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Improving the nautical performance of a surface ship with the Hull Vane® appendage

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SOMMAIRE

L'optimisation des performances propulsives des navires est un enjeu primordial et quotidien lors des phases de conception. Pour les navires de combat, il s'y ajoute la recherche constante de l'augmentation de l'opérabilité à travers l'amélioration des performances de tenue à la mer, de la discrétion acoustique et des performances manœuvrières.

Dans ce cadre, Naval Group a étudié les impacts hydrodynamiques de l'ajout d'un appendice arrière Hull Vane® sur une carène de monocoque. Cet appendice a été conçu et optimisé spécifiquement pour cette carène puis comparé par calculs CFD à plusieurs géométries d'autres types d'appendices arrière plus classiques comme les wedges, flaps et interceptors. Des gains significatifs ont été obtenus sur la résistance à l'avancement et sur la puissance propulsive, et dépassent largement ceux obtenus avec les autres appendices arrière.

Cette analyse a enfin été complétée par des essais sur maquette, avec et sans le Hull Vane®.

SUMMARY

The optimization of propulsive performance of ships is a primary and daily issue during design phases. For combat ships, the constant search for increasing operability through the improvement of seakeeping performance, acoustic discretion and manoeuvring ability is also a concern.

For this reason, Naval Group studied the hydrodynamic impacts of the integration of the appendage Hull Vane® on a monohull. The appendage has been designed and optimized specifically for this hull, then compared by CFD computations with several geometries of more classic aft appendages such as wedges, interceptors and flaps. Significant gains on resistance and propulsive power were obtained, and exceeded largely what is obtained with more classic stern appendages.

This analysis was completed by model tests, with and without the Hull Vane®.

1. INTRODUCTION

In order to improve the propulsive power of its ships, Naval Group, like other companies [1], uses for a long time aft appendages.

During last years, Naval Group studied more especially a new type of aft appendage: the Hull Vane®.

2. HULL VANE® DEVICE

2.1. Development

The Hull Vane® is a patented energy saving and passive seakeeping device originally developed for high-performance sailing. It was invented by Dutch hydrodynamicist Dr. Pieter van Oossanen and applied for the first time on "Défi Aréva" a French contender for the America's Cup in 2002. At the time, an optimisation was done with model tests carried out at the Val de Reuil basin near Paris.

The Hull Vane® consists of a submerged fixed wing at the transom, very similar to a hydrofoil, but with a completely different goal and application range of typical hydrofoils. It is applied on ships which operate at speeds below planing speed (due to their weight and powering), and uses the wing to reduce the resistance, not to lift the vessel out of the water.

The Hull Vane® is optimised for each ship individually and can have many different forms and shapes, such as the TT-shaped, U-shaped and X-shaped (segmented) Hull Vane®, or combinations thereof.

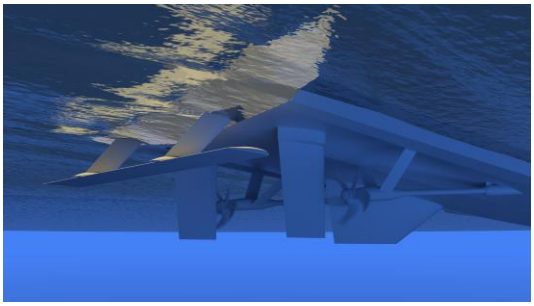

Figure 1: Hull Vane® in TT-shaped configuration

After many years of Research & Development, the Hull Vane® was introduced to the market as a commercial product in 2014, and has now (2019) been installed on 20 ships, including motoryachts, patrol vessels, offshore supply vessels and passenger ships.

Due to their weight and their operating speeds (in the transitional speed range, Froude number 0.2-0.8), naval surface ships can achieve great resistance reductions from the Hull Vane®, leading to a lower fuel consumption and emissions, a higher top speed and a longer range or higher crossing speed for a given range.

Over the years, research has shown that the Hull Vane® presents a number of additional benefits which are particularly desirable for naval ships: the improved efficiency leads to a quieter ship, the reduced wavemaking reduces the visual signature and the improved seakeeping makes all operations onboard safer in waves.

2.2. Working principles

Similar to the bulbous bow, an often-used energy saving device on naval ships, the Hull Vane® has an influence on all resistance components of a ship. It increases the frictional resistance but reduces the pressure (or wavemaking) resistance. For clarity, four distinctive effects are described. However, in practice, the ship and Hull Vane® are always considered as one complete system during a Hull Vane® optimisation, as maximising one effect can have a negative influence on another.

2.2.1. Forward thrust

A wing placed in a flow generates two forces: a lift force, by definition perpendicular to the flow, and a (much smaller) drag force, by definition in the direction of the flow. Because a displacement ship is deeper amidships than at the stern, the flow under the aft ship is not horizontal, but angled upwards. When designed well, the force generated from the Hull Vane®, which is the sum of the lift and drag force, is angled forward.

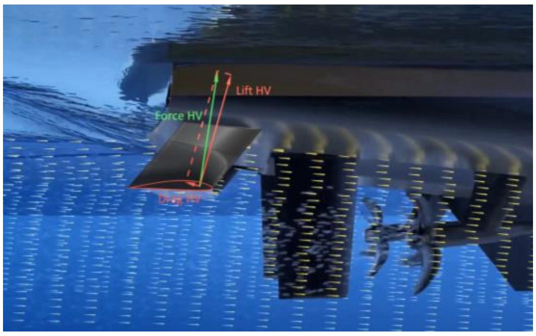

Figure 2: Lift and Drag on Hull Vane®

This means that it has a vertical component (lifting the aft ship), as well as a net forward horizontal component (pushing the ship forwards).

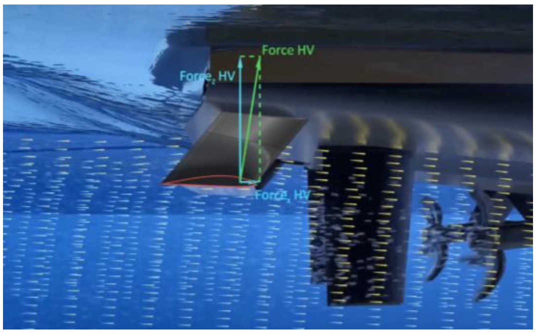

Figure 3: Vertical and horizontal force on Hull Vane®

2.2.2. Reduced wavemaking

The waves generated by a ship are a sign of the energy required to propel it. Much like a bulbous bow reduces a ship's own bow wave, the Hull Vane® reduces a ship's own stern wave. The low pressure area on top of the Hull Vane® brings down the stern wave.

2.2.3. Reduced running trim

Ships operating in the transitional speed usually experience dynamic trim: at different speeds, the trim angle is not the same as the trim at standstill. The vertical part of the lift keeps the ship close to even keel, which is advantageous for the resistance. Other solutions exist to reduce the dynamic trim, such as stern flaps, stern wedges or interceptors, but such devices are typically effective at higher speeds than the Hull Vane®. The purpose of this paper is to compare the Hull Vane® with such devices.

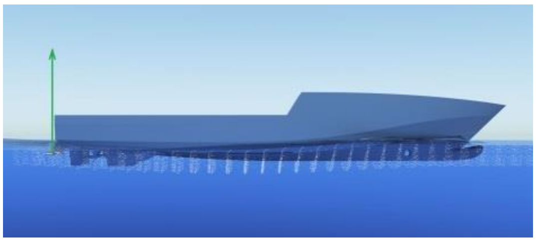

Figure 4: Trim correction effect

2.2.4. Reduced motions in waves

When a ship sails in waves, the ship motions can generate a significant amount of added resistance. Model tests and CFD computations in waves have shown that the Hull Vane® significantly reduces ship motions such as pitching, heaving, rolling and yawing, and thereby reduces the added resistance from these motions by 10 to 30%. Furthermore, when the ship is pitching, the Hull Vane® produces more forward thrust, an effect which is called the "pumping effect", as it is similar to what surfers do on surfboards equipped with hydrofoils.

3. OPTIMISATION OF THE HULL VANE®

3.1. Input data

Hull Vane BV designed and optimised a Hull Vane® for a Naval Group surface ship.

Naval Group supplied the 3D model of the vessel, the hydrostatics and the location and characteristics of the propellers. In addition, the integration constraints were provided, as well as the location of strong structural members in the aft ship for the positioning of the struts.

The chosen speeds for the optimisation were the top speed and the range speed.

3.2. Optimisation process

All optimisation work for Hull Vane® is carried out by sister company Van Oossanen Fluid Dynamics (VOFD), who use FINE™/Marine, a CFD package from Numeca, based on a code developed in conjunction with École Centrale de Nantes and CNRS. The solver uses Reynolds-averaged Navier Stokes (RANS) equations, which means that both pressure and viscous effects are calculated for each cell, resulting in accurate predictions.

A systematic (non-automatic) multi-point optimisation was carried out for the Hull Vane® for the hull, which means that each configuration was analysed in CFD at both speeds. In a first stage, only the horizontal wing part of the Hull Vane® was optimised. The best compromise of performance and structural feasibility was then chosen, and for this configuration, the struts were designed and optimised.

During the optimisation, the effect of the propellers on the Hull Vane® performance is analysed by including Actuator Disks. These are "virtual propellers" which give an approximated rotation and acceleration to the water as propellers do.

The optimisation led to a U-shaped Hull Vane® configuration. Due to the large span, an intermediate strut was added on centreline.

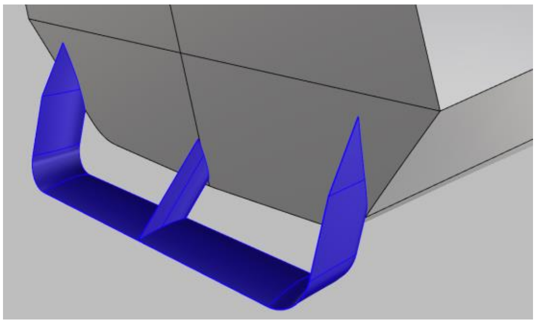

Figure 5: Final Hull Vane® geometry, as seen from aft

The results were checked in CFD for the likeliness of cavitation and ventilation, and both were effectively prevented.

A basic structural feasibility analysis was carried out, showing that the chosen geometry is buildable, even if a more detailed structural design and Finite Element Analysis will be done before the construction of the first Hull Vane®.

4. DESIGN OF OTHER AFT APPENDAGES

In order to compare resistance and propulsive power gains for the hull, Naval Group designed 30 other more common aft appendages: 10 wedges, 10 flaps and 10 interceptors with the aim to reduce propulsive power at transit speed and maximal speeds.

4.1. Flaps

Naval Group designed 10 flaps geometries with several lengths and angles.

Figure 6: Example of flap design

4.2. Wedges

Naval Group designed 10 geometries with several angles and different types.

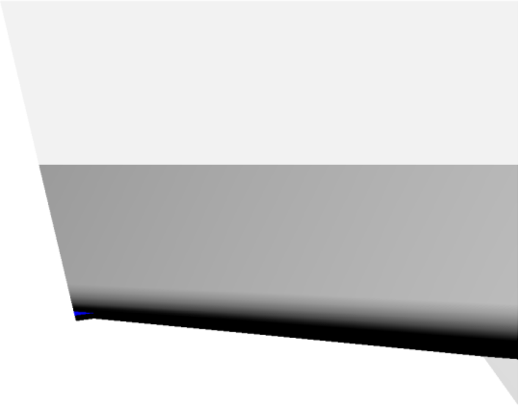

Figure 7: Example of wedge design

4.3. Interceptor design

Naval Group designed 10 geometries of interceptors.

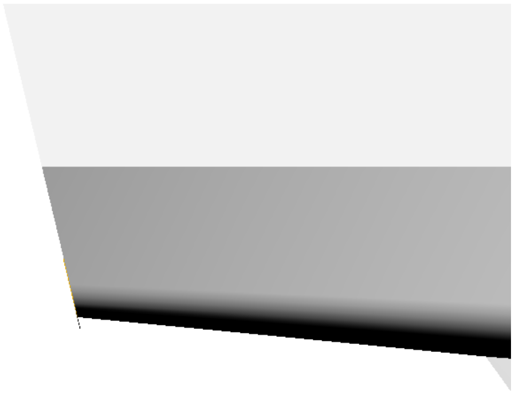

Figure 8: Example of interceptor design

5. CFD CALCULATIONS

CFD computations were performed by SIREHNA in order to assess the towing resistance, propeller-hull interactions, and the propulsive power for 2 speeds.

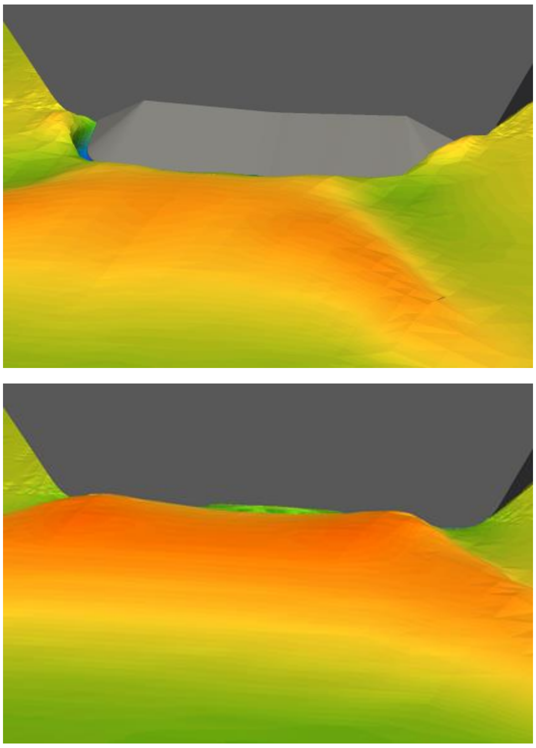

Figure 9: Examples of stern wave during CFD calculations

On the following graphs, the reference is the hull without aft appendage. The gain in resistance and propulsive power is shown in Figure 10 and 11.

5.1. Comparison in term of towing resistance

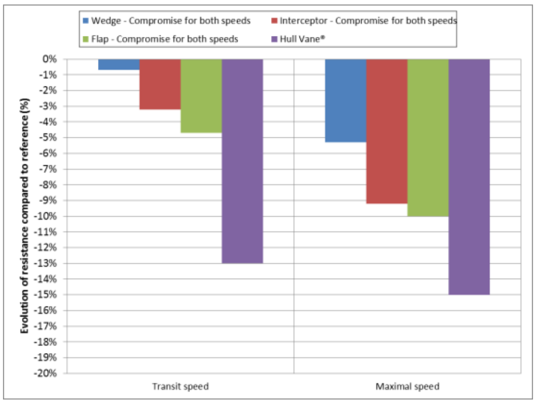

Figure 10: Resistance with appendages optimized for both speeds

5.2. Self-propulsion point investigation and comparison in term of propulsive power

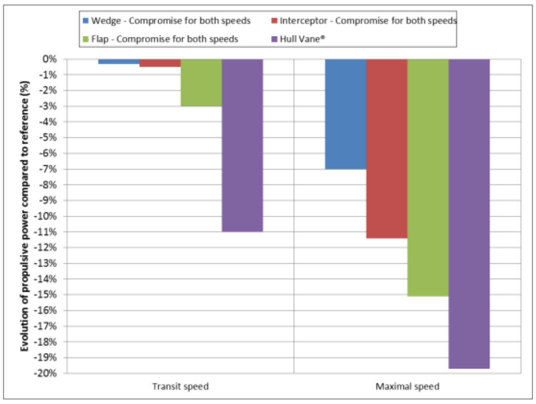

Figure 11: Propulsive power with appendages optimized for both speeds

5.3. Wake field

Because transom stern is dewatered, the wave height is reduced by aft appendages:

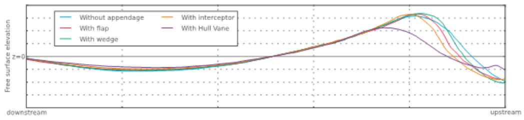

Figure 12: Wave height with aft appendages

5.4. Conclusion on the comparison

For each of the aft appendages studied, there is one configuration which decreases the propulsive power at both transit and maximal speed.

There are significant gains for both resistance and power, but these gains are not identical, due to different interactions between propellers and aft appendages.

These computations especially show the important gains that can be obtained with the Hull Vane®, in comparison with the more common aft appendages.

6. MODEL TESTS

In order to complete the CFD analyses, model tests were performed by MARIN with and without the Hull Vane®: Seakeeping, manoeuvring, resistance and propulsion, and cavitation tests.

6.1. Seakeeping

Because the Hull Vane® is composed of three struts and of a foil, it is expected to reduce ship motion on waves. In order to measure the effect of the appendage on ship motions, seakeeping model tests were performed at two speeds. Five headings and two sea states were tested.

Figure 13: Seakeeping model tests

6.1.1. Pitch motion

The model tests bring to light the significant reduction of pitch motion by head waves (between 3% and 11%). Furthermore, the more the speed increases, the more the Hull Vane® is efficient for pitch reduction for this heading.

6.1.2. Roll motion

Model tests also highlight a significant reduction of the roll motions thanks to the appendage up to 17% on stern quartering waves and around 7% on beam seas.

6.1.3. Vertical accelerations

During model tests, vertical accelerations were measured on the helicopter spot (helicopter launch and recovery) and on the bridge (transit and patrol).

Measurements at the bridge show a gain around 6% by head waves at transit speeds for both sea states. Similar gains are reachable for other headings/speeds. These reductions are directly functions of the pitch reduction gains presented in the previous paragraphs.

Similarly, large gains (even very large by head waves) are found on the vertical acceleration on the helicopter spot (around 10% decrease on head waves for example).

6.1.4. Slamming

During seakeeping model tests, pressure sensors were installed at 15% from the forward perpendicular.

In case of slamming events, maximal pressures are reduced by more than 50% on head waves.

6.2. Resistance and propulsion

Figure 14: Resistance and propulsion model tests

6.2.1. Calm water model tests

Calm water model tests of resistance and propulsion were performed with and without the Hull Vane®.

These tests confirmed the gains estimated by CFD calculations.

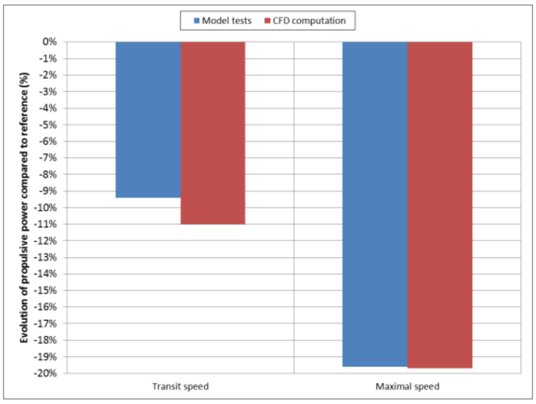

Figure 15: Propulsive power with Hull Vane®

6.2.2. *Added resistance on waves*

The effect of the Hull Vane® was also studied on added resistance on waves during seakeeping model tests.

Thanks to the reduction of pitch motions on the studied sea states, a reduction of around 12% was obtained in medium sea state and up to 23% in the high sea state.

6.2.3. *Wake field*

The Hull Vane® has also a positive effect on the reduction of the stern wave:

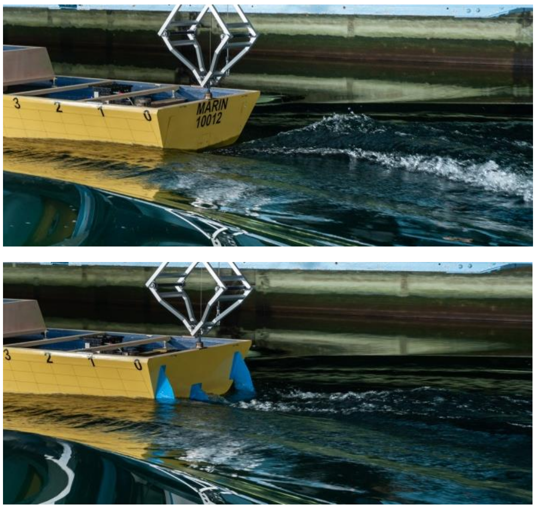

Figure 16: Height of stern wave (model tests)

Model tests highlighted the coupling between resistance reduction and stern wave decrease.

6.3. Cavitation and acoustic discretion

Cavitation tests were performed up to maximal speed for the ship and confirmed the non cavitation of the appendage on the whole range of speeds of the ship.

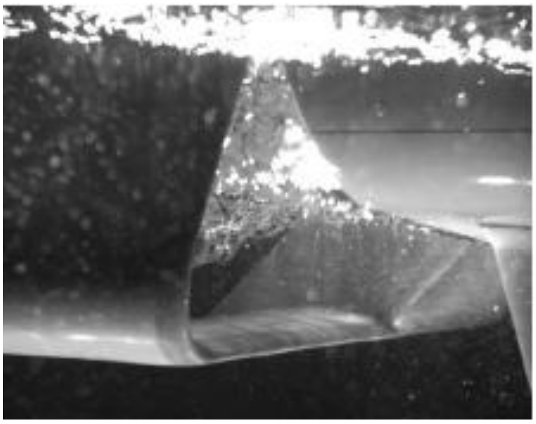

Figure 20: Cavitation model tests

Additionally, the reduction of propulsive power also leads to a reduction of rotational speeds of the propellers which is directly an improvement of stealth.

6.4. Manoeuvring

Manoeuvring tests were performed with and without the Hull Vane®.

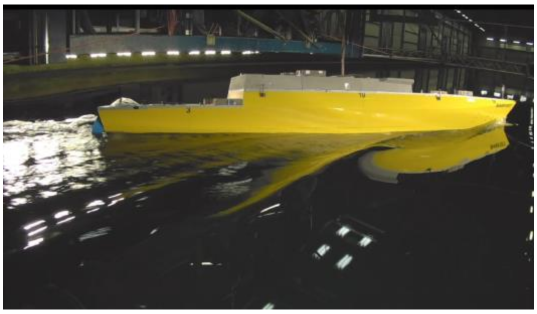

Figure 17: Manoeuvring model tests

The Hull Vane® has a small effect on turning circle but it remains acceptable.

7. PHYSICAL INTEGRATION OF A HULL VANE®

The physical integration of a Hull Vane® requires special attention from the Naval Architect.

The following issues must be taken into consideration:

- Positioning with regard to the hull and other appendages
- Structural integration and reinforcements.
- Interferences with systems deployed astern of the ship

7.1. Position of the Hull Vane®

The most common position for a Hull Vane® is underneath and aft of the corner of the transom of the hull (Figure 18).

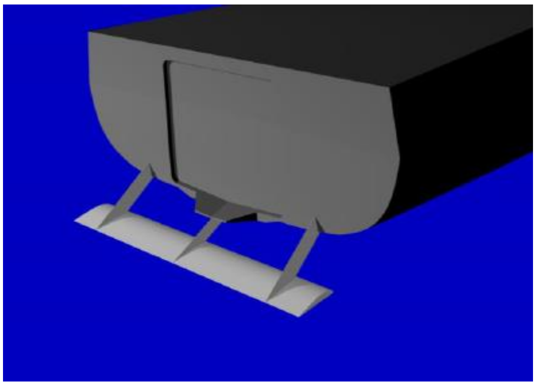

Figure 18: Typical integration for a Hull Vane® [2]

Thus it extends aft of the Aft Perpendicular of the ship and tends to increase the overall length of the ship. Taken in consideration early enough in the project this does not present in any particular problem, except the interferences with systems deployed astern of the ship (see §7.3 below).

Some attempts have been made to integrate a Hull Vane® below the hull (without extending aft of the transom). This would take care of the interference issue.

However such integration would in turn create new problems with the position of the rudders and propellers which would have:

- Either to be moved further forward. This is not practical in general as the hull form does not allow setting a propeller of sufficient diameter in a more forward location.
- Or fit it between the hull and the rudders, as illustrated below (Figure 19), which entails probably creating a recess in the hull above and creating hydrodynamic interferences with the rudders.

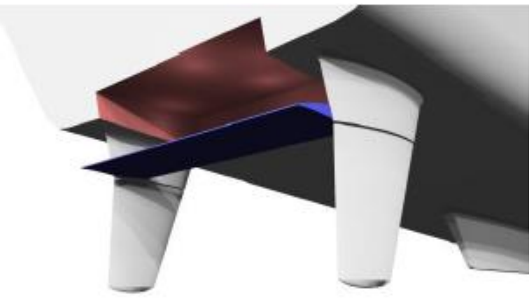

Figure 19: Integration under the hull

The latter approach was tried but showed a significant drop in benefits, notwithstanding the risk regarding steering performance which was not evaluated.

In the end such a configuration is not deemed satisfactory.

7.2. Structural integration

Since the Hull Vane® generates significant forces, it must be expected that these forces will in turn be transmitted to the hull structure.

The Hull Vane® generates both horizontal and vertical forces. It acts as most stern appendages (flaps, wedges, interceptors) to reduce the natural tendency of a hull to trim bow up at a speed. But, and that is not the case of other stern appendages, it also develops a forward pushing force which helps in reducing powering requirements.

These forces must be evaluated and used as inputs both for:

- local reinforcement at the junction of the Hull Vane® and the hull and
- Increment in hull girder bending moment

However, one must also consider the positive impact of the Hull Vane® on slamming loads. It was found to have up to 50% reduction of these structural loads. This will have a positive impact on hull bottom structural scantlings but also will in turn reduce the hull girder bending moment seen by the ship in waves.

The latter effect is more difficult to evaluate. It would require segmented model testing to determine its effect on the design bending moment, which currently englobes the slamming effect without being able to single it out.

7.3. Interferences with stern deployed systems

Military ships often use systems that are deployed from their stern:

- Towed arrays,
- RHIBs,
- Unmanned systems (UUV for example).

Therefore it is important to identify the risk of interference between such systems and the Hull Vane®.

These systems are usually deployed with a speed of advance for sufficient stability. As a result; one should not look at the risk of direct interference at the point where the system is launched but along the trajectory it will follow.

Although specific investigations have not yet been conducted in this regard we may divide these systems in two categories:

- Systems that naturally float on the water (boats, surface vehicles in general),
- Systems that tend to sink and are towed by the ship (towed array).

7.3.1. Boat Launch

In that case the boat should not interfere with the Hull Vane® as the foil is at a significant depth and furthermore the pitch motion is reduced precisely through the effect of the Hull Vane®.

If there is a risk that the foil will lift up sufficiently in a pitch movement to hit the bottom of the boat during the launch operation, it is most likely that the sea state is too high already for launching the boat. There would in this case also be a risk of running the boat under the transom.

This of course must be carefully established by dedicated analyses (CFD simulations) or model testing, but is the authors belief that it will not be a problem in the end.

Other model tests on a naval ship, with open stern ramp, have indicated that the water level on the stern ramp fluctuates less with the Hull Vane®, making it easier to time the safe re-entry of a daughter craft. The turbulent zone behind the transom (reverse wake) at low speed is also less with a Hull Vane® than with a trim wedge for example.

7.3.2. Sonar launch

In the case of a stern launch of an immersed body, such as a towed array for example, it must also be looked at carefully.

However, as mentioned before, the trajectory of the body being launched in the water will slide aft as it immerses deeper into the ship wake. It is quite possible therefore that there will be no interference at all.

There again, the pitch motion of the ship is reduced by the effect of the Hull Vane®. Furthermore, the stern heave is especially reduced. The Hull Vane® acts as a hydraulic damping of the stern motion.

Note that another effect of the Hull Vane® is to flatten out the ship wake. This has been clearly demonstrated through model testing as well as in real ship installations. The reduced wake turbulence will reduce the vibrations in the cable of a towed array, and the reduced underwater noise will improve sonar performance.

Some simulations are required in order to decide whether something must be done or not.

In case it is decided that the risk is too high to maintain this arrangement, one solution to the problem may be to add a stern overhang aft of the transom. Such overhang is common for ships with waterjet propulsion and is well mastered as far as its design implications (see Figure 20).

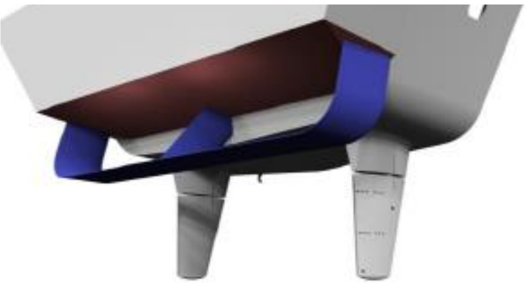

Figure 20: Stern Overhang arrangement

If identified early, the stern overhang also enables more internal deck space at the stern of the ship and extending the helicopter deck. Thus it has additional benefits that must be factored in the decision.

8. WHAT ARE THE PERSPECTIVES?

The extensive review of the benefits of a Hull Vane® carried out in this research project by Naval Group has helped forge a view on the possibilities offered by such a system.

8.1. Not only for high speed ships

The first conclusion that can be drawn is that, contrary to all competing stern appendages known today (including wedges, flaps and interceptors), the Hull Vane® operates not solely by modifying the ship trim but also profoundly changes the hydrodynamic flow at the stern, affecting the ship wake in particular.

The result of this action is that positive effects are seen at rather low speeds (if not at all speeds) while other stern appendages see a reverse trend usually at such speed (increased power).

Thus, Naval Group will consider Hull Vane® potentially in most projects and determine if the benefits are sufficient to justify its use.

8.2. Improvement in seakeeping

The second conclusion from this work is that seakeeping can be greatly improved by using a Hull Vane®.

The impact of a Hull Vane® on pitch motion in particular is a significant progress, not possible with any known appendage.

That in itself makes the Hull Vane® also of interest for nearly any military ship, gaining operability and therefore having an advantage over other ships of the same size.

This leads to a whole new perspective: it may be of interest to consider an active version of a Hull Vane® in order to push further the seakeeping improvement.

In addition to reducing pitch motion, one can easily see that the damping effect of stern heave will also result in moving the natural pivot point of the ship further aft than is usually seen. Thus it is possible that a forward T-foil, such as those commonly used to stabilize high speed ships, could be very effective as its righting arm is further increased thanks to the Hull Vane® (Figure 21)[1].

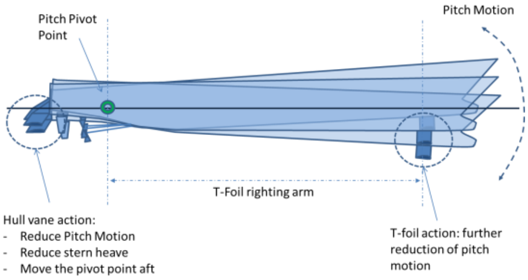

Figure 21: Combined effect of Hull Vane® and T-Foil

Since T-foils are already “sea proven” solutions. This arrangement is of particular interest as it does not require a more complex design of the Hull Vane® itself, thus resulting in minimal risk.

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[1] Both the dynamic/active Hull Vane® and the combination of a Hull Vane® with a forward-placed T-foil are patented solutions.

Before considering such an upgrade however, one should carefully weigh the interest of converting what is a rather simple and rugged system (no moving parts, only structures, with a hydrodynamic profile) into a more complex system. However, depending on the additional seakeeping gains, this may be considered.

8.3. Carefully consider integration issues

Finally, as was discussed in the paper, careful consideration must be made regarding integration issues.

Interferences with stern launch in particular must be looked at, taking a deeper look into such interactions before adopting the best configuration.

Thus it is not considered that having some form or other of stern launch is incompatible of a Hull Vane®.

9. REFERENCES

[1] DRDC – Hydrodynamic design of a stern flap appendage for the HALIFAX class frigates – MARI-TECH – June 2006

[2] Bruno Bouckaert & al. – A Life-Cycle Analysis of the Application of a Hull Vane® to an Offshore Patrol Vessel – FAST 2015 – February 2015