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HIGH PERFORMANCE CONTROLLABLE PITCH PROPELLERS FOR LOW ACOUSTIC SIGNATURES

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Abstract: *In order to maximize the design of the Controllable Pitch Propellers for low acoustic signature it is necessary to analyze more aspects the general features of propeller and the effect of air emission, the effect of cavitations by using different computer programs which can stimulate a lot of parameters developed on the model on scale and on the full scale model. The result made possible a new way for improvement of design techniques to obtain more and more less noisily Controllable Pitch Propellers*
Key words*: Ship propulsion, propeller, cavitations*

1. INTRODUCTION. GENERAL FEATURES OF THE CONTROLLABLE PITCH PROPELLERS SYSTEM

VA TECH Escher Wyss has delivered or has on order complete propeller systems for five different MEKO® Class Frigates for four different end users. All of these systems are equipped with shaft line mounted actuating units. Four of these sets have an air emission system with the air inlet box being located at the forward end of the gearbox.

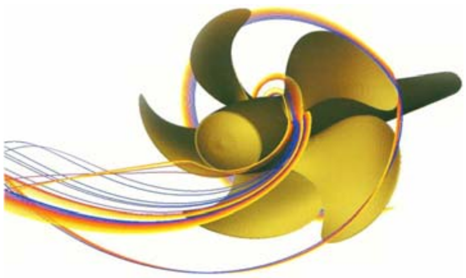

Figure 1: Escher Wyss Controllable Pitch Propellers with calculated streamlines

2. BLADE BEARING SYSTEM

Escher Wyss Controllable Pitch Propellers are commonly known for their unique type of blade fastening. The Escher Wyss hubs of the trunnion bearing type with blades and trunnions cast in one piece are especially applicable for naval vessels, see Figure 2 (below). This design delivers the following beneficial features:

• By eliminating blade bolts, the flow in the blade palm area is smooth which reduces the vortex formation and delays cavitation inception. With bolted-on blades, the bolt heads and the pockets in the blade root constitute flow obstacles which can contribute to early inception of cavitation.

• The number of propeller blades can be increased up to seven with an acceptable low hub ratio (approx. 32%).

3. HUB SHAPE

The hub shape has been developed in order to achieve a minimum hub resistance and a high inception speed of the hub vortex cavitation. Cavitation predictions in the model scale as well as full scale viewings confirmed that, for this type of hub shape, hub vortex cavitation is not present during a straight ahead course. During the full scale viewings, such vortex cavitation could only be observed at extreme propeller loadings in the maneuvering mode.

4. AIR EMISSION

Emitting air (see Figure 2), can reduce or eliminate the increase of the noise levels associated with cavitation inception at the higher frequency range. The emission of air is also effective at ship speeds with developed cavitation. The large number of delivered propellers with air emission systems for naval vessels is proof that the benefits of this system are highly appreciated. Up to date, any detrimental impact of the air emission on the propeller efficiency could not be verified during the sea trials (and is impossible to detect in model scale). No erosion damages around the blade air emission holes have ever been discovered.

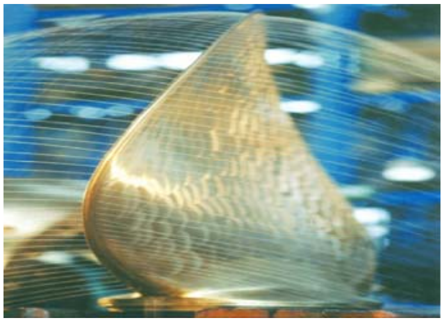

Figure 2: Air emission test with water

5. DEVELOPMENT OF THE BLADE DESIGN

By making immediate use of the rapid progress in computer technology of the past 25 years, VA TECH Escher Wyss was able to optimize the blade designs on computer screens. At present VA TECH Escher Wyss is able to adapt a blade design completely to the given design conditions by calculation, prior to verifying the design by model tests. The major progress consists of the ability

to control the blade design's cavitation behavior and thus increase the cavitation free ship's speed without sacrificing propeller efficiency. However, although the present design tools, as well as the analytical procedures enable the propeller designer to optimize the blade geometry, the hull and appendages ahead of the propeller regulate the limits for a successful blade design. Therefore, if a quiet propeller is required, the ship's hull and appendages must be appropriately designed and fabricated.

6. WAKE DATA PROCESSING. 3D-WAKE SURVEY

For the adaptation of the blade design to the given wake field, an experimental 3D-Wake Survey is necessary. The blade designer is able to optimize the blade geometry locally after access to all three velocity components in the propeller plane.

Usually, navy vessels are twin screw vessels whose wake field typically looks like the one illustrated in Figure 3. The wake survey report of the model basin comprises, as a standard, the plot of the transversal components (top plate) as well as the axial velocity isolines (bottom plate). The wake peak due to the propeller shaft is clearly visible as well as the spikes created by the struts. An illustrative presentation of the "wake peak" shows the mountain in the middle of the plot where the region of reduced axial velocities are readily visible as a groove.

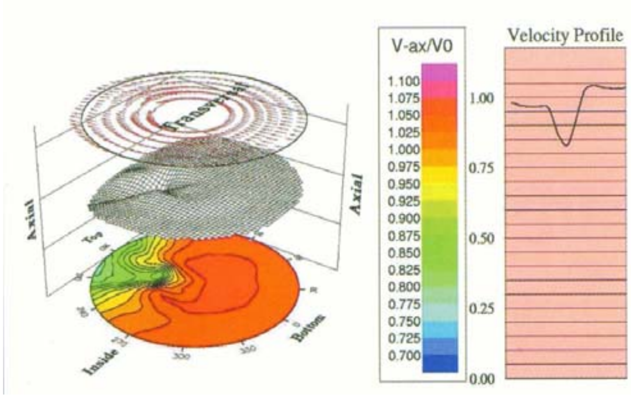

Figure 3: Typical 3D wake of a twin screw navy vessel

7. WAKE ADAPTION OF THE BLADE DESIGN. BLADE TIP AND BLADE SURFACE

The wake adaptation of a blade design consists of step by step modifications to the blade geometry and to the subsequent cavitation calculations. Though VA TECH Escher Wyss has developed strategies for the wake adaptation of ship propellers, a sizable number of calculation loops remain necessary to reach a satisfactory status.

When considering blade geometry, the cavity volumes and cavitation extension are calculated with the program system PUF-3A, which was originally developed by the M.I.T., Cambridge, Massachusetts and has been continuously updated by the University of Texas in Austin, USA. PUF-3A calculates - for a given wake field and blade geometry - the surface pressure on a large number of panels on the blade surface, and, based on sophisticated criteria (not only the vapour pressure), determines whether cavitation will take place at this panel. From the surface pressures on the suction side and pressure side, mean values as well as the fluctuations of the forces and moments for the cavitating and non-cavitating case are computed. The pressure pulses on a given hull can be calculated by means of the utility program HULLFPP (another M.I.T. product).

The present design-tool PUF-3A is based on a potential theory technique, which does not allow the prediction of the tip vortex structure and the complex processes in the vortex.

8. DEVELOPED CAVITATION

The large differences between the calculated developed cavitation and the calculated incipient cavitation in the chordwise extension, as well as in the cavity volumes, require different post-processing techniques. In order to visualize the developed cavitation, VA TECH Escher Wyss has implemented a rendering program which superimposes the calculated cavitation as well as the surface pressures on the three-dimensional blade surface, as illustrated in Figure 4. With decreasing pressure the colour changes from blue to red. The suction side sheet cavitation is depicted in pink in order to distinguish between the regions of low pressure from those regions in which the program predicts cavitation. On the back, where a low pressure area has been calculated, the cavitation inception criterion of the program is not satisfied. Nevertheless, by experience, mid-chord bubble cavitation has to be expected.

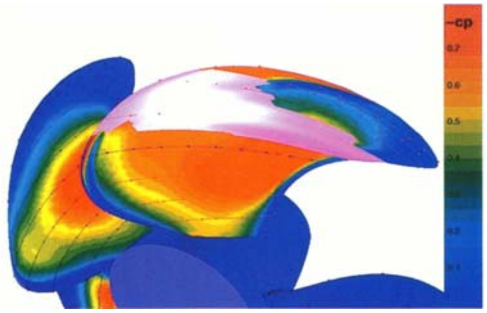

Figure 4: Calculated developed cavitation (PUF-3A)

9. INCIPIENT CAVITATION

Cavitation inception is crucial for the noise signature of a vessel's propeller, and for this necessitates a precise determination of the first indication of cavitation. In order to depict the few cavitating panels which have only a small chord wise extension of cavitation, a specific kind of presentation is needed. Figure 5 shows a typical plot of incipient cavitation that is characterized by a small angular sector in the vicinity of the top position of the blade where the cavitation occurs, and by the restricted radial extension.

The colour scale facilitates the identification of the chord wise extension of the cavitation sheet. In comparing the cavitation extension as calculated in this manner with full scale viewings, it has been found that calculated sheet lengths up to 1% chord length seem to vanish in an uncertainty range, and that cavitation sheet lengths only greater than 1% chord length are significant. PUF-3A is not able to calculate tip vortices. This appears to be an important disadvantage. However, previous studies showed, that the presence of a tip vortex agreed with the program's indication of a sheet cavitation which might be sufficient for a practical approach.

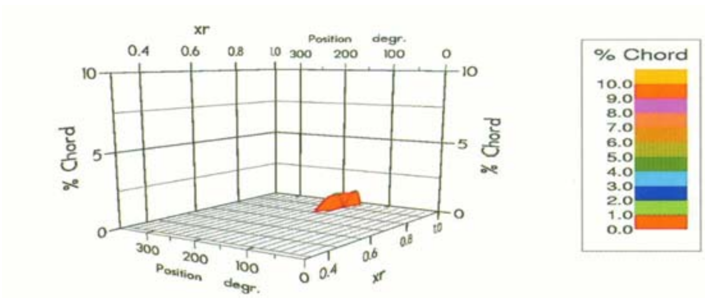

Figure 5: Calculated incipient cavitation ***(PUF-3A)***

10. BLADE ROOT

In the past, interest has been focused on the flow around the blade tip since the cavitation inception used to first occur here. Meanwhile, the analysis tools and countermeasures have been developed in such a way that the blade tip does not necessarily constitute the inception point of cavitation on the propeller. In some cases, cavitation inception has been observed earlier on the root (or even on the appendages). Therefore, the knowledge of flow phenomena in the root region is of interest, in particular if the blades are fastened with blade bolts.

11. SIMULATION OF CAVITATING TIP VORTEX

The simulation of three dimensional tip vortex structures at Controllable Pitch Propellers becomes significantly more stringent when dealing with noise target requirements. The induced vortex from the blade tip is strongly dependent on friction and turbulence structures. VA TECH Escher Wyss simulates such tip vortices with a RANSE-solver. The RANSE-solver FENFLOSS (Finite Element based Numerical Flow Simulation System) has been developed by the University of Stuttgart's Institute of Fluid Mechanics and Hydraulic Machinery. FENFLOSS is able to calculate the three dimensional, turbulent flow under consideration of the friction around the propeller. Both blades have been calculated with FENFLOSS for three different operation points each simulating the wake peak, the mean wake and the minimum wake. The propellers investigated by VA TECH Escher Wyss are highly loaded. Furthermore, they are characterized by a small rake and a reduced pitch near to the blade tip. The skew is adapted to the wake. One blade is meshed with roughly one million calculation elements for simulations. The wall shear stresses are calculated with a logarithmic wall function. The wake ahead of the propeller is simplified as a homogeneous boundary condition. The influence of different operation points is realized through various axial velocities at the inlet of the calculation model. A radial constant axial velocity is thus defined as an inflow boundary condition. Additionally a degree of turbulence of 5% is applied at the inlet. A natural boundary condition dp/dx=0 is defined at the outlet. A symmetrical boundary condition is applied for the surface of the calculation model. Three different wake fractions are compared for the studied blade geometry. Figure 6 shows a comparison of streamlines around the tip of each propeller blade. It seems that the variant two can hamper the tip vortex rolling up.

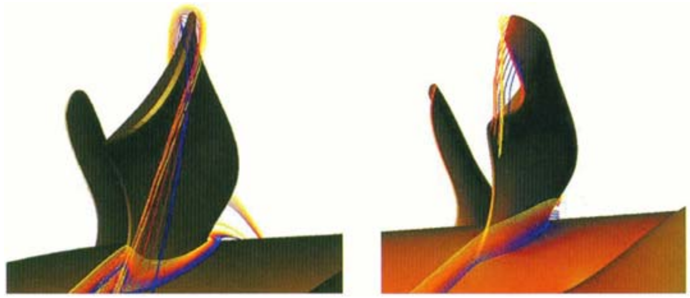

Figure 6: Comparison of two geometrical variations of blade tip with calculated streamlines (FENFLOSS)

However, the evaluation of the pressure distribution behind the propellers illustrates that the low pressure peak for both geometries is quite similar, as to be seen in Figure 7.

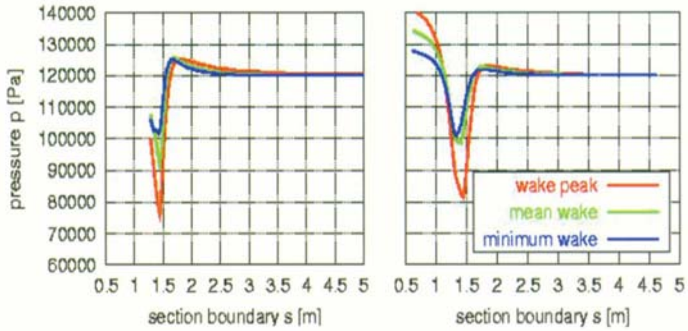

Figure 7: Comparison of the calculated pressure distribution behind the propellers for both geometries (FENFLOSS)

12. CONCLUSIONS

Due to the strong impact of the hull and appendages on the propeller performance, the given wake field constitutes the limits for a successful blade design. Therefore, the ship's hull and appendages must be designed and fabricated appropriately if a quiet propeller is required. By means of a M.I.T. program system, the cavity volumes and the surface pressures of a given blade geometry can be calculated and optimized in several design loops.

However, the analysis shows clearly that the variation and calculation of a propeller with modern RANS-solver is possible and leads to a new way of propeller design.

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