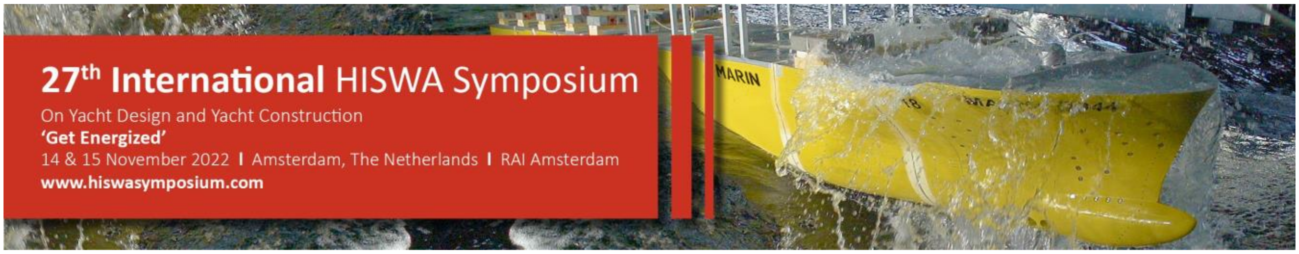

Enhanced Dampening of the Pitch Motions with an Actively Controlled Hull Vane

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Figure 1 - Dynamic Hull Vane

SUMMARY

Among other characteristics, a main performance parameter of a yacht is comfort. The parameter is dominated by ship motions. Besides a well-designed hull, several appendages can be used to increase performance. One of these is the Hull Vane®, a patented energy-saving and seakeeping device which consists of a submerged wing mounted on the aft ship. The Hull Vane® is an appendage with the potential to create large lift forces on the aft of the ship, thereby changing the resistance and dynamic position of the vessel. The goal of this study is to investigate the potential of further pitch and heave motion reductions, by enabling the Hull Vane® to rotate, so the lift of the Hull Vane® is varied. The solution is called Dynamic Hull Vane®. Naiad Dynamics US Inc, is a supplier of ride control systems and has worked with Hull Vane BV to develop the Dynamic Hull Vane®. Based on CFD and strip theory computations, the research clearly illustrates the added value of the Dynamic Hull Vane®. Where the passive Hull Vane® dampens pitch motions with 5-20%, the Dynamic Hull Vane® leads to a dampening of pitch motions of 30-50% in the most extreme cases.

1. INTRODUCTION

Ship motion dampening devices such as gyro stabilizers and stabilizer fins have been used on yachts with great success. For fast (planing) yachts effective solutions are available to actively dampen the heave and pitch motions, such as interceptors, trim tabs and T-foils. The patented Hull Vane®, a fixed stern-mounted hydrofoil, is known as an appendage to improve the performance of the vessel, while also dampening the heave and pitch motions of displacement yachts [1]. Because comfort is one of the most important performance parameters of superyachts, the Dynamic Hull Vane® was developed to further reduce the heave and pitch motions of displacement yachts. The pitch dampening effect of the passive Hull Vane® has been demonstrated on displacement vessels in CFD [2] and in model tests [3].

Ship motion reduction has long been a topic of research, and this has led to a number of solutions, which are widely applied. Most of the study work and products have been related to the rolling motions of ships, and there are indeed various effective solutions available, such as fin stabilizers, gyrostabilizers, interceptors, trim tabs and anti-roll tanks. The pitching motion of ships has been studied less, and while there are systems on the market to actively dampen the pitching motions of fast (planing) vessels, it has always been a challenge to dampen the pitch and heave motions of displacement ships, due to their inertia and limited speed. The pitch and heave motions are the prime source of vertical accelerations on board and these in turn are one of the main contributors in the Motion Sickness Incidence (MSI). Now that rolling underway is practically eliminated, the vertical accelerations are the main source of discomfort when sailing in waves. Passive systems to reduce pitch motions exist, such as bow foils, which are preferably retractable to avoid their resistance penalty in calm water, and the passive Hull Vane®. The interest of further developing the passive Hull Vane® into an active ship motion dampening device, comes from the fact that it has no penalty on the resistance. On the contrary, on many yachts, the resistance is reduced significantly [4].

It is possible to minimize or maximize the lift generated by the Hull Vane®, by continuously varying the angle of attack of the foil. This is done by means of a ride control system, which takes input from the ship motions and translates this into the desired angle of attack at each moment.

2. THEORETICAL BACKGROUND

2.1 The Hull Vane

The application of the Hull Vane is proven to be very effective on motor yachts in terms of energy saving and the increased comfort due to the dampened pitch and heave motions [1]. The theoretical background of it, are four distinct effects of the Hull Vane: 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.

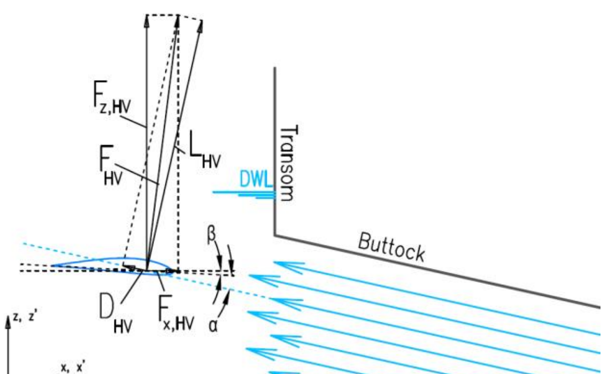
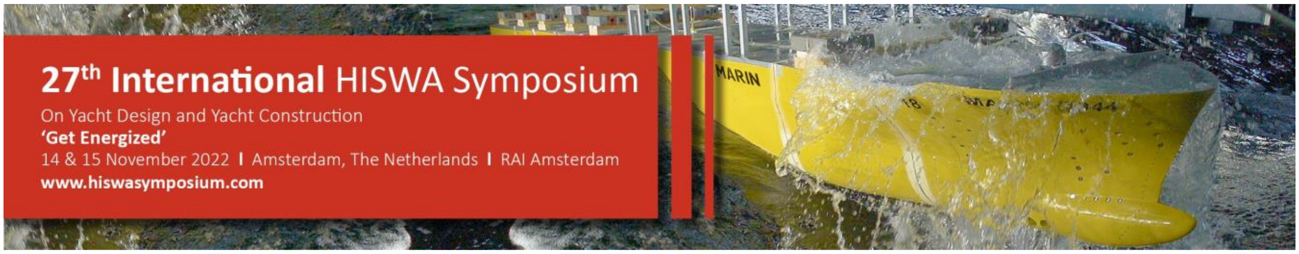


Figure 2 - Schematic overview of the forces on the Hull Vane in a section view of the aft ship.

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 force in z-direction, $F_{z,\,HV}$ affects the running trim of a motor yacht. The trim reduction generally has a positive effect on the total resistance of the vessel.

A paper, presented at the RINA Warship conference [5], described a comparison of the Hull Vane with trim wedges, interceptors and ballasting for AMECRC series 13. The paper showed the potential of the Hull Vane to reduce the



resistance of such vessels, particularly in the range of Froude numbers of 0.2 to 0.8, with over 15% improvement compared to trim wedges and interceptors at Froude numbers 0.25 to 0.4 (speeds 10.8 to 17.2 knots for a 50 m motor yacht). The results of that paper are summarized in the below graph, with the 0% line representing the bare hull, and the other curves the relative resistance of the hull with Hull Vane, a variable interceptor and a trim wedge. The AMECRC series 13 hull form. scaled to a waterline length of 50m, has been used as the reference vessel for the studies in the current paper.

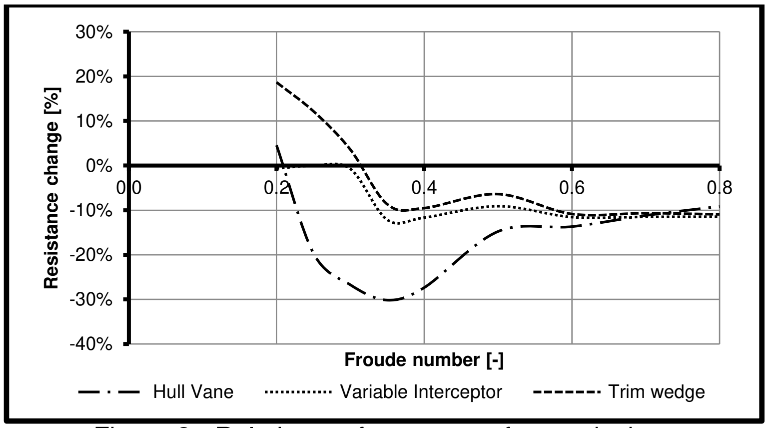


Figure 2 - Relative performances of stern devices

In addition to resistance reduction, the Hull Vane clearly reduces the stern wave, which is presented in the paper by a CFD comparison [5]. This is consistent with the differences seen on full scale, such as on the 52 m Offshore Patrol Vessel *Thémis*, which has a similar hullform as a typical displacement yacht and of which the wave profiles before and after retrofit at 15 knots (Fn 0.35) are shown in Figure 3 (left picture is without Hull Vane, right picture is with Hull Vane).

a) Without Hull Vane **b)** With Hull Vane

Figure 3 - Stern wave profiles at full scale at Fn 0.35 (15 kn)

A paper presented at the 24th International HISWA Symposium, discussed the towing tank results of a 42m yacht[1]. In 9 different conditions in irregular waves, the root-mean-square (RMS) of the pitch motions where reduced by 5% in average.

2.2 Angle of Attack on the Hull Vane

Theoretically the pitch motions can be further reduced by minimizing and maximizing the lift on the aft ship produced by the Hull Vane. Since the lift of the Hull Vane is based on basic foil theory, the lift can be calculated by the following formula:

$$L = \frac{1}{2} \cdot C_L \cdot \rho u^2 \cdot S \qquad (1)$$

The lift coefficient for a fixed-wing has a proportional relationship with the angle of attack. For this reason, is the lift force can effectively influenced by changing the angle of attack of the Hull Vane. Where rho is density of the fluid, u the velocity and S the planform area of the foil. The Dynamic Hull Vane will operate at high Reynolds numbers, between $5*10^6$ and $10*10^6$. Assuming a NACA 4412 profile starts stalling at high Reynolds numbers at around 16 degrees, the C_L can be varied from -0.8 to 1.6, see Figure 4 [6]. It can be observed that potentially, the lift can significantly be varied by rotating the foil.

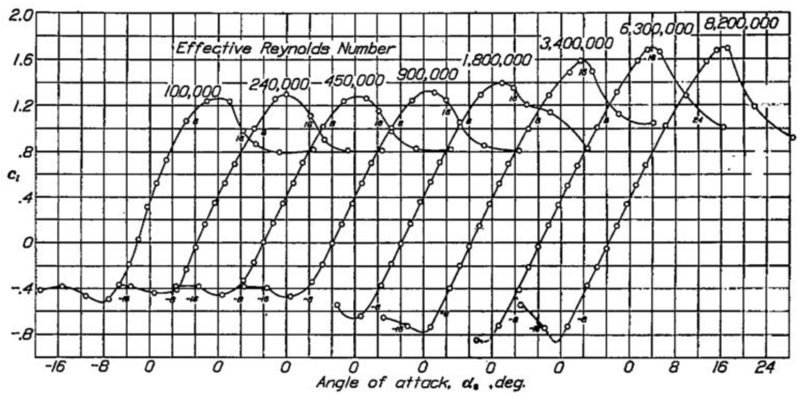


Figure 4 - Lift coefficient for NACA4412 airfoil

Besides controlling the angular position of the Hull Vane, the circumstances around the foil also influence the angle of attack. Theoretically, there are three distinct effects which influence the angle of attack: pitch motions, vertical motions of the aft ship and the undisturbed wave. A CFD analysis in waves of the reference ship without foil at Froude 0.4, shows a different magnitude of contribution of each system to the changing of the local angle of attack, see Figure 5. It can be observed that the angle of attack change caused by the vertical velocity and caused by the direct pitch change are out of phase, so they dampen each other out to some extent. The phase difference between the effects may change at different wavelengths, also the magnitude of the effects may change at different encounter frequencies. The possibility to rotate the foil and the multiple influences of the flow, provide further support for the hypothesis that the change of angle of attack is a complex system. A control algorithm has been developed for this.

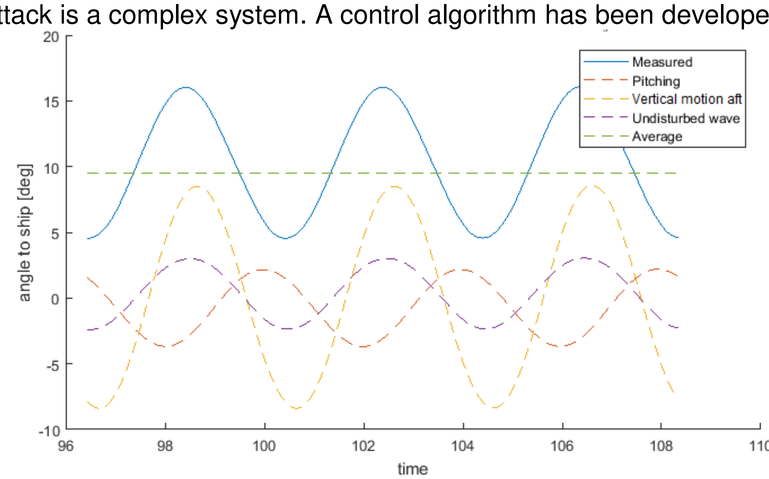
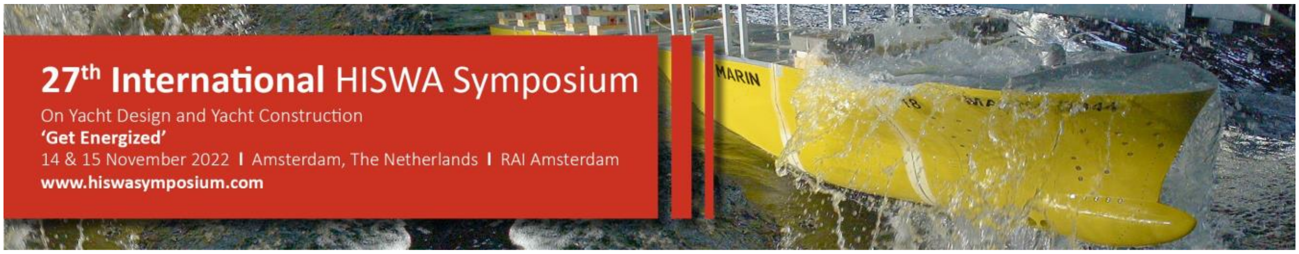


Figure 5 - Contribution of each system to the changing angle of attack, at Froude 0.4, encounter frequency of ω_{enc} = 1.75 rad/s and h = 1m



3. METHOD

3.1 Overview

Analysis of the Dynamic Hull Vane was done using several programs, utilizing their different characteristics to produce the results. Computational Fluid Dynamics (CFD) was used to obtain an accurate estimate of the force generated by the Hull Vane and the motion of the vessel in regular waves. However, CFD is limited in how many waves can be analyzed in a single run due to the long calculation time. Simulation programs based on strip theory are capable of longer runs in the time domain program. Once validated in the time domain, strip theory was used in the frequency domain, at multiple headings, speeds and wave spectra.

Initial studies were performed independently with the programs and later in the study, these elements were combined. An emulation of the Naiad motion controller was linked to the CFD program such that at each time step the Hull Vane was positioned according to the control algorithm to reduce the pitch motions of the vessel. A time domain simulation of the vessel, based on strip theory, in the regular waves with the controller was also performed. Comparison of the two demonstrated that both methods gave comparable results. The final strand of the analysis was to run the frequency domain version of the simulation program in irregular waves defined by the JONSWAP spectrum at different headings and speeds, thus giving an insight into the performance of the Dynamic Hull Vane in more realistic conditions.
The schematic diagram in Figure 6 shows the process.

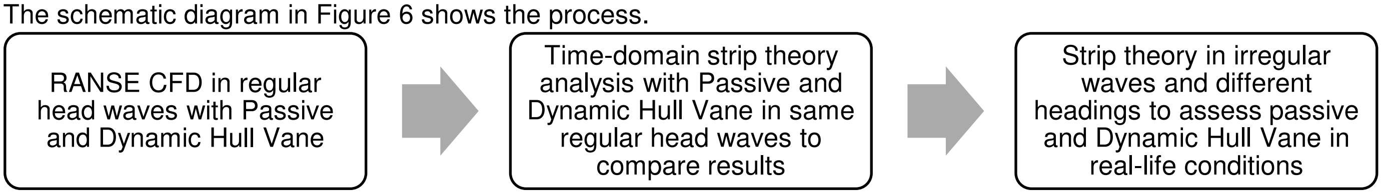


Figure 6 - Schematic diagram of process

3.2 Hull Form AMECRC #13

The study was carried out on a 50 m version of the AMECRC series 13 fast displacement hull. This is a generic hull form, available for academic purposes and very representative as a parent hull form for ships operating in the displacement and semi-displacement speed range, such as superyachts, patrol vessels, naval ships, fast supply vessels and passenger vessels. The principal particulars of the studied vessel are shown in Table 1. A lines plan of the hull form is shown below in Figure 7.

Table 1 - Principal particulars of AMECRC #1

PARAMETERS	DIMENSION
Displacement	493 t
Length on the waterline	50.0 m
Beam	8.33 m
Draft	2.5 m
LCG	22.8 m
VCG	3.6 m
GM_T	1.44 m
GM_L	105.0 m

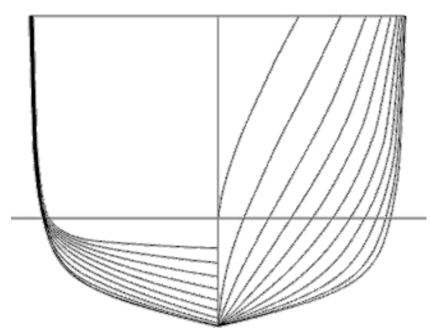


Figure 7 - Body plan of AMECRC series 13 hull

3.3 CFD Simulations

For the CFD computations the commercial software of Fine/Marine is used. The CFD computations are based on RANSE (Reynolds Averaged Navier-Stokes) simulations. RANSE computations are used to consider the viscous effects on the Hull Vane. To solve the flow, the RANSE solver ISIS developed by Ecole Centrale de Nantes is used.

The domain around the hull is constructed such that the boundaries are enough far away so as not to influence the results. Using the symmetry about the center-line, only half of the ship was modelled. The dimensions of the computational domain around the hull are given in Table 2.

Table 2 - Domain size in metres relative to the reference point

Direction	Minimum [m]	Maximum [m]
X (LONGITUDINAL)	-200	100
Y (BEAM)	0	100
Z (HEIGHT)	-100	25

The grid refinement study as described by Eca and Hoekstra is used to calculate the uncertainty of the discretization [7]. The domain volume is divided into small cells to generate the mesh. The initial grid start with a dimension of (X,Y,Z) 24,8 and 10 cells. The cell size varies throughout the grid, therefore a typical cell size (h_i) is defined that is representative for the cell size through the entire grid. The typical cell size is 0.9308. The final mesh counts 4,650,055 cells. With the third order error estimator the calculated discretization uncertainty is +/- 3.33%. For an overview of the grid see Figure 8.

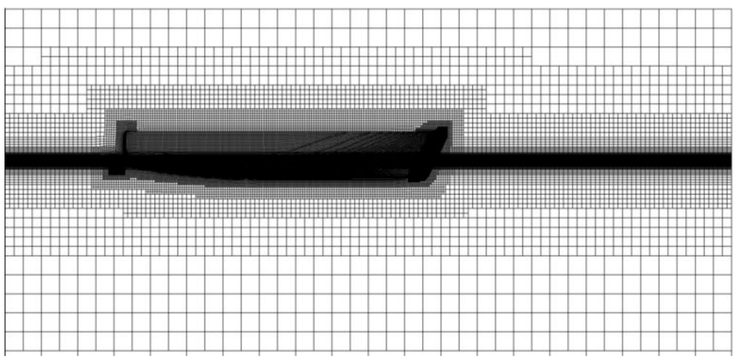


Figure 8 - Overview of grid of refinement study

The CFD simulations were carried out by Hull Vane BV with the hull in regular head waves. Comparisons were made at three speeds (Fn 0.3, 0.4 and 0.5) with encounter frequencies chosen based on the natural frequency of the ship (1.75 rad/s) and, at Fn 0.4, at two frequencies next to it (1.25 rad/s and 2.25 rad/s), see Table 3. The chosen wave height was 1.0m.

The CFD simulations were carried out by Hull Vane BV with the hull in regular head waves. Comparisons were made at three speeds (Fn 0.3, 0.4 and 0.5) with encounter frequencies chosen based on the natural pitch frequency of the ship (1.75 rad/s). At Fn 0.4, additional frequencies are analyzed (1.25 rad/s and 2.25 rad/s) to have results on frequencies which lower and higher than the natural frequency. The chosen wave height was 1.0 m. To summarize, the following conditions are analyzed.

Table 3 - Conditions analyzed in CFD

Encounter frequency/ ship speed	Ship speed in knots [kn]	1.25 [rad/s]	1.75 [rad/s]	2.25 [rad/s]
Fn 0.30	12.9		X	
Fn 0.40	17.2	X	X	X
Fn 0.50	21.5		X	

Multiple algorithms were tested. Regarding motion damping, the pitch based algorithm is the best performing. The angle of attack is changed as a function of the pitch velocity. The Dynamic Hull Vane then rotates increasing or decreasing lift, to counteract the pitch motion. Different setups in different conditions were tested. Significant reductions in ship motions, good performance for resistance in waves and the possibility to tune the algorithm, make it the best algorithm at this phase. The results in this paper are based on this algorithm.

In these CFD analyses, the Hull Vane was rotating around an axis close to its centre of lift. During the later development of the Dynamic Hull Vane, additional CFD runs were done to confirm whether similar performance could be obtained by rotating the Hull Vane not around its axis, but rotating it around a point closer to the transom. These CFD analyses showed similar results, with some practical benefits: by having the centre of rotation at the top of the Hull Vane struts, all of the surfaces of the Hull Vane in the ship's flow could remain fully optimized for hydrodynamic performance, as it would not be necessary to integrate mechanical elements into the struts or wing. Furthermore, this solution would maintain the freedom to opt for the optimal Hull Vane shape for optimal performance in terms of resistance and pitch dampening. Another practical advantage of placing the rotation point higher up is that all mechanical parts (hinges, actuators) could be placed above the waterline or even inboard, which simplifies (and reduces) maintenance.

3.4 Strip Theory Analyses

To test the Dynamic Hull Vane on the same ship, a seakeeping program based around strip theory was used by Naiad Dynamics. This in-house developed program, MHW, uses 5 degrees of freedom, with forward speed assumed constant, and has two modes: a frequency domain mode for rapid testing of spectral response at different headings and a time domain mode for testing of the controller with specified control parameters including limits. While the prime purpose of this program is to compare the motions of a vessel with and without ride control, it has been found to give accurate results when compared to tank tests and sea trials [8].

4. RESULTS

4.1 CFD Analysis – Motion Dampening

Based on the algorithm optimized for reducing pitch motions, the Dynamic Hull Vane reduces significantly the pitch motions with respect to the passive Hull Vane, see Table 4. The presented reductions are between 12.1% and 40.4%. The closer the encounter frequency to the natural frequency of the ship, the larger the reductions will be.

Table 4 - CFD results for pitch amplitude reduction (Dynamic Hull Vane vs. passive Hull Vane)

Pitch amplitude	**1.25 [rad/s]**	**1.75 [rad/s]**	**2.25 [rad/s]**
0.30 (Froude)		-20.6%	
0.40 (Froude)	-27.8%	-32.7%	-12.1%
0.50 (Froude)		-40.4%	

The dampening is achieved by maximising the lift amplitude of the foil. The passive Hull Vane is set at a continuous angle whereas the angle of the Dynamic Hull Vane is continuously changed to minimise and maximise lift at the right moment. In the figures below, you can see a comparison of the flow around the passive Hull Vane (Figure 9) and the Dynamic Hull Vane (Figure 10) at the same timestep.

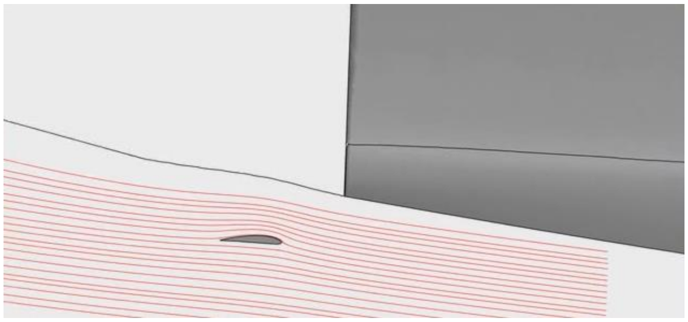


Figure 9 - Passive Hull Vane during Bow-up Motion

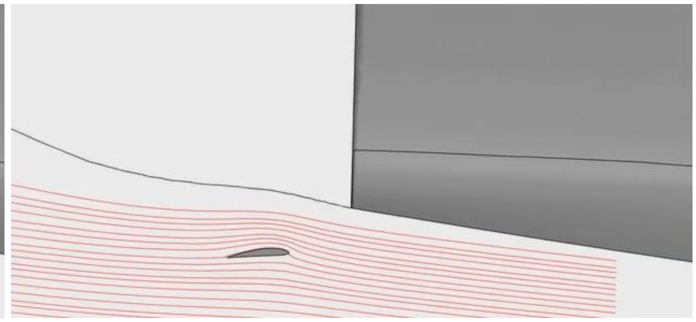


Figure 10 - Dynamic Hull Vane during Bow-up Motion

4.2 CFD Analysis – Effect on resistance

The research showed that the Dynamic Hull Vane reduces the added resistance from sailing in waves more than the passive Hull Vane, which could be expected. However, due to the angle of attack variations, the forward thrust developed by the Dynamic Hull Vane was less (integrated over time) than the forward thrust of the passive Hull Vane. The provided thrust is lower, since the induced drag becomes significant at larger angle of attack so the thrust will be largest for small angles of attack. The net result, for the chosen speeds and wave conditions, was approximately break-even, as can been seen in Table 5, which shows the relative difference in ship resistance (integrated over time) of the ship with Dynamic Hull Vane, compared to the ship with passive Hull Vane. Positive numbers indicate a higher resistance, while negative number indicate a reduced resistance

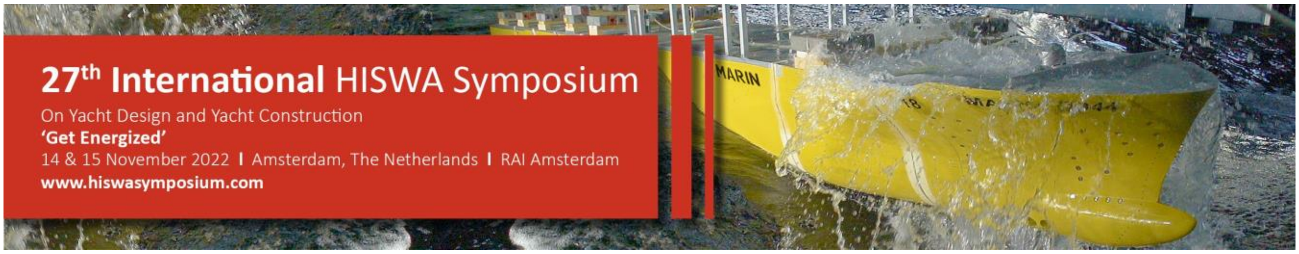
Table 5 - Effect on ship resistance from CFD (Dynamic Hull Vane vs passive Hull Vane)

Relative resistance	1.25 [rad/s]	1.75 [rad/s]	2.25 [rad/s]
0.30 (Froude)		+3.7%	
0.40 (Froude)	+4.8%	+0.7%	+3.3%
0.50 (Froude)		+1.0%	

In the cases studied for this paper, the added resistance due to waves was relatively small compared to the total resistance (10-22%). In cases were the added resistance due to waves is a larger part of the total resistance, it is possible that the Dynamic Hull Vane will be able to provide a higher resistance reduction in waves than the passive Hull Vane, with the right controller. This is assumed because the added resistance from waves (in kN) will then have a larger order of magnitude than the thrust developed by the Hull Vane (in kN).

4.3 Strip Theory Analysis – time Domain Simulation

The time domain program was used to compare the strip-theory results with the results from the CFD computations. Therefore, the program was configured to run with regular waves. The results are shown in Figure 11 and Figure 12, which show the double amplitude pitch and heave for the two simulation methods (CFD and strip theory) at the resonant pitch frequency (1.75 rad/sec) and two side frequencies (1.25 and 2.25 rad/sec). Whilst there are differences in the absolute values, the trends are consistent with similar reductions in pitch as shown in Figure 13. The values of heave are shown in Figure 14 where there are some differences between the programs particularly at the higher frequency.



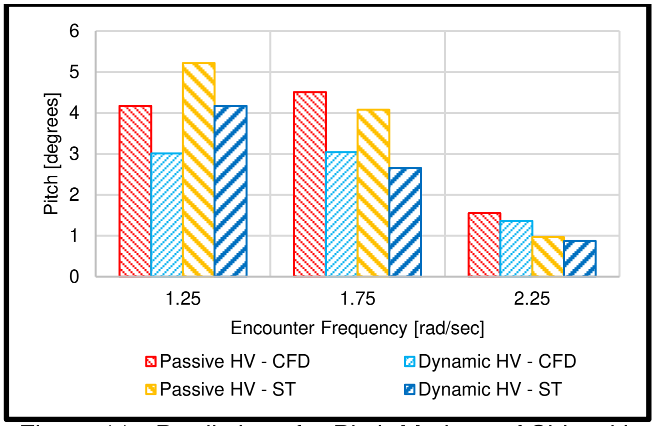


Figure 11 - Predictions for Pitch Motions of Ship with Passive and Dynamic Hull Vane by CFD and Strip Theory (ST) at Fn 0.4.

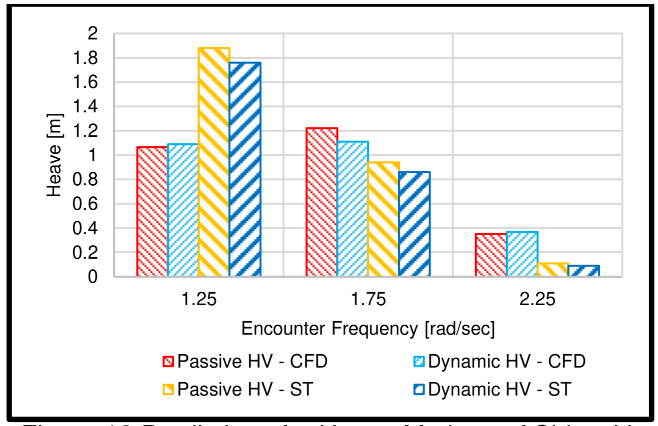


Figure 12 Predictions for Heave Motions of Ship with Passive and Dynamic Hull Vane by CFD and Strip Theory (ST) at Fn 0.4.

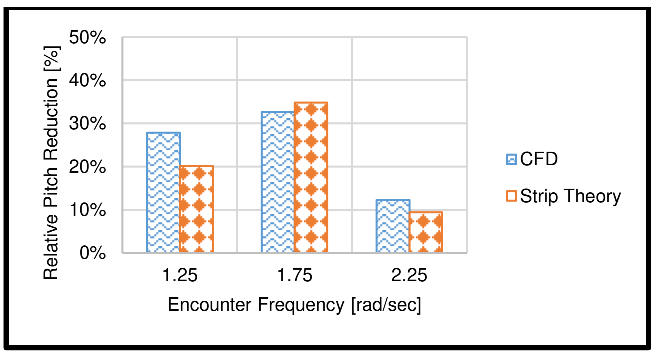


Figure 13 - Relative Pitch Reduction of Dynamic Hull Vane vs Passive Hull Vane as Predicted by CFD (blue) and Strip Theory (orange)

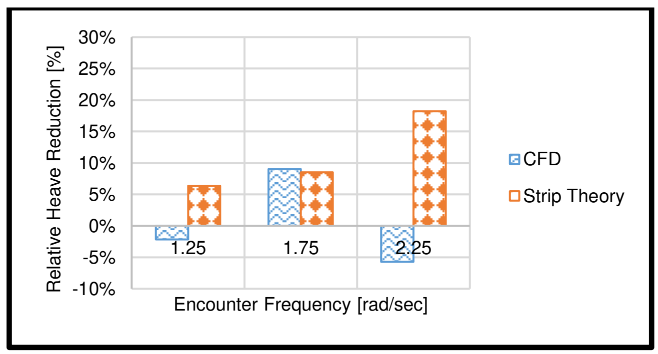


Figure 14 - Relative Heave Reduction of Dynamic Hull Vane vs Passive Hull Vane as Predicted by CFD (Blue) and Strip Theory (Orange)

4.4 Strip Theory Analysis – time Domain Simulation

The simulations were performed at Froude numbers 0.3, 0.5 and 0.7 (for speeds see Table 6) in unidirectional waves represented by the JONSWAP spectrum as listed in Table 7 at headings from 0 degrees (following) to 180 degrees (head) at 15 degree intervals. The chosen speeds and wave spectra are representative to superyachts and used for seakeeping studies for roll stabilizers as well.

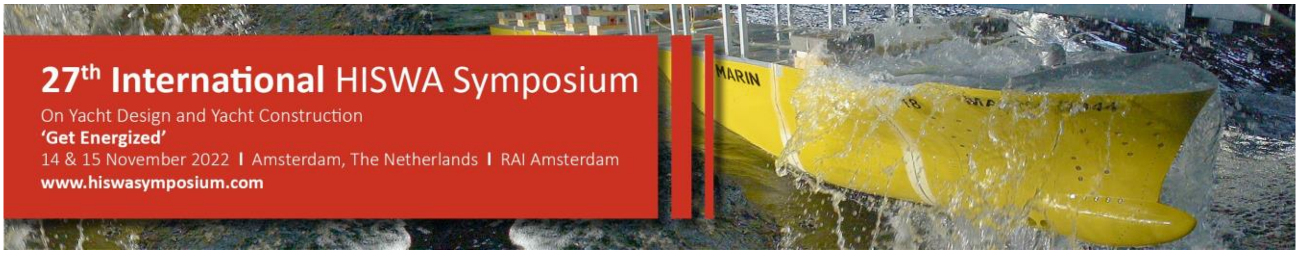
Table 6 - Speeds

Froude number [ ]	**Speed [kn]**
0.3	12.9
0.5	21.5
0.7	30.2

Table 7 – Wave conditions

Significant wave height [m]	**Modal wave period [s]**
1.0	5.0
1.5	6.0
2.0	7.0

The heading of the vessel is controlled by a simple autopilot to maintain directional stability. The Hull Vane is used to reduce pitch motions and the controller uses a combination of pitch and pitch rate as input variables. To account for mechanical and hydraulic delays a first order lag is added to the control signal going to the Dynamic Hull Vane. The movement of the Dynamic Hull Vane is limited in two ways: the mechanical limits of the arrangement, in this case set



to +/- 10 degrees and by limits posed by cavitation and stall of the foil, particularly an issue for the high Froude number case.

For the ship owner, the key parameter is the reduction of the pitch motion between a passive Hull Vane and a Dynamic Hull Vane. Therefore, the simulation was performed twice, firstly with the fixed or passive Hull Vane and secondly with the Dynamic Hull Vane.
The results of the simulations are shown in Figure 15, Figure 17 and Figure 19 for Froude numbers 0.3, 0.5 and 0.7.

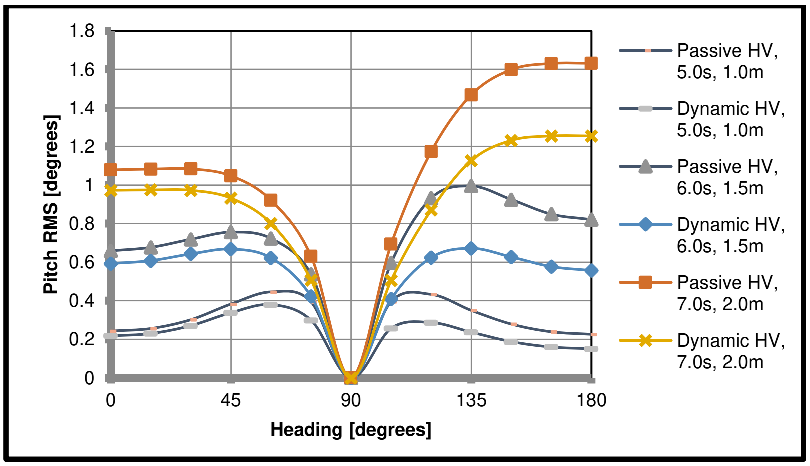


Figure 15 - Standard deviation of pitch at Fn 0.3

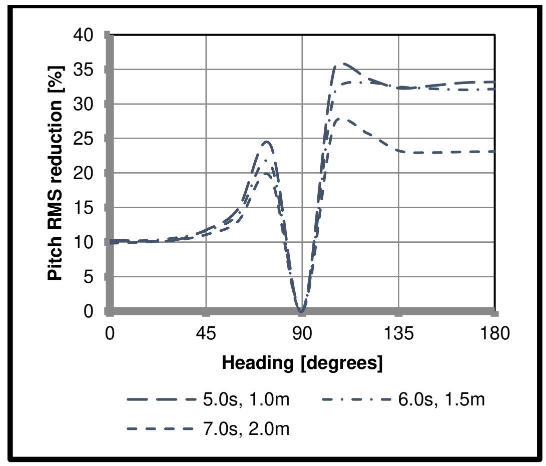


Figure 16 - Standard deviation of pitch reduction Dynamic HV compared to passive HV at Fn 0.3

Two factors are influencing the results: firstly, the encounter frequencies and secondly the speed of the vessel. These are obviously linked in that the forward speed changes the encounter frequency, however, as can be seen in Figure 15, the peak of the pitch response is situated at a different heading in different spectra (respectively at 105 degrees, 135 degrees and 180 degrees).

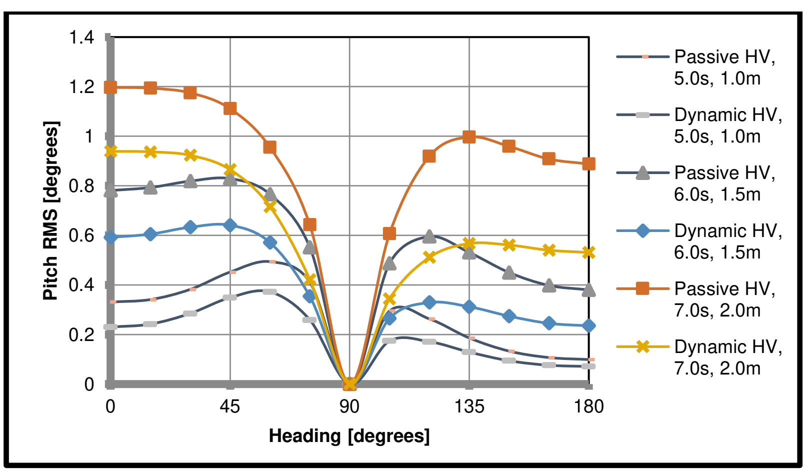


Figure 17 - Standard deviation of pitch at Fn 0.5

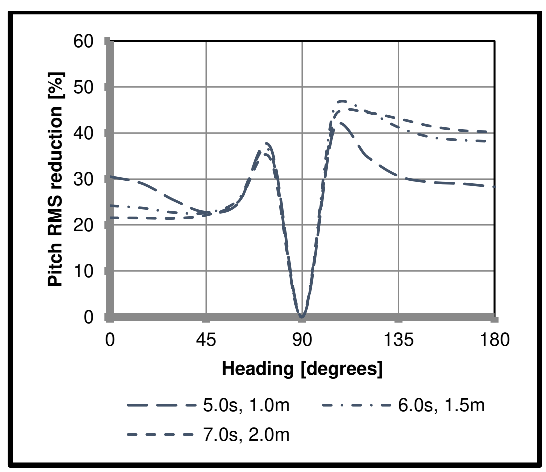


Figure 18 - Standard deviation of pitch reduction Dynamic HV with respect to passive HV at Fn 0.5

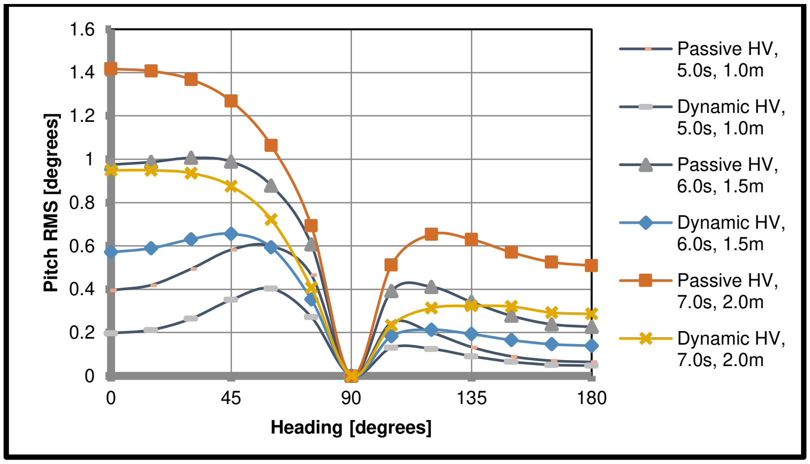


Figure 19 - Standard deviation of pitch at Fn 0.7

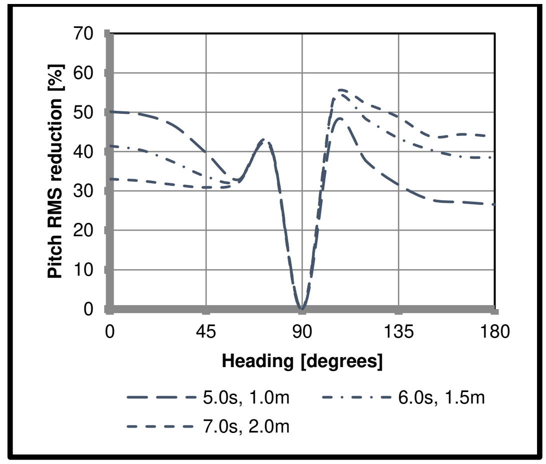


Figure 20 - Standard deviation of pitch reduction Dynamic HV with respect to passive HV at Fn 0.7

The reduction in pitch motions for Froude number 0.3 is greatest for headings forward of the beam and varies between 23 and 35%, see Figure 16. The results for Froude number 0.5, Figure 17, show a significant change in response with the highest pitch motions occurring in stern-quartering seas. The percentage reductions remain highest for the seas with headings forward of the beam with values of between 28% and 45%, see Figure 18. The results for Froude number 0.7, Figure 19, show a similar trend to the 0.5 case with the highest pitch occurring in seas with headings aft of the beam. The percentage reductions are similar across all headings varying from 25% to 54%, see Figure 20.

5. WHAT ARE THE PERSPECTIVES?

5.1 Technical Design

Just like the passive Hull Vane, the Dynamic Hull Vane can have various geometries, depending on hydrodynamic performance, and the preferred attachment points on the hull. So like the passive Hull Vane, it is possible to take into account swim platforms, transformers and tender garages of the yacht.

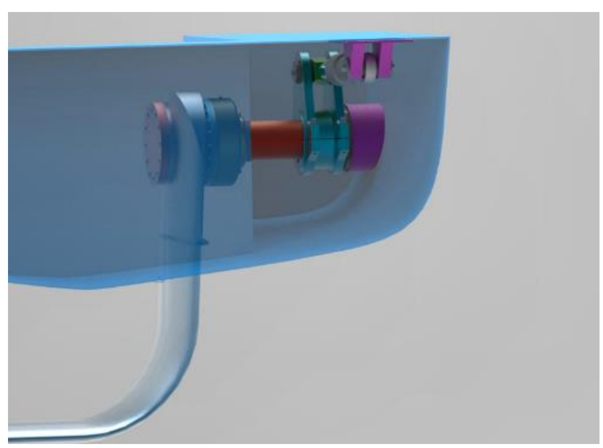


Figure 21 - Dynamic Hull Vane mechanical system

The design of the Dynamic Hull Vane is generally made in such a way that the lift forces are aligned with (or close to) the pivot point, much like a balanced rudder. Because of this, the actuator cylinder is mainly used for position setting, and most of the force is transferred through the hinge. Because of this, the Dynamic Hull Vane has a low power consumption, comparable to an active interceptor, and much less than a stabilizer fin (designed for at-rest stabilization), in spite of the large surface area of the Hull Vane. The hydraulic cylinder(s) can either be placed outboard or inboard, but it is expected that for superyachts, the inboard position will be preferred.
In some cases, the hinge is also the seal, and both the tiller and the actuator are placed inboard, as shown in Figure 20.

In addition, there are no limitations for combining innovative propulsion systems with the Dynamic Hull Vane like hybrid power plants, alternative energy carriers or podded units. To make alternative energy carriers more cost-effective, it is advantageous to minimize energy consumption by minimizing the ship's resistance. The Dynamic Hull Vane reduces the resistance in the same order as the passive Hull Vane. Instead of the classical propeller/rudder configuration, many yachts are designed with podded propulsion units. The passive Hull Vane has already been used in combination with such a system. For the Dynamic Hull Vane, this combination will work just as well. There are hydrodynamic advantages such as the improved course stability provided by the Hull Vane.

5.2 Dynamic Hull Vane as part of a Ride Control System

The Dynamic Hull Vane can be incorporated into a ride control system. For yachts, roll control is frequently an essential requirement to increase comfort on board and that is generally met by the use of fins. Control of pitch motions and vertical accelerations can be provided by the use of a forward T-foil and/or Dynamic Hull Vane. As presented in the results, the Dynamic Hull Vane will be effective for displacement speeds of from at least Fn 0.3 up to at least Fn 0.7. In terms of sailing speed of yachts the Dynamic Hull Vane will be effective from 10 knots up to +25kn.
Similar to stabilizer fins, the digital controlling system of the Dynamic Hull Vane is operating on a CANbus distributed network, which is well known on board of the yachting industry. By this it possible to combine the stabilizer fins with the Dynamic Hull Vane to get a total ride control system to reduce ship motions for roll, yaw, heave and pitch.

6. CONCLUSIONS

This paper shows the results of a feasibility study of a Dynamic Hull Vane on a 50 m hull shape, typical for a superyacht, a patrol vessel, or passenger vessel. The flat water resistance of the bare hull is reduced by the passive Hull Vane at all speeds above 11 knots by up to 30%. However, no positive effect in further reducing the resistance by the Dynamic Hull Vane is measured. While the passive Hull Vane leads to a dampening of pitch motions of 5 to 20% in head seas compared to the bare hull, the Dynamic Hull Vane leads to a further dampening of pitch motions of 30-50% in the most extreme cases compared to the passive Hull Vane.
Hull Vane and Dynamic Hull Vane are both solutions protected by patents.

7. RECOMMENDATIONS FOR FURTHER WORK

The next step will be to validate the simulations with model tests in waves or during full scale trials.
An interesting topic for future study would be the development of a control algorithm which focuses on resistance reduction rather than motion dampening.
It would also be an interesting research topic to investigate what can be achieved when the Dynamic Hull Vane is coupled to forward-looking systems which predict upcoming ship motions based on radar scanning of the ocean surface.

Since the vertical motions can be reduced significantly by the Hull Vane and Dynamic Hull Vane, also the vertical accelerations are reduced significantly [3]. Vertical accelerations play a key role in the design of structural arrangements like machinery foundation on deck or podded propulsion. Further research could investigate the advantage of the reduced motions by the Dynamic Hull Vane for the structural design.

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