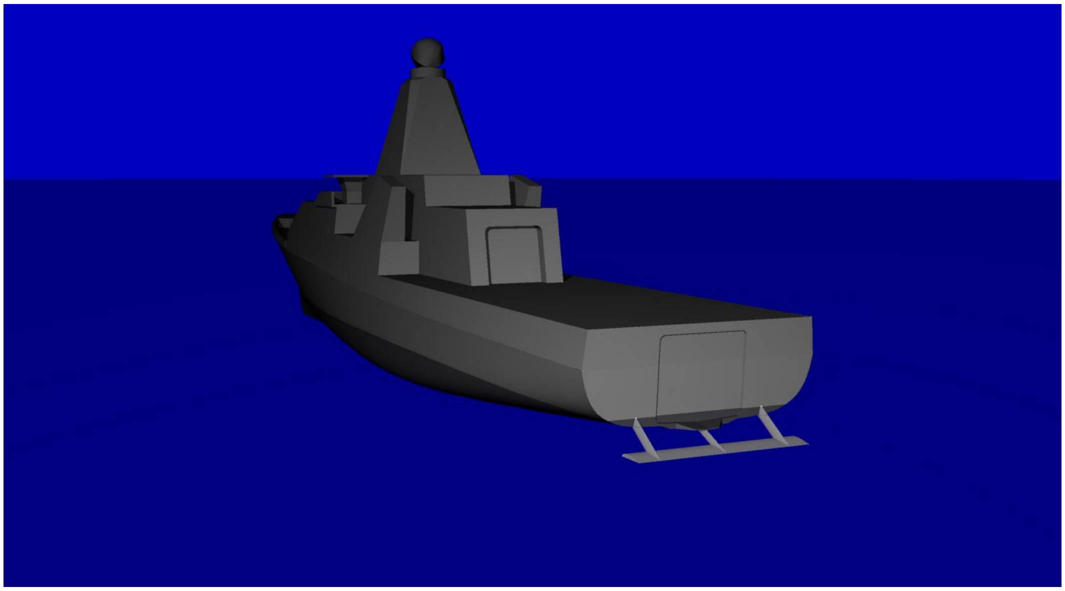
A Life-cycle Cost Analysis of the Application of a Hull Vane® to an Offshore Patrol Vessel

Bruno Bouckaert[1] (V), Kasper Uithof[2] (V), Perry van Oossanen[3,4] (V), Niels Moerke[3,4] (V)
Bart Nienhuis[5] (V), Jan van Bergen[6] (V)



ABSTRACT

The consequences of applying a Hull Vane® to a Holland Class 108 m Oceangoing Patrol Vessel of the Royal Netherlands Navy were studied by means of a Computational Fluid Dynamics study using Fine/Marine. The effect on the annual fuel consumption was determined by linking the savings percentages at several speeds to the operational speed profile. This paper demonstrates that – from propulsion point of view – a reduction in total fuel consumption can be achieved of 12.5% if a Hull Vane is installed, along with a small modification to the ship's hull. At the speed at which most fuel is consumed annually (17.5 knots), the total resistance is reduced by 15.3%. Further operational benefits were quantified, such as a reduction of the vertical accelerations at the helicopter deck when sailing in head waves (-13%), a reduction of the turbulent zone just behind the slipway enabling small craft launch & recovery (from 5 to 2.5 meters), an increased range (from 5,000 nautical miles to 5,850 nautical miles at 15 knots) and an increased top speed (from 21.5 knots to 22.1 knots).

[1] Sales Director at Hull Vane BV
[2] Project Manager at Hull Vane BV
[3] Managing Director at Hull Vane BV
[4] Managing Director at Van Oossanen Naval Architects BV
[5] Hydromechanics engineer at DMO
[6] Structures engineer at DMO

KEY WORDS

Hull Vane®; Hydrofoil; Fuel Saving Device; Energy Saving Device; Offshore Patrol Vessel; OPV; Seakeeping; Naval Ships; Fast Displacement Ships; Emissions Reduction

NOMENCLATURE

AFC: Annual Fuel Consumption
DMO: Defence Materiel Organisation
Fn: Froude Number
O.P.: Operational Profile
OPV: Oceangoing Patrol Vessel
R: Resistance
R_F: Frictional Resistance
R_P: Pressure Resistance
R_T: Total Resistance, including correction for surface roughness
RHIB: Rigid Hull Inflatable Boat
RNlN: Royal Netherlands Navy
S_W: Wetted Surface
V_S: Ship's speed, in knots

1. INTRODUCTION

The purpose of this paper is to investigate the economical and operational consequences of retrofitting a Hull Vane® to a Holland Class 108 m Oceangoing Patrol Vessel (OPV) of the Royal Netherlands Navy (RNlN). The RNlN liaised Defence Materiel Organisation (DMO) provided an estimated and measured operational speed profile, and limiting conditions for the organic unit operations such as launch & recovery of an onboard helicopter and Rigid Hull Inflatable Boats (RHIBs).
The research presented in this paper bears heavily on CFD (Computational Fluid Dynamics) work carried out by Van Oossanen Fluid Dynamics, a sister company to Hull Vane BV.

2. HULL VANE

The Hull Vane® is a patented fuel saving device, consisting of a submerged hydrofoil-type appendage, fixed at or below the stern of a ship. A typical configuration of the Hull Vane is represented in Figure 1.

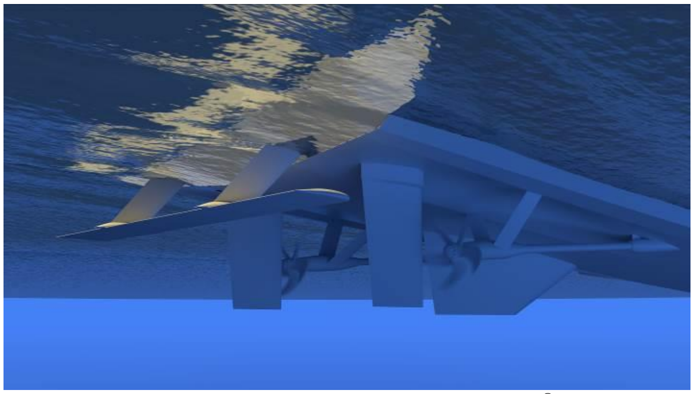


Figure 1: A typical configuration of the Hull Vane®

Unlike hydrofoils, the goal is not to lift the vessel out of the water but to generate a forward-oriented lift force and to reduce the stern wave. The Hull Vane® has been called an "underwater spoiler" and "the bulbous bow of the stern", but both of these comparisons are incomplete. The Hull Vane® reduces the fuel consumption of ships through four different effects (Uithof, 2014):

1. it produces forward thrust out of the upward flow under the aft ship (see Figure 2)

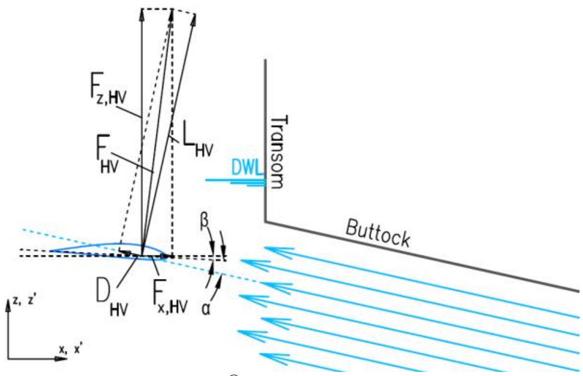


Figure 2: Hull Vane® generates a net forward thrust force out of the upward flow under the stern

2. it reduces the wavemaking or pressure resistance (see Figure 3)

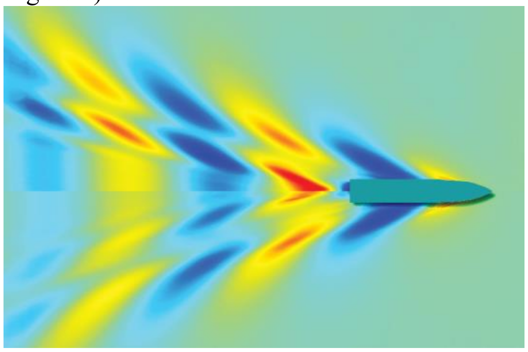


Figure 3: The wave profile of a 55m vessel at 20 knots without Hull Vane® (above) and with Hull Vane® (below)

3. it generates vertical lift to reduce the running trim of a ship, and

4. it reduces the ship motions in waves such as pitching, heaving, rolling and yawing (and therefore the added resistance caused by these motions).

The Hull Vane® was invented by Dr. Ir. Peter van Oossanen and is patented in all major shipbuilding countries. It has been successfully applied on a 55 meter Fast Supply Intervention Vessel and a 42 meter Superyacht.

3. INITIAL DATA AND OBJECTIVES

3.a The ship

The Holland Class consists of four OPVs, which were built for the RNlN by Damen Schelde Naval Shipbuilding in the years 2008-2011. The goal was to create a cost-efficient vessel for coastguard, anti-piracy and search and rescue missions. These tasks used to be carried out by frigates, which are over-qualified for the job, and therefore more costly in terms of fuel consumption, crew and armament. The top speed of the Holland Class vessels was set at a moderate 21.5 knots (service conditions), with the knowledge that fast interventions could be carried out by its two RHIB-type FRISCs (Fast Raiding Interception Special Forces Craft) having a top speed of 45 knots, and its onboard NH90 helicopter.

The Holland Class OPVs have two controllable-pitch propellers, driven directly by two diesel engines. For the frequent low-speed patrol activities, two electrical motors are coupled to PTI's (Power-Take-In) on the gearboxes for a diesel-electric propulsion mode. The result is a very fuel-efficient vessel over the entire speed range.

The lead vessel in the Holland Class OPVs, called *HNLMS Holland,* is pictured in figure 4.

Figure 4: HNLMS Holland (P840) © Damen Shipyards

3.b Ship model

DMO provided the 3D hull shape definition, the static displacement and trim of the vessel. A structural drawing of the stern sections was provided for proper integration of the Hull Vane's struts into the ship's structure and limiting parameters were given to ensure complete functionality of the slipway.

The principal particulars of the vessel are given in Table 1.

Table 1. Main dimensions of Holland Class OPVs

Length-over-all	108.4 m
Waterline length	102.8 m
Design displacement	3.750 ton
Beam-over-all	16 m
Design draught	4.55 m
Propulsion power	2 x 5460 kW
Range at 15 knots	5.000 nm
Max. service speed	21.5 knots

3.c Objectives of the research

The RNlN recently imposed themselves new challenging goals for the entire fleet, including a substantial reduction in emissions and an even more significant increase in energy efficiency, and the DMO is investigating whether applying a Hull Vane® can contribute to this, and by how much.

In addition, experience has shown that the Hull Vane® provides an improvement to the seakeeping characteristics of a vessel. The Holland Class OPVs were specifically designed with seakeeping and operability in mind, which explains why their main dimensions are much larger than those of conventional patrol boats, allowing to remain at sea for longer periods of time. This clarifies the denomination "oceangoing" patrol vessel rather than the more common "offshore" patrol vessel. In particular, DMO wished to see if the safety or operational performance could be increased for following activities:

- Launch & recovery of a helicopter from the aft deck (see Figure 5)
- Launch & recovery of a RHIB from the slipway

DMO provided the current limiting environmental conditions in which these operations can still be executed and wanted to know to what extent these limits could be raised.

Figure 5: Helicopter operations on deck of HNLMS Holland in heavy weather

4. METHOD

4.a Fuel saving aspect

Similar to other fuel saving devices, such as the bulbous bow, the Hull Vane® is optimized for one speed, after which the savings can be determined for other speeds. For this case study, the decision was made to optimize the Hull Vane® for the speed at which the ships consume most fuel on an annual basis. DMO provided both a theoretical and measured operational speed profile. These are represented in Table 2. We opted to use the measured operational profile for this study, even though it is less beneficial to the application of the Hull Vane, due to a lower average speed. As the theoretical operational speed profile may prove to be more correct in the long run, we have also calculated the effect for that case.

Table 2. Operational speed profiles of Holland Class OPVs

Speed	Theoretical profile	Measured profile
<5 kn	20%	43%
5-10 kn	10%	24%
10-15 kn	40%	19%
15-20 kn	22%	13%
>20 kn	8%	1%

DMO also provided the speed/power curve of the vessel, which allowed calculating the fuel consumption in each condition over the year. For each range of speeds, the average speed was used for the calculations. The lowest speed was set at 5 knots, while the highest speed was set at 22.5 knots. For each speed, the percentage of annual fuel consumption spent at this speed was calculated, as shown in Table 3.

Table 3. Annual Fuel Consumption (AFC) per speed without Hull Vane

Speed	O.P.	Froude number	Power	O.P. x Pwr	AFC
5 kn	43%	0.08	257 kW	110 kW%	7.8%
7.5 kn	24%	0.12	551 kW	132 kW%	9.3%
12.5 kn	19%	0.20	1.873 kW	356 kW%	25.1%
17.5 kn	13%	0.28	5.313 kW	691 kW%	48.7%
22.5 kn	1%	0.37	12.953 kW	129 kW%	9.1%

From table 2 and 3, it can be seen that even though the vessel sails only 13% of the time at speeds between 15 and 20 knots, it is still the condition in which almost half of the fuel is consumed per year (48.7% of the total). It was therefore decided to optimize the Hull Vane® for a speed of 17.5 knots. The results of table 3 are graphically represented in figure 6.

A Hull Vane® for this condition was designed by Hull Vane BV, along with a modification to the hull (see chapter 5) and a CFD study was carried out by Van Oossanen Fluid Dynamics to determine the effects of the Hull Vane® on the still water resistance at the following speeds: 5 kn, 12.5 kn, 17.5 kn, 22.5 kn.
The results of this CFD study are presented in chapter 6.

4.b Seakeeping/operational aspect

To quantify the impact of the Hull Vane® on the operability, one seakeeping case was analyzed using a CFD study in regular waves. A comparison was made between the behavior of the benchmark OPV and the OPV with modified trim wedge and added Hull Vane®, of the same design as described in 4.a. The numerical results of the seakeeping study are presented in chapter 7. The video will be published on the website www.hullvane.com.

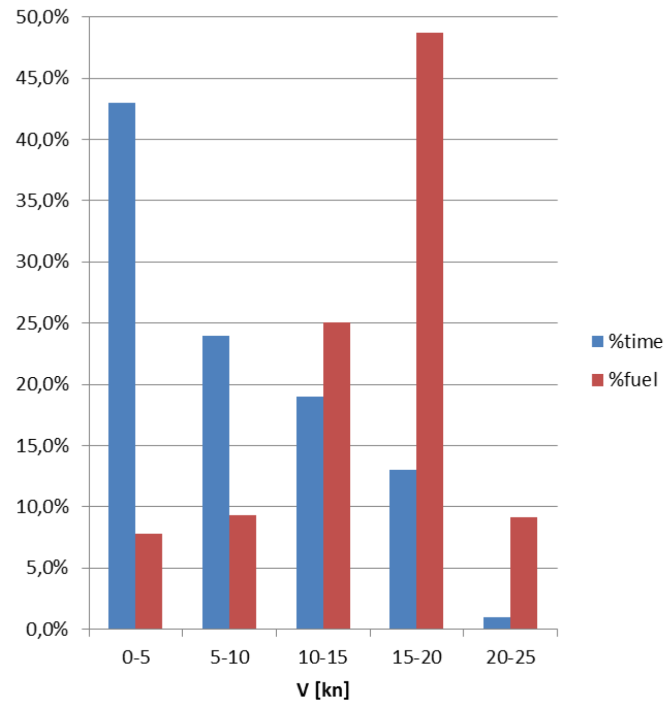


Figure 6: Fuel consumption times operational profile (without Hull Vane®)

Helicopter operations are to be carried out on these ships up to and including sea state 5. The impact of the Hull Vane® on the vertical accelerations due to pitching was evaluated when sailing 20 knots in a head sea, with regular waves with a height of 2 m and a wave period of 8 seconds, resembling a typical North-Atlantic wave condition. The Holland Class OPVs are frequently employed as coastguard vessels around the Caribbean islands of Aruba, Curaçao and Sint Maarten.
The results of this seakeeping study are represented in a video, showing the actual movements of both the benchmark vessel and the ship with Hull Vane®, along with graphs representing heave, pitch angle, vertical accelerations on the aft deck and resistance.
Experience has shown that the Hull Vane® also has a beneficial influence on the rolling motions at speed (like the bilge keels), and on the yawing motions, which will provide additional benefits for helicopter operations. The quantification of these effects was not part of this study. A follow-up study could include an analysis at speed in bow- or stern-quartering waves. It is also noted that the Holland Class OPVs are equipped with fin stabilizers designed for low-speed operation.

RHIB launch & recovery through the slipway is currently carried out at forward speeds of approximately 5 knots for the mother vessel. From the CFD study for resistance, a graphical representation of the wake at 5 knots could be extracted, allowing for a visual comparison of the benchmark vessel and the Hull Vane®-equipped vessel.


Figure 7: Slipway arrangement of the Holland Class OPVs

5. MODIFICATION TO HULL

5.a Trim wedge modification

The hull of the Holland Class OPVs is equipped with a trim wedge over the entire width of the transom. The purpose of the trim wedge is to create vertical lift, needed for the top speed of the vessel. As an alternative to trim wedges, many ships are equipped with stern flaps, ducktails or interceptors.
As a trim wedge directs the waterflow downwards, and a Hull Vane® works by generating forward thrust out of the upward flow, the base lines plan of the ship was modified by removing a part of the trim wedge. In the central part, about 50% of the depth of the trim wedge was removed, while on the sides it was slightly more. A larger part of the trim wedge was conserved in the central part, as this was needed to keep clear of the slipway. On the sides the modification was limited to keep clear of the swing area of the rudders.

The consequence of this modification is that retrofitting of a Hull Vane® to the Holland Class OPVs will require dry-docking. It is expected that the modification can be completed within a scheduled dry-docking period, and therefore would not cause additional off-hire time.
The modification to the hull design is represented in figures 8, 9 and 10, with in each case the benchmark hull at the top (or left) and the modified hull at the bottom (or right).

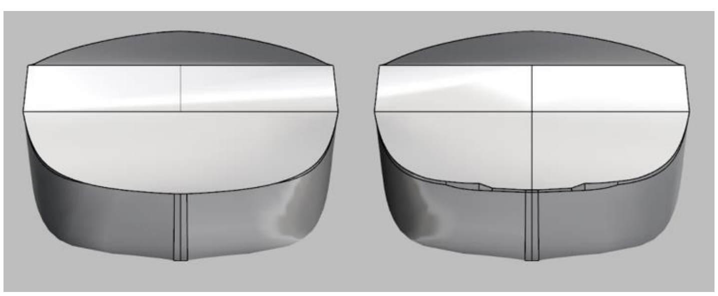


Figure 8: Aft view of stern: benchmark vs. modified

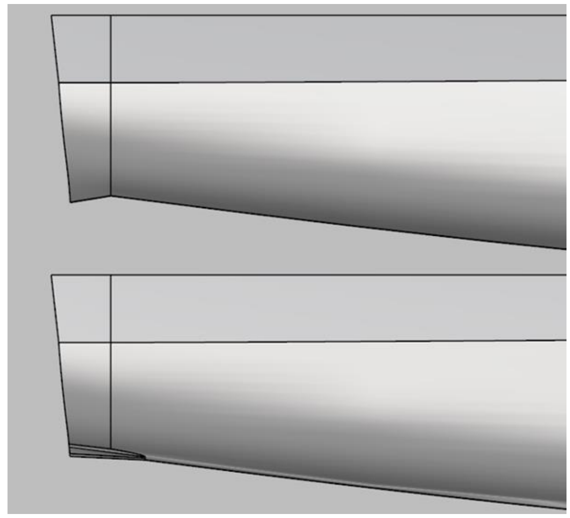


Figure 9: Side view of stern: benchmark vs. modified


Figure 10: Bottom view of stern: benchmark vs. modified

5.b Slipway extension

Because the outer struts (placed in line with the main longitudinal girders) are positioned quite far apart, and due to the high lift force on the Hull Vane®, an excessive bending moment would be generated in the connections between Hull Vane® and struts if only two struts were used. It was therefore opted to design a Hull Vane® with a three-strut configuration. On the ship's centerline, a small extension was created, consisting of a lengthening of the slipway surface on its upper side and a lengthening of the bottom surface on its lower side. This extension makes sure that a RHIB launched & recovered through the slipway will never contact the centerline strut, and that there is sufficient transversal steel structure to adequately support the centerline strut in an area with very limited height.

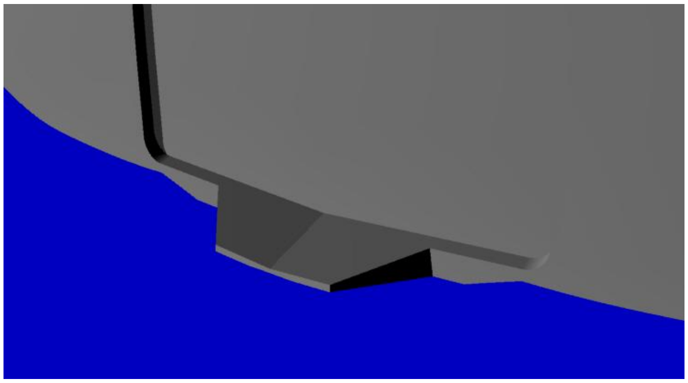


Figure 11: Slipway extension on centerline

6. RESULTS FOR STILL WATER RESISTANCE

The Hull Vane® was first designed and optimized by visualizing the flow on the bare hull at a speed of 17.5 knots. An optimization routine developed in-house by Hull Vane BV yielded the optimal position of the horizontal wing-section of the Hull Vane® for this hull shape. The CFD code used by Van Oossanen Fluid Dynamics, Fine/Marine, uses a RANS solver and is therefore able to capture viscous effects in the flow. It provides full details of the flow around the hull in terms of streamlines, pressure and force plots. In the CFD calculation, the vessel is allowed to freely trim and sink, which leads to very reliable results.

In a second phase, both the benchmark hull (with trim wedge) and the hull with Hull Vane® were analyzed in CFD with actuator disks, and including the vertical struts. The actuator disks are a simulation of the propeller flow, which is known to have an impact both on the ship's resistance and on the Hull Vane®'s performance. The vertical struts are a preliminary design, which may be improved upon in a more detailed design study.

The stern, equipped with Hull Vane® and struts, is represented in Figure 12.

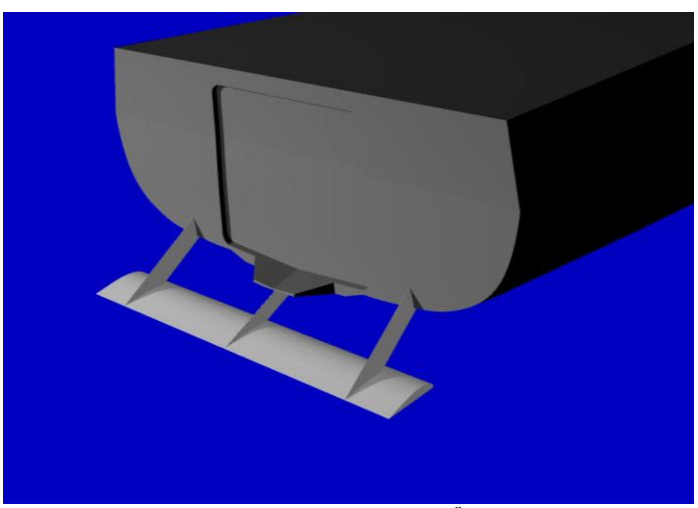


Figure 12: Stern equipped with Hull Vane®

The following figures show the output of the CFD runs at 17.5 knots, each time comparing the benchmark hull (with trim wedge) on the upper side, with the hull equipped with Hull Vane® on the lower side.

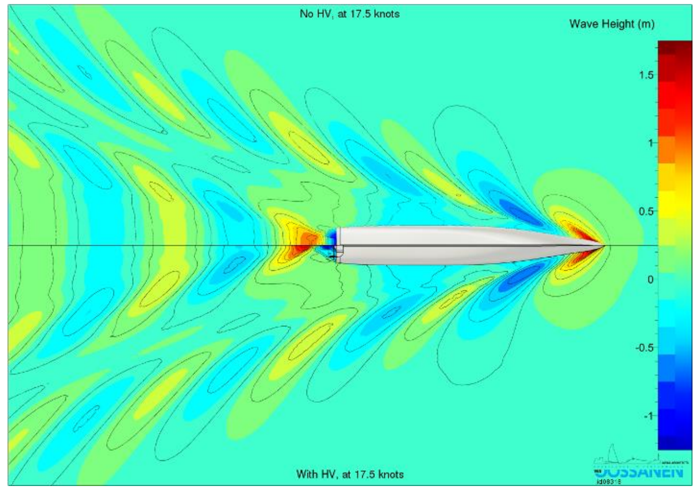


Figure 13: Wave pattern, as seen from below

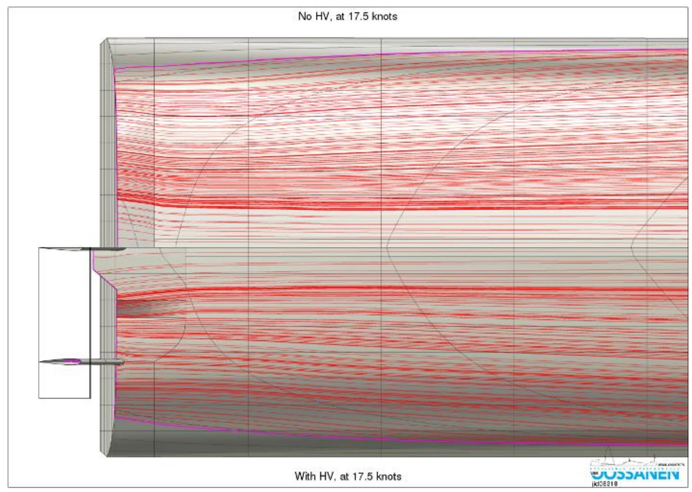


Figure 14: Streamlines on the hull at the stern, as seen from below

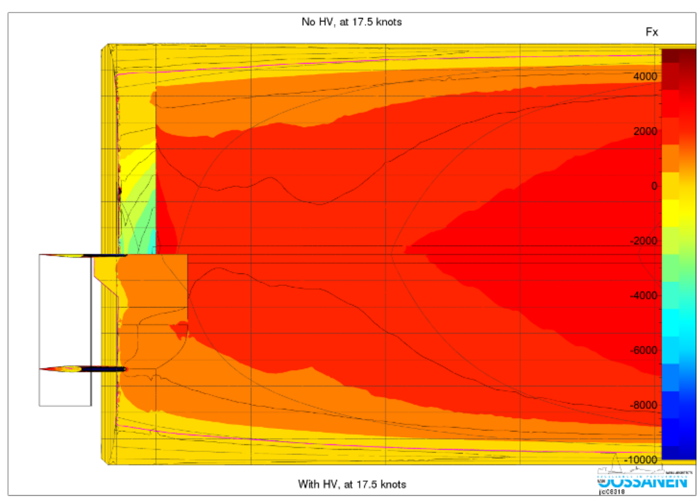


Figure 15: Colour contours of the force in X-direction, due to pressure, as seen from below

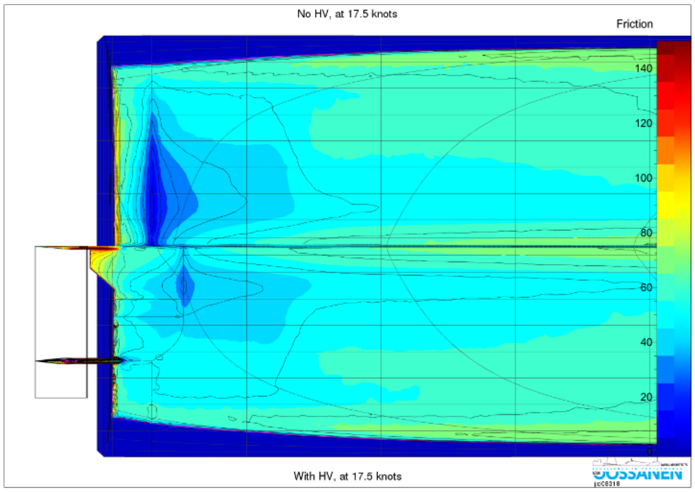


Figure 16: Colour contours due to skin friction, as seen from below

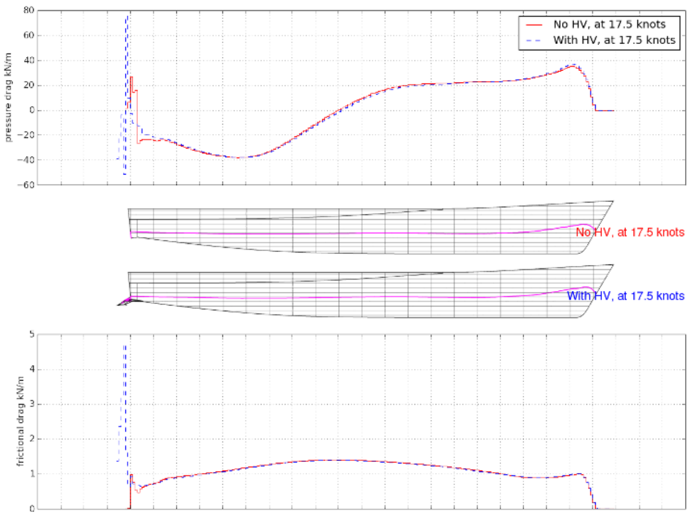


Figure 17: Longitudinal distribution of pressure and frictional force in X-direction compared

The numerical data of the CFD runs at 17.5 knots are represented in Table 4.

Table 4: Numerical results from CFD for 17.5 knots

	V_S	R_F	R_P	R	R_t	Rise	Trim
Units	knots	kN	kN	kN	kN	m	degr.
Benchmark Hull	17.5	114.3	163.8	278.1	292.0	-0.17	0.052
Hull with Hull Vane®	17.5	120.7	114.8	235.5	249.5	-0.15	0.199
Difference		+6%	-30%	-15%	-15%	+0.02	+0.15

From these figures, the following can be observed:

- Due to the addition of the Hull Vane®, the frictional resistance is increased by 6%. This is about 2% of the total resistance of the ship.
- The pressure resistance is reduced by 30%. This is about 17% of the total resistance of the ship.
- The total resistance is reduced by 15.3%.
- The trim nose-down has increased slightly, from 0.05 degrees to 0.2 degrees (the Hull Vane® generates more vertical lift than the trim wedge).

The same comparative CFD analysis of the benchmark hull and the hull with Hull Vane® was then done for the speeds of 5 knots, 12.5 knots and 22.5 knots. The results of these CFD analyses are represented in Table 5.

Table 5. Calculated resistance values using CFD

Speed	Froude number	Benchmark hull	Hull with Hull Vane®	Resistance reduction
5 kn	0.08	19.2 kN	18.9 kN	1.3%
12.5 kn	0.20	126.7 kN	109.3 kN	13.7%
17.5 kn	0.28	278.1 kN	235.5 kN	15.3%
22.5 kn	0.37	490.6 kN	436.0 kN	11.1%

Comparative CFD runs were not carried out at 7.5 knots. For the financial implications in chapter 7, a value for the resistance reduction was assumed by linear interpolation of the savings percentage at 5 knots and 12.5 knots.

It is interesting to note that the resistance at 5 knots is almost exactly the same for the benchmark hull with trim wedges and the hull with Hull Vane® (and modified trim wedges). The added surface area of the Hull Vane® increases the frictional resistance, but this is entirely compensated for by the reduction in immersed stern area, obtained by reducing the depth of the trim wedge. In many cases, the Hull Vane® will increase the resistance at low speed. It depends on the operational speed profile and the fuel consumption at each speed whether this is a negligible penalty or something to carefully consider.

The resistance reduction is highest at the optimization speed of 17.5 knots. In some Hull Vane® applications (usually newbuilding projects), the optimization speed is not chosen as described in chapter 4a, but is taken at the maximum speed of the vessel with the goal to reduce the required amount of propulsion power to achieve a given top speed.

7. RESULTS FOR OPERABILITY

7.a Influence on pitching

To determine the impact of the Hull Vane® on the vertical accelerations at the helicopter deck and the added resistance when sailing in waves, comparative CFD runs were done at 17.5 knots in regular head waves, with a height of 2 meters and a wave period of 8 seconds, as requested by DMO. The result of a CFD seakeeping study is time-dependent and therefore best visualized in a video. The video related to this study is available on the website of Hull Vane BV. Figure 18 shows a screenshot of the OPV in waves during a CFD seakeeping analysis. On the left side the benchmark hull (with trim wedge) is shown, while on the right side is the hull with Hull Vane®. To limit the computational time, the seakeeping analyses have been carried out without the struts of the Hull Vane®, hence the higher savings percentage in flat water of 17.3%. While these struts have a positive impact on directional stability, their influence on the pitching behavior is considered minimal.

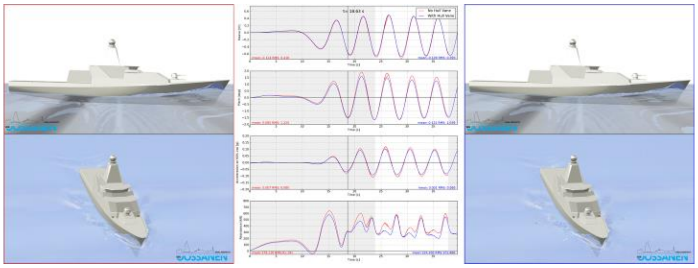


Figure 18: Seakeeping analysis for pitching

To compare the values of a signal with a highly varying value, the root mean square (RMS) of each signal is calculated. In this case, this has been done for the vessel once it reached a cyclic pitching motion. The numerical results of this seakeeping study are represented in Table 6.

Table 6: Seakeeping results

	Benchmark hull	Hull with Hull Vane®	Difference
Heave RMS (meters)	0.407	0.391	-3.7%
Pitching RMS (degrees)	1.090	1.011	-7.2%
Vertical accelerations at helicopter deck (10% Lwl) RMS (m/s^2)	0.754	0.655	-13.1%
Resistance (excl. struts) (kN)	379.2	326.1	-14%
Resistance flatwater (excl. struts) (kN)	278.1	229.9	-17.3%
Added resistance (mean) (kN)	101.1 kN	96.2 kN	-4.9%

7.b Influence on RHIB launch & recovery

The Holland Class OPVs feature a slipway with a rolling-shutter door on centerline in the transom. From the slipway, a RHIB-type FRISC can be launched & recovered while the mothervessel is underway (typically 5 knots). To see what the influence of the Hull Vane® is on this operation, the water flow at the stern was visualized at a speed of 5 knots both for the benchmark hull (with trim wedge) and the hull equipped with Hull Vane®. See figures 14 and 15 for the comparison. It was noticed that at this low speed, the transom is wet, because there is a backflow towards the stern, creating an area with turbulence. This turbulence is not desirable for the launch & recovery phase, as it impairs both the steering and thrust of the stern drives of the RHIB, particularly when it is embarking the mothervessel. From the CFD figures below, it can be observed that the turbulent zone was reduced from approximately 5 meters behind the stern to approximately 2.5 meters behind the stern.

Because the turbulent zone is significantly shorter, it is expected that the RHIB will be more controllable during the launch & recovery phase when the Hull Vane® is installed.

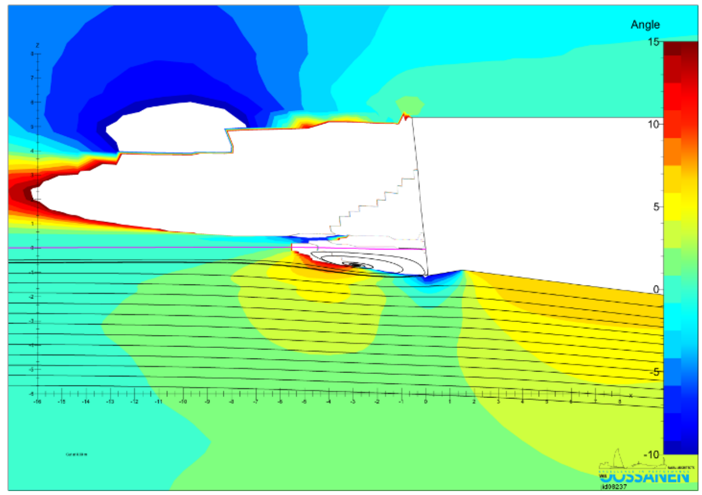


Figure 14: Turbulent zone behind transom (on CL) without Hull Vane®

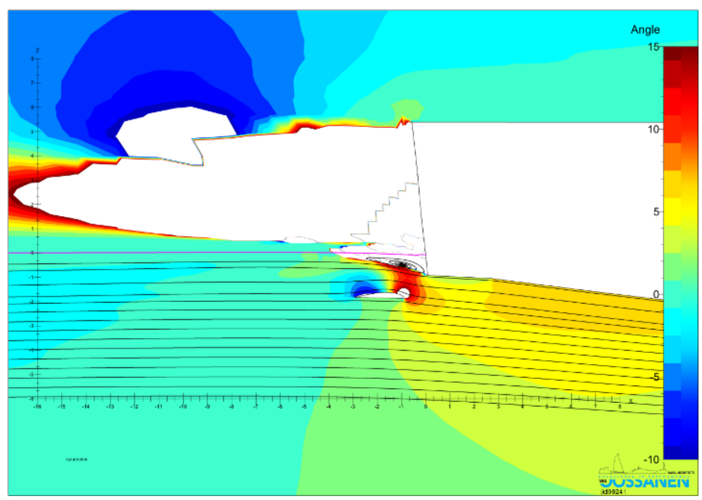


Figure 15: Turbulent zone behind transom (on CL) with Hull Vane®

7.c Influence on range and top speed

The range of the Holland Class OPVs is currently 5,000 nautical miles at 15 knots in sea state 3. The value for the savings percentage at 15 knots was obtained by interpolating the results for 12.5 and 17.5 knots in flat water and is therefore assumed to be 14.5%. It is not known what the effect of sea state 3 is on the savings percentage, but it is assumed that the added resistance is minimal in those conditions, so we have used the savings percentage calculated for flatwater. With the total fuel capacity

unchanged, the Hull Vane will then increase the range of the vessel from 5,000 nm to 5,850 nm. This can lead to more efficient operations, as refueling stops will be needed less frequently.
At the top speed of the vessel, the reduction in required power is 11.1%. With the current total installed propulsion power (10,920 kW), a maximum speed of 21.5 knots can be achieved. Around the top speed, the required propulsion power per additional knot is 1,900 kW. The top speed of the vessel will therefore be increased from 21.5 knots to 22.1 knots.

8. COST-SAVING ANALYSIS FOR RETROFIT

The Holland Class OPVs have a hybrid propulsion installation. At speeds up to 9 knots, the vessel is driven in diesel-electric mode, shutting down the main engines and driving the propellers through electric motors connected to a PTI on the main gearbox. At speeds above 10 knots, her two main diesel engines - coupled directly to the gearboxes - provide the propulsion power. The propellers are of the controllable pitch type.
Due to the controllable pitch propellers, the main engines' speed (rpm) is not linked to the propeller curve, and an efficient working point can be chosen at any speed. It is therefore safe to assume that the savings percentage in fuel consumption is almost identical to the savings percentage in resistance.
Comparative CFD runs were not done for the speed of 7.5 knots, as it is quite close to 5 knots. For the savings percentage at 7.5 knots, a value was obtained by linear interpolation of the savings percentages at 5 knots and 12.5 knots.
The obtained annual saving on the fuel consumption, based on the measured operational profile, is 12.5%. The calculation of this figure is presented in Table 7.
If the same calculation is done for the theoretical operational profile, an annual saving on the fuel consumption of 13.1% is obtained.

Table 7. Calculated fuel saving as percentage of total Annual Fuel Consumption (AFC) without and with Hull Vane

Speed	Operating profile	AFC without Hull Vane	Fuel savings generated with Hull Vane	AFC with Hull Vane as % of total AFC without Hull Vane
5 kn	43%	7.8%	1.3%	7.7%
7.5 kn	24%	9.3%	5.4%	8.8%
12.5 kn	19%	25.1%	13.7%	21.6%
17.5 kn	13%	48.7%	15.3%	41.2%
22.5 kn	1%	9.1%	11.1%	8.1%
Total	100%	100%		**87.5%**

The results of Table 7 are graphically represented in Figure 16, where the fuel saving corresponds with the difference between the red and green bars.

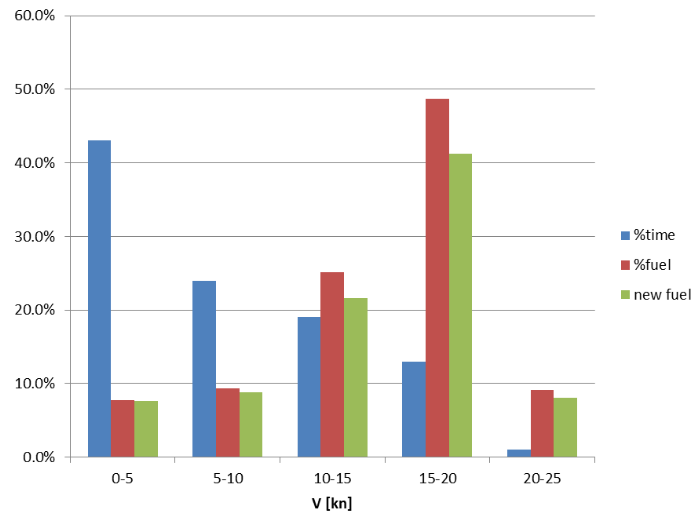


Figure 16: Fuel consumption before (red) and after (green) installation of Hull Vane® divided over measured operational speed profile

Accounting for further information provided by DMO such as realistic maintenance periods, the annual number of days at sea, the fuel consumption per day at sea (from a propulsion point of view), and the fuel price results in an estimated annual fuel consumption at a total cost of approximately 2,054,000 € per ship per year.

Based on the measured operational speed profile, the Hull Vane saves 12.5% of this amount, which translates to **257,000 € saved per year**.
Based on the theoretical operational speed profile, the savings percentage is higher, because more high-speed sailing time was estimated. The Hull Vane® would then save 13.1% of fuel, amounting to **270,000 € per year**.
Because reducing the fuel consumption reduces emissions on all fronts by an equal percentage, such as CO_2, NOx, particulate matter, etc. there is a clear ecological benefit to the application of the Hull Vane. The CO_2-emissions saved per vessel per year will be about 1,060 tons.

The four Holland Class OPVs were commissioned around 2011, and were designed for a lifetime of 30 years, which is common practice for naval vessels. This means that each of them has a remaining lifetime of at least 25 years. The required time for both maintenance and capability upgrades means that only 87.5% of the remaining lifetime will be used in service, thus bringing the remaining active service time of each vessel to about 22 years.
Based on the abovementioned fuel cost parameters this means that the Hull Vane® will generate fuel cost savings of 5.65 million € to 5.92 million € per ship, or **22 to 24 million €** for the whole fleet of four vessels, based on the current fuel prices (July 2015).

9. INVESTMENT

Due to the modifications to the current hull shape and therefore the amount of additional structural work involved, it was not possible to accurately estimate the investment cost at this early stage. However, it is expected that the initial investment will be paid back in two to three years in fuel savings alone.

As discussed in chapter 7, the Hull Vane® would be worth considering for the operational benefits even if there was a net cost to it, but chapter 8 elaborates on the Hull Vane® being paid back in fuel savings, and this many times over. As there are no moving parts on the Hull Vane®, and therefore no significant maintenance costs or long-term risks, it can be considered a safe investment. The only risk to the profitability of the Hull Vane® is a collapse of the oil prices, but this would not be a risk to the profitability of the ship owner, in this case the RNlN. Even if the Hull Vane® would then yield less significant returns in fuel savings, it would still have the same positive impact on the operability of the vessel and on the reduction in harmful emissions.

10. COST-SAVING ANALYSIS FOR NEW SHIPS

Were the Holland Class series of ships not yet built, but currently in the design stage, the cost analysis would be significantly more favorable for the following reasons:

1. Optimization of the hull lines in conjunction with the Hull Vane® would most likely lead to higher savings percentages. For the retrofit case, the modifications were limited to a small alteration of the trim wedge.
2. To achieve a given top speed, the installed propulsion power could be reduced by the savings percentage at top speed. The cost savings in installed engine power, exhaust systems, shaft lines and cooling systems would most likely exceed the investment cost of the Hull Vane®, possibly even generating a net profit before the ship has been launched.
3. To achieve a given range (autonomy), the fuel tank capacity could be reduced by the same percentage as the fuel saving at cruise speed. This would lead to more useable space onboard.
4. The modifications to the vessel would not be an extra cost as these would be incorporated in the design from the beginning.
5. The Hull Vane® would generate savings over the entire lifetime of the vessel.

11. CONCLUSIONS

This paper, and the underlying CFD study, have demonstrated that the Holland Class OPVs of the RNlN represent an excellent application of the Hull Vane®, in spite of the fact that the vessels sail most of the time at a low speed. Not only will the Hull Vane® help to achieve a significant reduction in fuel costs and in emissions (both by 12.5%), it will also improve the comfort onboard and the safety of critical operations such as launch & recovery of the RHIB (through the slipway) and helicopter.

The top speed of the vessel will be slightly increased from 21.5 knots to 22.1 knots and the range of the vessel will be increased from 5,000 nautical miles (at 15 knots) to 5,850 nautical miles (at 15 knots). Both of these higher values can provide significant tactical advantages.

The initial investment to retrofit a Hull Vane® to these vessels is relatively small, compared to the returns in the long term.

While the Hull Vane® is relatively easy to retrofit to existing ships such as the Holland Class OPVs, the advantages are even greater in case of a newbuilding project.

For naval ships with signature and shock requirements, the Hull Vane application would obviously require more detailed studies than performed within this case study. DMO has indicated that they will certainly consider the Hull Vane for their future newbuilding projects.

12. ACKNOWLEDGEMENTS

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