numbers (typically 0.3 to 0.7) but they sail most of the time at speeds corresponding to Froude numbers of 0.2 to 0.4. To determine the suitability of an energy saving or trim correction device for a specific vessel, it is important to take the entire operational profile of the vessel into account. Ideally, this would also include the typical sea states encountered.

To conclude, of the trim correction devices tested the Hull Vane® showed the best results over the major part of the tested speed range. It is therefore very effective in lowering naval vessels' fuel consumption, increasing their top speed, and increasing the ships' tactical range. In addition, it reduces the pitch of the vessel significantly, resulting in an improved comfort on board, increased safety for operations on deck or over the side and a more stable platform. Finally, the significant reduction of the stern wave by the Hull Vane reduces the ship's visual and noise signature.

7. LITERATURE

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BIOGRAPHY

Kasper Uithof works as a project manager at Hull Vane BV. He is responsible for the design and engineering of the Hull Vanes, as well as R&D and project planning. Kasper holds a MSc in Maritime Technology from Delft University of Technology (with distinction), and a MSc in Management from the Rotterdam School of Management.

Nils Hagemeister works in the Fluid Dynamics department of Van Oossanen, focusing on sailing and R&D projects. Prior to joining Van Oossanen he was involved with performance prediction and optimization of sailing vessels. He holds a Master's degree in Naval Architecture from University of Applied Sciences Kiel (Germany).

Bruno Bouckaert is the commercial director of Hull Vane BV. Before he became involved with the Hull Vane®, he has worked as a class surveyor in cruise ship construction and as an independent naval architect. Bruno holds a MSc degree in Naval Architecture from the University of Ghent (Belgium).

Perry van Oossanen is partner of Van Oossanen and Hull Vane BV. Since University he has been working at Van Oossanen as Naval Architect with a special interest in the performance and seakeeping of vessels. Together with his partner he took over the Van Oossanen in 2012. In 2014, Hull Vane BV was founded with the aim of engineering, building and selling the Hull Vane. Perry holds a Bachelor degree in Naval Architecture from the university of Haarlem.

Niels Moerke is partner of Van Oossanen and Hull Vane. Since University he has been working at Van Oossanen as Naval Architect with a special interest in Fluid Dynamics and yachts below 24 m. Together with his partner he took over Van Oossanen in 2012. In 2014 Hull Vane BV was founded with the aim of engineering, building and selling the Hull Vane. Niels holds a Bachelor degree in Naval Architecture from the University of Haarlem and a Master's degree in Hydrodynamics from the university of Delft.