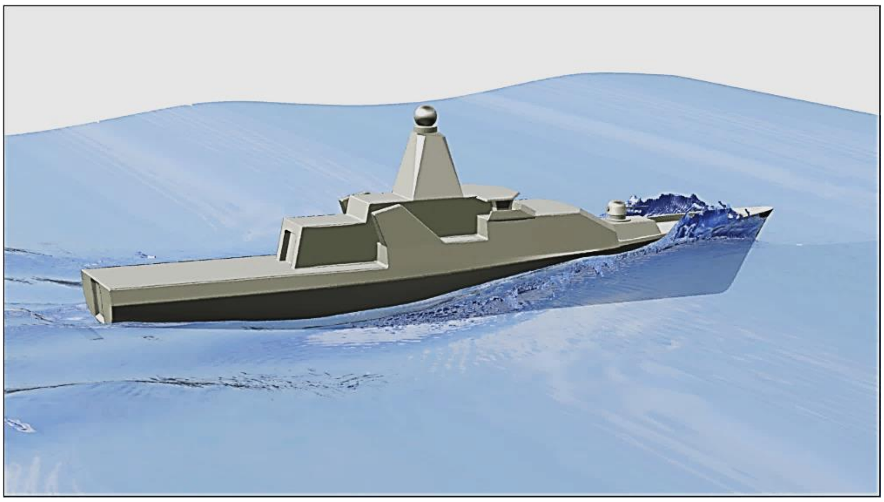
Hull Vane® on 108m Holland-Class OPVs: Effects on Fuel Consumption and Seakeeping

B Bouckaert, MSc SNAME, *Hull Vane BV*, **K Uithof**, MSc, *Hull Vane BV*, **N Moerke**, MSc, *Van Oossanen Fluid Dynamics*, **P G van Oossanen**, BSc, *Van Oossanen Naval Architecture*



SYNOPSIS

The consequences of applying a Hull Vane® to a Holland Class 108 m Oceangoing Patrol Vessel of the Royal Netherlands Navy are studied by means of a Computational Fluid Dynamics study using Fine/Marine. The effect on the annual fuel consumption is determined by linking the savings percentages at several speeds to the operational speed profile. This paper demonstrates that a reduction in total fuel consumption can be achieved of 12.5% if a Hull Vane® is installed. At the speed at which most fuel is consumed annually (17.5 knots), the total resistance is reduced by 15.3%. Further operational benefits are 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). Seakeeping analyses with and without Hull Vane® are performed in regular head waves of 2 m and 4 m, both at a speed of 17.5 knots. Roll decay tests were done to determine the roll damping at zero speed and at 17.5 knots.

INTRODUCTION

Many navies and coastguard agencies are currently faced with conflicting requirements. Political instability in various regions of the world has led to increasing demands on their fleets, leading to more frequent deployments e.g. in anti-piracy and border patrol missions. At the same time, governments have in many cases reduced the available budgets, and have imposed ambitious emissions reduction goals. The easiest way to reduce fuel costs and CO_2 emissions is to sail slower or not to sail at all. This measure has already been implemented as far as possible, and further speed reductions would reduce the fleet's capabilities or would require an increase in the number of ships in the fleet – leading to extra costs. Navies and coastguards are looking for ways to reduce their fuel consumption - and therefore their fuel costs and emissions - without impacting on their operability. In the past fifteen years, the advancement of Computational Fluid Dynamics software has led to innovations which can significantly improve the performance of fast displacement vessels. The Hull Vane® is one of them. Recent research has shown that it is not only beneficial for the ship's resistance, but also has a positive impact on the seakeeping characteristics of a vessel.

HULL VANE® BACKGROUND

The Hull Vane® is an energy saving device in the shape of a hydrofoil, invented by Dr. Peter van Oossanen in 1992[i]. Years of development – initially for America's Cup sailing yachts – led to a first patent application in 2002. In later years, the use of Computational Fluid Dynamics (CFD) software helped understand and optimise the Hull Vane® until it was launched commercially in 2014, coinciding with the launching of two vessels equipped with Hull Vane®, a 42 meter motoryacht and a 55 m Fast Supply Intervention Vessel.

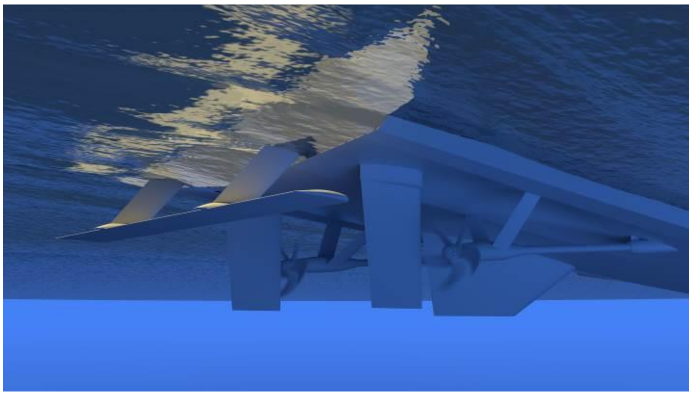


Figure 1 - A typical Hull Vane configuration

While the Hull Vane® looks similar to a hydrofoil, it is used on a different type of ship (heavier), in a different location (at the stern) and with different goals than a conventional hydrofoil (not just vertical lift). The Hull Vane® reduces the overall resistance by four distinct effects:

1. The foil generates a forward-angled lift force out of the upward flow under the aftbody of the vessel. The horizontal component of this lift provides forward thrust. The thrust force is represented as $FX_{,HV}$ in Figure 2.

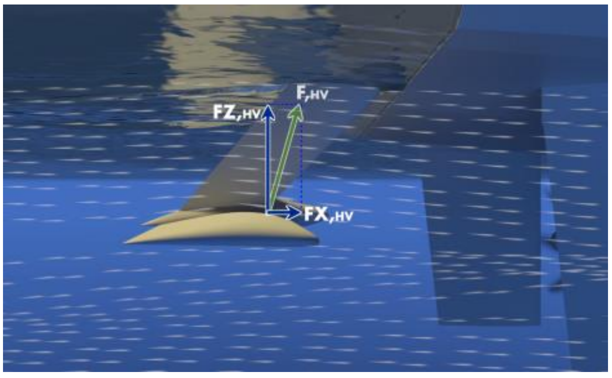


Figure 2 - Thrust force from the angled lift force

2. The hydrofoil influences the wave pattern. By reducing the stern wave, it reduces the wavemaking resistance of the ship. This can be seen inFigure 3, for a 55 m vessel sailing at 20 knots.

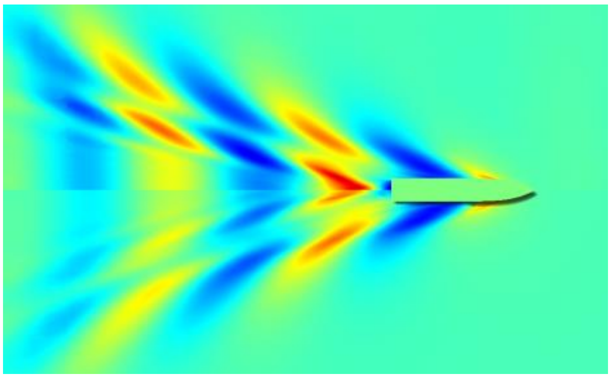


Figure 3 – Typical wave profile without (top) and with (bottom) Hull Vane®

3. The vertical component of the lift generates a bow-down moment in a more efficient way than trim wedges, stern flaps or interceptors.[iii]

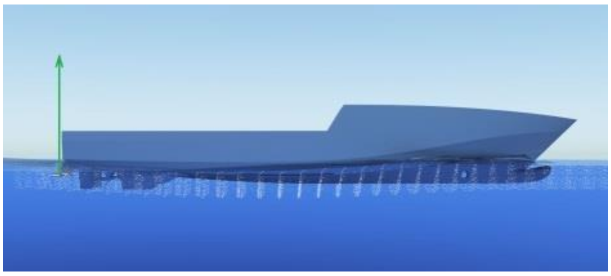


Figure 4 - Trim correction

4. The Hull Vane® dampens the ship motions such as pitching, rolling and yawing when sailing in waves, and therefore reduces the added resistance caused by these motions.

Figure 5 - Pitching motions in waves are dampened

Sea trials with and without Hull Vane® on the 55-metre Fast Supply Intervention Vessel MV Karina (Figure 6) – which is also available as an Offhsore Patrol Vessel with identical principal dimensions – confirmed a reduction in power of 10% at 12 knots, which increased up to 15% at 21 knots. During the sea trials, speed runs were done at various speeds, with shaft power measurements carried out by Belkoned, a Dutch company specialised in independent verification and reporting of sea trials.

Figure 6 - Karina during sea trials with Hull Vane®

The 42-meter motoryacht Alive, of which the stern is pictured in Figure 7, confirmed her frugal fuel consumption figures during sea trials, but because the Hull Vane® is integrated into the construction, sea trials without Hull Vane® could not be carried out. From CFD computations, it is known that the Hull Vane® induces a resistance reduction of more than 20% in the yacht's most used speed range (12 to 16.5 knots).

Figure 7 - MY Alive with Hull Vane® under transom

HOLLAND-CLASS OPV'S

The Holland-Class Oceangoing Patrol Vessels series consists of four vessels, developed by the Defence Materiel Organisation (of the Royal Netherlands Navy) and Damen Schelde Naval Shipbuilding. The vessels were built to provide an economical platform for duties such as coastal patrolling, anti-piracy and search & rescue missions. These tasks were previously performed by frigates, which were overqualified for the job, and therefore too costly. The ships have a top speed of 21.5 knots, a range of 5.000 nautical miles at 15 knots and are equipped with a NH-90 helicopter (in a hangar) and two RHIB-type interceptor craft, of which one is launched over the side and the other from a stern slipway. A picture of the lead vessel in the series, HNLMS Holland (P840) is shown in Figure 8.

Figure 8 - HNLMS Holland P840 Copyright Damen Shipyards

OPERATIONAL PROFILE

A Hull Vane® study was done on the Holland-Class of Oceangoing Patrol Vessels[ii]. Similar to other fuel saving devices, such as the bulbous bow, the Hull Vane® is optimised 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 an operational speed profile of one of the ships. Multiplying this operational profile with a characteristic fuel consumption value for each speed in the range gives an indication of the annual fuel use at each speed. This is represented in Figure 9. From the figure, it can be clearly seen that although the vessel sails 86% of the time at a speed below 15 knots, the majority of the fuel (58%) is consumed in the 14% of time spent sailing faster than 15 knots. Based on this graph, it was decided to choose 17.5 knots as the optimisation speed for the Hull Vane®.

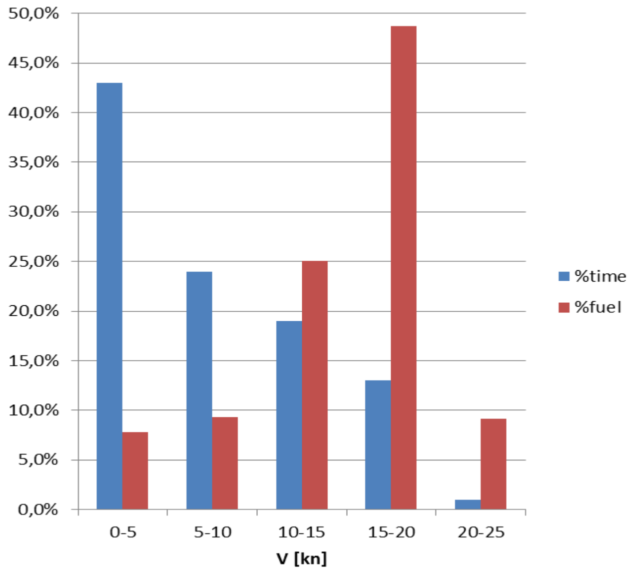


Figure 9 – Graph representing fuel consumption per speed range

MODIFICATION TO HULL

Two modifications were done to the ship's hull shape. The trim wedge at the stern, which was originally optimised by model testing for the top speed of the vessel, was partially removed, to the extent allowable taking into account the slipway in the transom. This modification is shown in Figure 10. A trim wedge and a Hull Vane® do not work well together, as the trim wedge deflects the flow downwards. The second modification was done to create a solid basis for the strut on centreline. The Hull Vane® is sometimes built with two, sometimes with three struts. In this case, the combination of the Hull Vane® span, the ship speed, and the distance between the longitudinal girders required a third strut on centreline. To create a solid basis for the centreline strut and to avoid any interference with the RHIB launching operations, the bottom was slightly lengthened in the central part (aligned with the reduced trim wedge), and on the top side, the slipway was lengthened. This modification is shown in Figure 11.

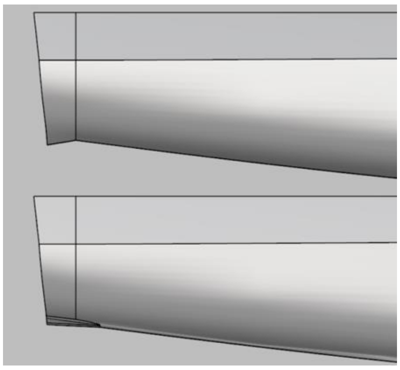


Figure 10 - Trim wedge modification

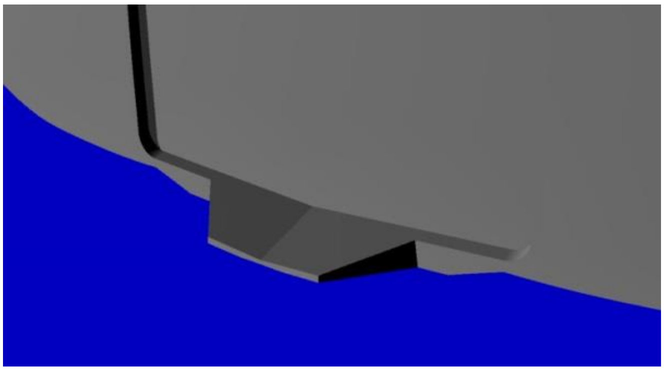


Figure 11 - Bottom lengthening for centre strut

HULL VANE DESIGN AND PERFORMANCE

The Hull Vane® was optimised using a variation of positions and angles of attacks. In total, 32 CFD computations were carried out in flat water to obtain a good result at 17.5 knots and verify its performance at 5 knots, 12.5 knots and 22.5 knots.

CFD computations with and without the chosen Hull Vane® at 17.5 knots showed a reduction in total resistance of 15.3%, in spite of an increase in viscous resistance of 5.6%. The achieved resistance reductions for the other speeds are shown in Table I.

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%

Table I - Resistance reductions with Hull Vane

The resistance reduction is highest at the optimisation speed of 17.5 knots. In some Hull Vane® applications (usually newbuilding projects), the optimisation speed is not chosen based on the operational profile, 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.

All CFD work was carried out by Van Oossanen Fluid Dynamics, using the Fine/Marine software from Numeca. This software code is based on a RANS solver, including both viscous and pressure resistance, and with the model free to trim and heave. Furthermore all CFD computations (except for initial runs during the optimisation phase) were done including actuator disks to simulate the effect of propeller wash over the Hull Vane® and struts. Figure 12 shows the rotation generated in the streamlines when passing through the actuator disks and consecutively over the Hull Vane®.

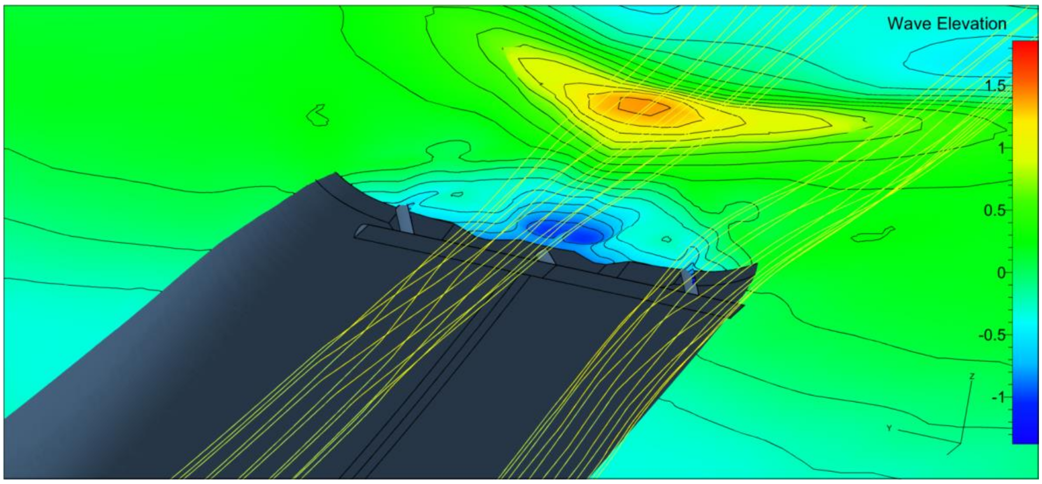


Figure 12 Actuator disk effect on Hull Vane®

The effect on the annual fuel consumption in each speed range, along with an estimated performance (based on linear interpolation) at 7.5 knots are shown in Table II, where AFC stands for Annual Fuel Consumption, showing a reduction of 12.5% on a yearly basis. The results of Table II are graphically represented in Figure 13, where the blue bars represent the operational profile, the red bars represent the current fuel consumption and the green bars represent the fuel consumption after retrofitting of the 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%**

Table I - Savings on annual fuel consumption with Hull Vane

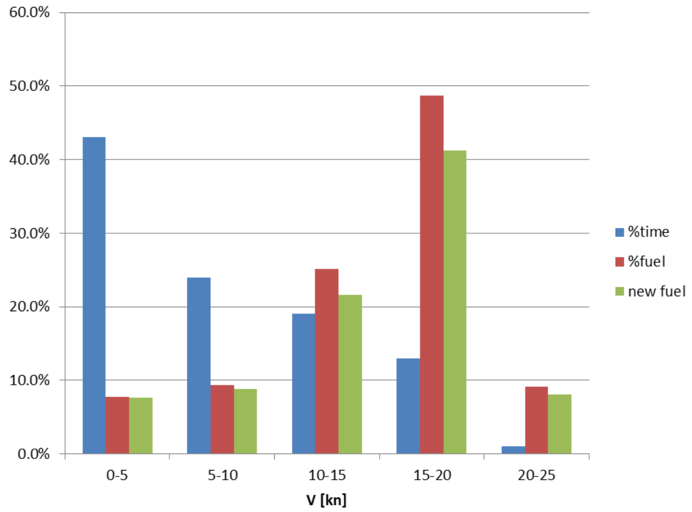


Figure 13 - Impact on fuel consumption per speed range

The geometry of the Hull Vane® for the Holland-Class OPV is represented in Figure 14. Noteworthy is the fact that the Hull Vane® even generates a small resistance reduction at the lowest speed of 5 knots. For vessels with a lower top speed it is often difficult to achieve resistance reductions with the Hull Vane® at Froude numbers below 0.2. The reason for the Holland Class being a positive exception lies in the reduction of the trim wedge. The increased immersed transom area of the original trim wedge causes a larger resistance penalty at low speed than the added wetted surface and pressure resistance of the Hull Vane®. The consequence is that the combination of the adjusted aft ship and Hull Vane® reduces the resistance over the entire speed range of the vessel. However, in Figure 13 can be observed that a small resistance penalty at lower speeds can be justifiable if large savings can be achieved at higher speeds.

Figure 14 - Hull Vane configuration on Holland-Class OPV

A preliminary structural analysis was carried out, which aside from confirming the need for the third strut on centreline, indicated that the design is buildable with grade S460N steel in normal thicknesses and internal strengthening. Due to the third strut and relatively high chord/span ratio of the elements composing the Hull Vane®, the natural frequency of the Hull Vane® is relatively high and will be out of the excitation frequency of the propellers. This will be studied more in detail in future work. Slamming loads on the Hull Vane® were not taken into account and will be investigated. In this respect, it is to be noted that the Hull Vane® is positioned almost a meter below the deepest point of the transom (and almost two meters below the static waterline), and will only emerge from the water during very severe stern slamming events. At the same time, it is expected that the Hull Vane® will reduce the probability of stern slamming during low-speed sailing as its large submerged surface area counteracts the vertical movement of the stern. In the current configuration, the Hull Vane® protrudes less than three meters beyond the aftmost point of the vessel. It is expected that a “swim platform” or bullbar construction will be built above the waterline to give a visual reference of the underwater dimensions and to protect the Hull Vane® from other vessels or harbour walls.

Based on the results of the CFD computations, the influence on the ship's range and top speed was calculated. The range will increase from 5.000 nm at 15 knots to 5.850 nm and the top speed will be increased from 21.5 knots to 22.1 knots. The silent speed (the maximum speed at which the ship can sail in diesel-electric mode) is increased by about 0.5 knots. The reduced backwash at 5 knots reduces the turbulent zone just behind the transom by about 50% and will make the launch and recovery of a RHIB from the stern slipway safer, as its propeller (or waterjet) will be in a clean flow for a longer time.

EFFECTS ON SEAKEEPING – PITCHING & HEAVING

Model tests and CFD studies in waves have indicated a positive effect on the seakeeping behaviour from the Hull Vane®. On smaller vessels, such as the 55 m Fast Supply Intervention Vessel *Karina*, this can amount to a reduction in vertical accelerations of 20% (on the aft deck) and 10% (in the forward accommodation), at a speed of 20 knots (regular waves, Hw = 1.0m, period 5.7 s). The added resistance caused by pitching and heaving was reduced by 29%.

For the Holland-Class OPV's, CFD computations were done in two wave conditions, both with the benchmark hull (with trim wedge) and the challenger hull (with Hull Vane®). To limit the computing time, the struts were not included and these CFD computations are without actuator disks for the propellers. The wave conditions were the following:

- Regular head waves of 2 meters with a period of 8 seconds
- Regular head waves of 4 meters with a period of 8 seconds

As the computations in waves are time-dependent, these are usually presented in the form of videos. Screenshots of these can be seen in Figure 15 and Figure 16. On the left-hand side, the motions of the benchmark vessel are visualised, on the right-hand side, the motions of the challenger vessel (with Hull Vane®) are visualised. In the central portion, four graphs are shown, indicating respectively (top to bottom) the heave signal, the pitch signal, the vertical accelerations at 10% of the waterline length (where the helicopter platform is located) and the total resistance. The red curve indicates the values for the benchmark vessel and the blue curves those for the challenger vessel (with Hull Vane®).

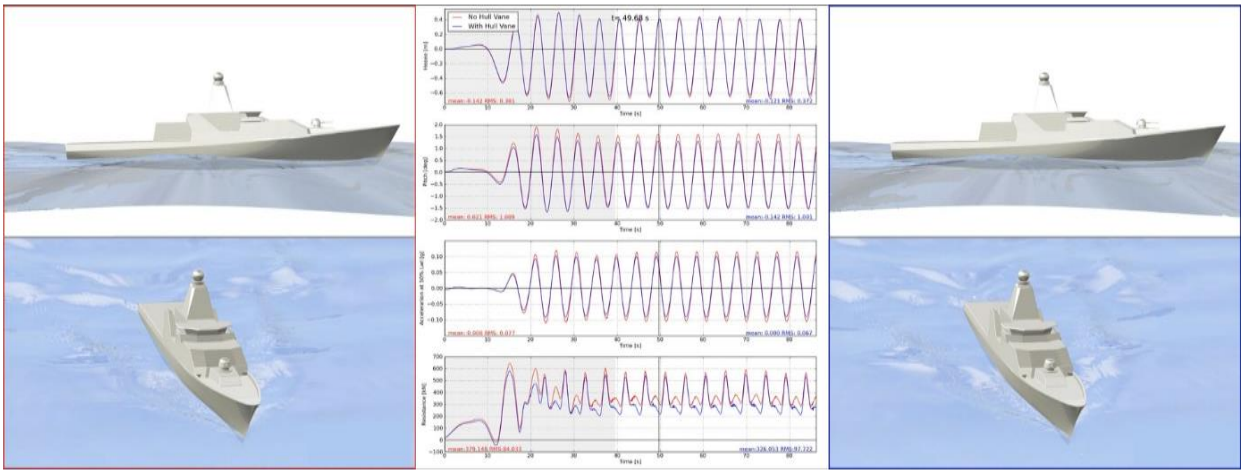


Figure 15 - Seakeeping analysis in 2m head waves

At sea, the vertical accelerations on the helideck are continuously monitored onboard with accelerometers and their readings determine whether helicopter operations can still be safely executed or not. The Royal Netherlands Navy therefore has a strong interest in reducing the vertical accelerations, as it broadens their operational envelope. A close-up of the graphs for vertical accelerations and total resistance in the 4-meter wave condition can be seen in Figure 17.

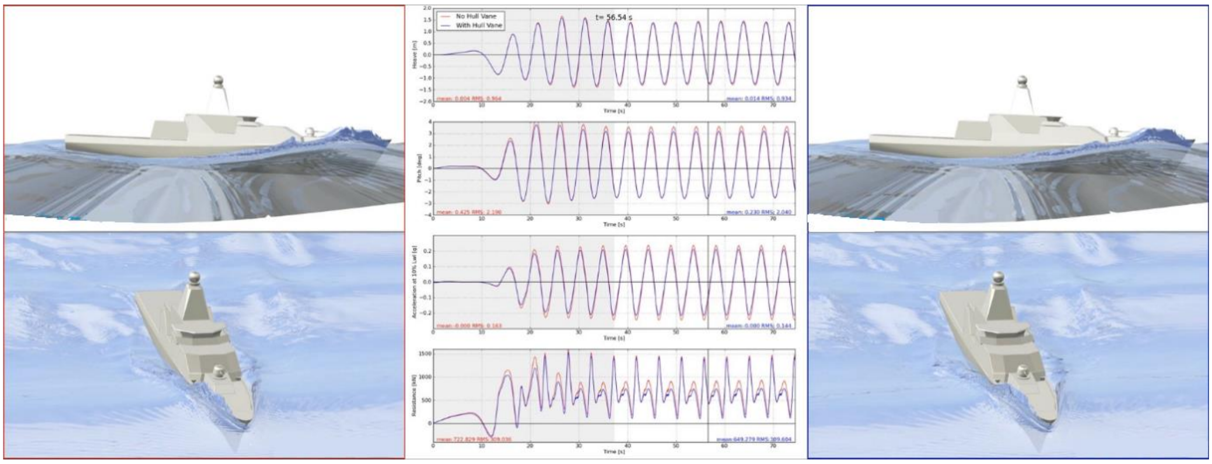


Figure 16 - Seakeeping analysis in 4 m head waves

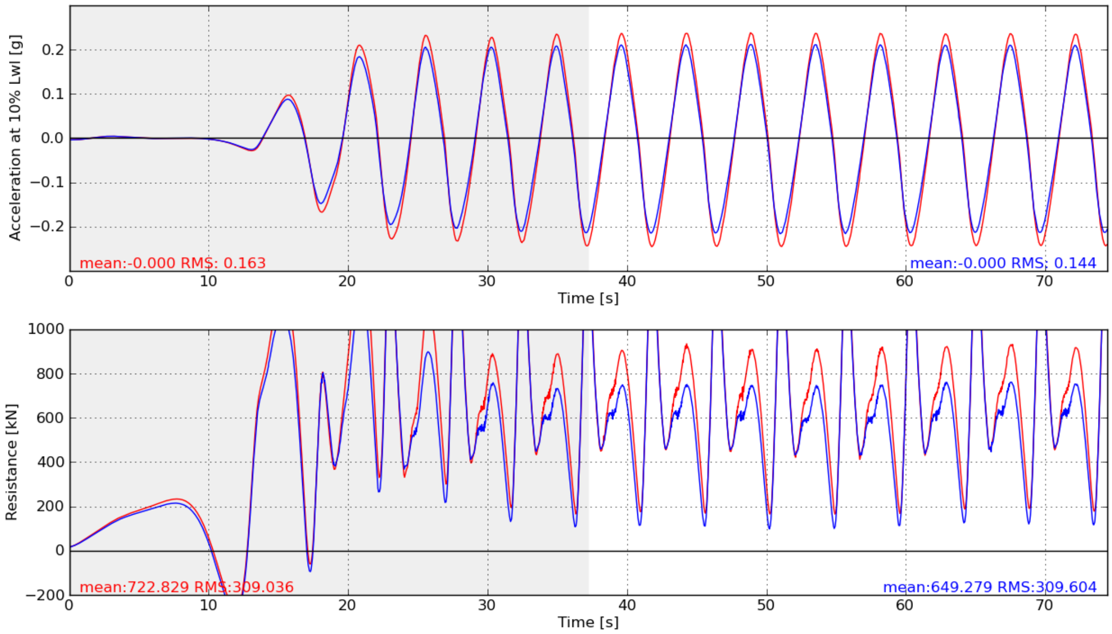


Figure 17 - graphs for vertical accelerations and resistance in the 4-m wave case

The results of the computations for 2-meter and 4-meter waves are represented in Table II and Table III. For the values of pitching, heaving and vertical accelerations, the RMS (root mean square) is calculated as an average value. For the resistance, a mean value is calculated. The RMS and mean values are computed over a period of eight wave encounters, which begins after the vessel has reached a steady motion. In the graphs above, this is the white area, following the run-up in the grey area.

Waves: 2 m, 8 s	Benchmark hull	Hull with Hull Vane®	Relative difference
Heaving RMS (meters)	0.381	0.372	-2.4%
Pitching RMS (degrees)	1.089	1.001	**-8.1%**
Vertical **accelerations** at helicopter deck (10% Lwl) RMS (g)	0.077	0.067	**-13.1%**
Resistance, mean value (excl. struts) (kN)	379.2	326.1	-14%
Resistance flatwater (excl. struts) (kN)	278.1	229.9	-17.3%
Added resistance, mean value (excl. struts) (kN)	101.1	96.2	**-4.9%**

Table II - Seakeeping results for 2 m waves

Waves: 4 m, 8 s	Benchmark hull	Hull with Hull Vane®	Relative difference
Heaving RMS (meters)	0.964	0.934	-3.1%
Pitching RMS (degrees)	2.19	2.04	**-6.8%**
Vertical **accelerations** at helicopter deck (10% Lwl) RMS (g)	0.163	0.144	**-11.7%**
Resistance, mean value (excl. struts) (kN)	722.8	649.3	-10.2%
Resistance flatwater (excl. struts) (kN)	278.1	229.9	-17.3%
Added resistance, mean value (excl. struts) (kN)	444.8	419.4	**-5.7%**

Table III - Seakeeping results for 4 m waves

From the results of the seakeeping computations in CFD and observation of the videos, the following conclusions can be drawn:

- The vertical accelerations on the helicopter deck are reduced by 13.1% in two-meter waves and by 11.7% in four-meter waves. This is a clear improvement for the helicopter operations.
- The pitching motion is reduced by 8.1% and 6.8% respectively, which will reduce the probability of slamming and of shipping green water on deck.
- The added resistance is reduced more in the higher wave condition (5.7% versus 4.9%).

EFFECTS ON SEAKEEPING – ROLL DAMPING

Experience gained from the 42 m motoryacht Alive already indicated that a roll damping effect could be expected from the Hull Vane®. Intuitively, it can be expected that the wingtips of the Hull Vane® have a similar effect as the bilge keels. This effect however had not been quantified. In order to quantify the roll-damping effect of the Hull Vane® for the Holland-Class OPV's, roll decay tests were carried out in CFD, both at standstill (zero speed) and at a speed of 17.5 knots. Like roll decay tests in a towing tank, this is done by giving the hull an initial heel angle (of 10 degrees) and then recording the motions it makes until it is back in the neutral position. As for the pitching/heaving behaviour, this is visualised in a video, of which a screenshot can be seen in Figure 18 for zero-speed roll damping and in Figure 19 for roll damping at speed. In these CFD computations, the struts were included, as they are likely to have an effect on the roll damping. The ship is free to roll, trim and heave.

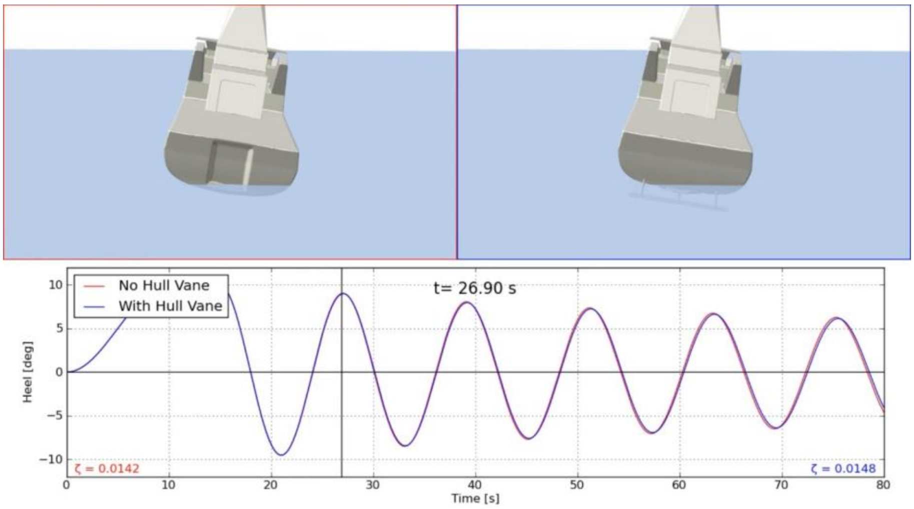


Figure 18 - Roll decay test at zero speed

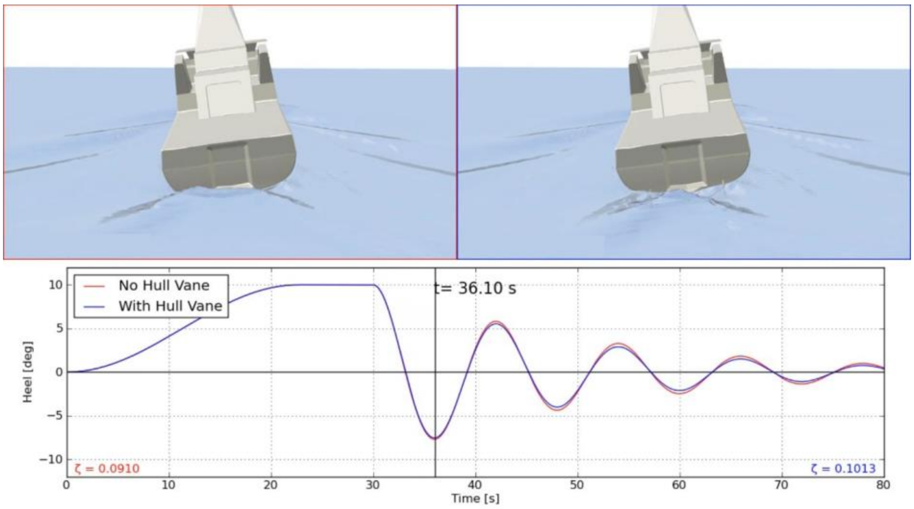


Figure 19 - Roll decay test at 17.5 knots

For both cases, the roll damping coefficient was calculated. In the zero-speed case, it increased from 0.0142 to 0.0148, which represents a marginal increase of 4.1%. As for bilge keels, the effect is stronger when the ship has forward speed. At 17.5 knots, the roll damping coefficient increased from 0.0910 to 0.1013, an increase of 11.4%. Other appendages such as rudders and bilge keels were not included in this calculation. If these are taken into account, the percentage of increase in roll damping factor caused by the Hull Vane® will be smaller, as the benchmark vessel will have a higher roll damping itself.

The Holland-Class OPV's are equipped with fin stabilizers, which are designed to be effective at low speeds. It is therefore expected that the influence of the Hull Vane® on the roll motions of the Holland Class vessels will be negligible.

CONCLUSION

For the resistance characteristics, as well as the ship's seakeeping (heaving, pitching and rolling motions), it is clear that the Hull Vane® will have a positive effect on the performance of the Holland-Class OPVs. Contrary to many appendages designed to improve the seakeeping behaviour of a vessel (bilge keels, course fins, etc.), the Hull Vane® does not carry a resistance penalty. On the contrary, it significantly reduces the resistance and – by approximately the same amount – the fuel consumption and emissions of the vessel.

Due to a combination of a wide operating profile and high demands for seakeeping, naval ships and coastguard vessels usually have hull shapes which can benefit significantly from the addition of a Hull Vane®. The Hull Vane® will allow navies to achieve their targets for cost and emission reductions, while at the same time improving the safety and comfort onboard. In retrofit applications, the Hull Vane® is an investment in fuel efficiency with a very short payback period, often less than a year for naval ships. On newbuild vessels, the Hull Vane® will often already be paid back by cost savings during the build, as it allows to install less propulsion power to achieve the same top speed.

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BIOGRAPHY

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

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 an MSc in Maritime Technology from Delft University of Technology (with distinction), and an MSc in Management from the Rotterdam School of Management.

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 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 BV. 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.