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Cavitation of a Propeller and Influence of a Wake Equalizing Duct

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ABSTRACT: The wake equalizing duct (WED) is one of the most commonly used energy saving devices for improving the propulsion performance of a ship and reducing the propeller-excited vibrations and viscous resistance forces. During the last three decades considerable research and development activities have been done within this context. Most of these devices are used to improve propulsive efficiency, but some of them aim to improve other performance characteristics, such as cavitations, vibration, noise, maneuverability, etc. Marine propellers are the most common propulsion systems; nevertheless, it is possible to improve their propulsive performance using additional auxiliary propulsion devices (unconventional propulsors). Two versions of an existing ship in normal version and fitted with WED were analyzed in order to demonstrate the influence on the WED on the propeller cavitations. It was determined that the values for the pressure coefficient are 1.98 for the case without WED and 2.029 for the case with WED. The difference is not so significant; thus, the conclusion is that the WED device did not influence the cavitations of the propeller. Moreover, the optimization of the dimension and form of WED did not help in reducing negative effects of cavitations. Because this paperwork is not a study, in order to decrease the cavitations we have other choices including a sound design of the propeller biased to improve the propeller behavior in cavitations. WED is clearly not a choice.

1 INTRODUCTION

One of the energy saving devices used widely in ships is the wake equalizing duct (WED) (Schneekluth's duct). It consists of two aero foils sectioned half-ring ducts integrated to the hull in front of the upper region of the propeller. Some important parameters for the effectiveness of the WED are the angles of duct axis to ship's center line plane, longitudinal positions, inner diameters, profile section shapes, angles of section to duct axis and lengths of the half-ring ducts. It is assumed that the WED accelerates the inflow of the upper region of the propeller where the flow is slow relative to the lower region of the propeller; and it improves the uniformity of the wake over the propeller disc, so the propeller efficiency is increased. In addition, a well-designed WED reduces the amount of flow separation at the after body, generates an additional thrust as in the accelerating type of duct, reduces the propeller excited vibrations due to the uniform wake, and improves the steering qualities because of the more straightened flow coming to the rudder. If the WED is installed to an existing ship, constructional changes or adaptation of the propeller design are not needed. A WED can also be used in combination with other energy saving devices such as vane wheel and asymmetric stern (Schneekluth, 1986).

Marine propellers are the most common propulsion systems owing to the high efficiency supplied by them; nevertheless, it is possible to improve its propulsive performance using additional auxiliary propulsion devices (unconventional propulsors). During the last three decades considerable research and development activities have been done within this context. Most of these devices are used to improve propulsive efficiency, but some of them aim to improve other performance characteristics, such as cavitation, vibration, noise, maneuverability, etc. There can be found a lot of review studies about various unconventional propulsors in Glover (1987), ITTC (1990), Blaurock (1990), Patience (1991), Breslin and Andersen (1994), and Carlton (1994).

Schneekluth (1986) reports that the effectiveness of a WED is most evident if the ship speed is between 12 and 18 knots and its block coefficient is higher than 0.6.

By now, most of the studies related to the estimation of the effect of the WED on propulsion characteristics of a ship have been carried out based on model tests. But it is difficult to extrapolate the powering performance from model tests (especially for very large ships) due to the Reynolds number effects (scale effects) stated in ITTC (1999). At higher Reynolds numbers the scale effects occurs more evidently, in such cases it is recommended that self propulsion tests should be performed to reduce these effects (ITTC, 1999). In addition, numerical flow computations as an alternative of the model tests can also be used to estimate the effectiveness of the WED.

One of the issues of intense debate is whether or not the WED device has any influence upon the cavitation conditions that appear when the propeller of a maritime ship is rotating.

2 CAD AND FINITE VOLUME ANALISYS (FVA) MODEL OF THE SHIP

The goal of this paper is to calculate via software Ansys 13™ the influence of placement of a WED to an existing ship over the propeller behaviour in terms of cavitation.

The model has as a starting point a real port container as seen below, with the following parameters:

- Length L- [m]- 173
- Breadth B- [m]- 25
- Draught T -[m] -9.50
- Diameter D- [m]- 5
- Number of blades Z - 6
- Propeller RPM-120
- Average Speed-16 knots (7 m/s)

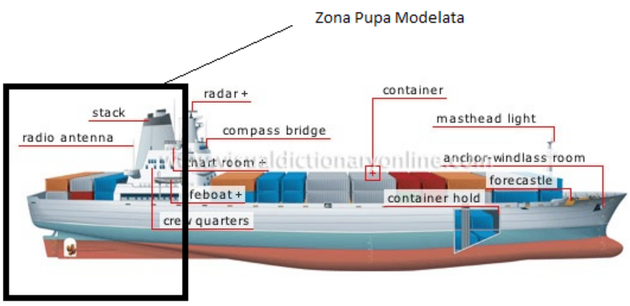
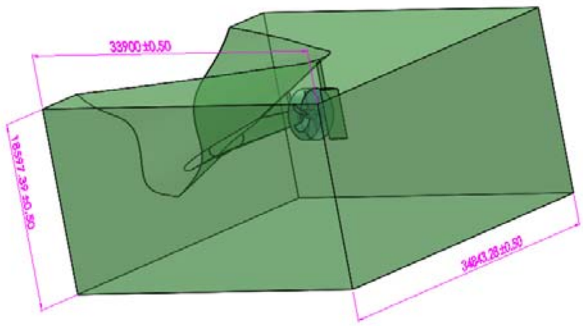
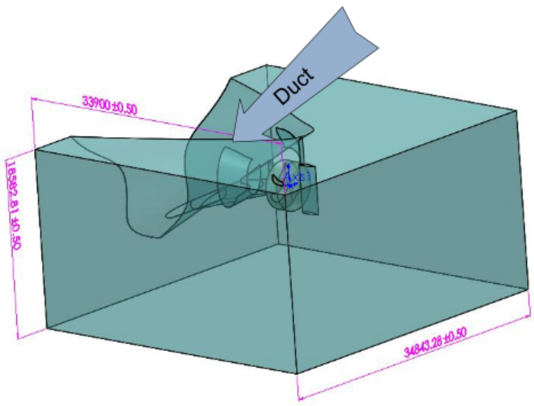


Figure 1. Port-Container

In order to have a starting point for the simulation, first of all the afterbody was firstly CAD generated without the WED device, and all the parameters for fluid flow were calculated accordingly. Secondly the WED device was attached to the CAD ship afterbody and, using the same boundary parameters for this second simulation, made possible to compare the results and draw the proper conclusions. The two CAD geometries are shown below:



a.



b.

Figure 2. CAD geometries a-without WED, b-with WED

In order to provide more details on the geometry of WED device, the below figure is shown, with dimensions in [mm]:

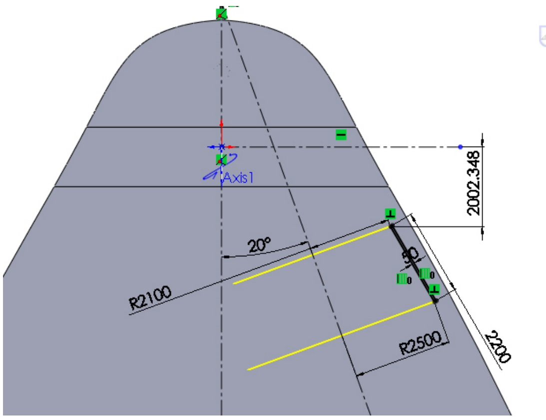


Figure 3. WED device geometry

The fluid area was divided in two: the fluid area which surrounds the afterbody having the relative velocity on Oz axis of 7 m/s and the Propeller fluid area with CFX option of “frozen Rotor” where the fluid is moving circularly around OZ axis with 120 RPM. There were established interfaces between these two areas. The other boundary conditions were inlet, outlet and openings as shown below:

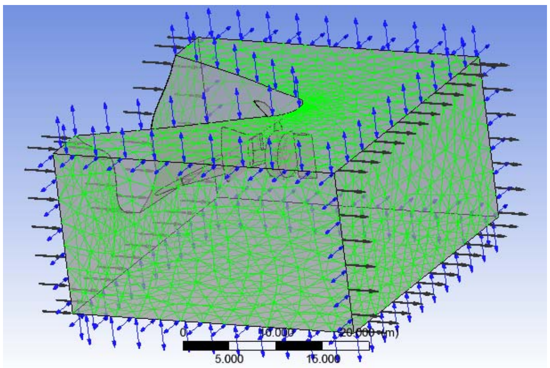


Figure 4. Boudary Conditions

In order to make clear some important surfaces, three control planes were defined as follows:

Control plane number 1 (P1) placed at 1200 mm above the propeller axis and coplanar with the two WED devices axis;

Control plane number 2 (P2) which includes the propeller axis;

Control plane number 3 (P3) placed at 1500 mm away from the propeller domain;

Target Plane which is in fact one of the propeller interfaces as below:

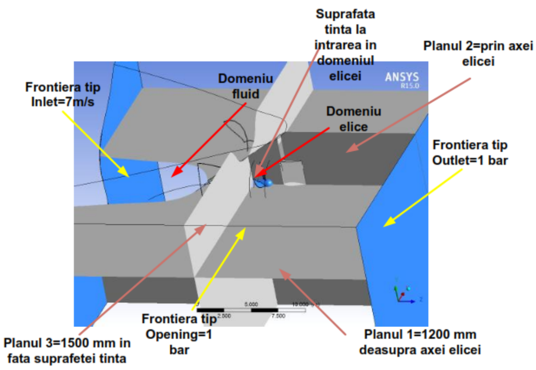


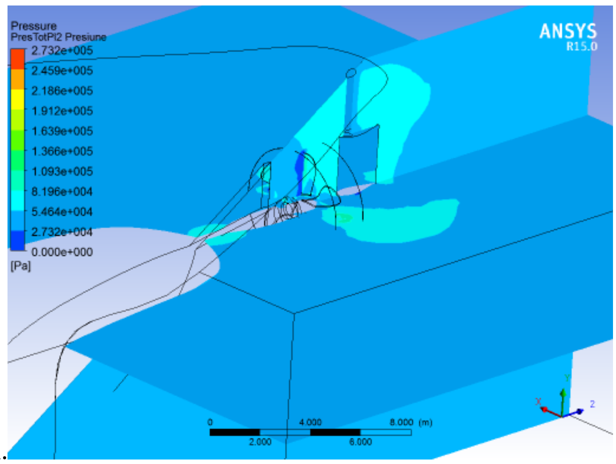
Figure 5. Control Planes

Cavitation is the phenomenon that appears in low pressure zones of a rotating propeller where fluid vapours are prone to develop. Cavitation is a harming phenomenon tending to destroy the integrity of the propeller surfaces by the implosion of the vapours near the surface leading to the pitting of those surfaces. To simulate this phenomenon in FVA a homogenous multiphase flow of the fluid will be considered. For this the absolute saturation pressure is 3574 Pa.

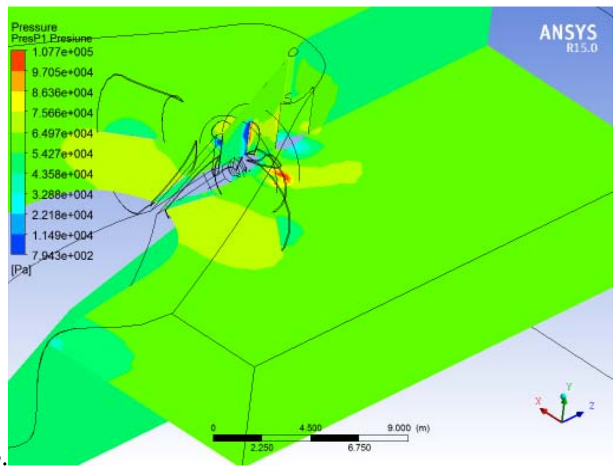
3 FINITE VOLUME ANALYSIS (FVA) SIMULATION AND RESULTS

After reaching the convergence of the given models, some important results were calculated. Next, the two models are presented simultaneously in order to ease the comparison.

Pressures in control planes P1 and P2



a.



b.

Figure 6-Pressure fields for P1and P2
a-without

By comparing the above figures, the maximum of pressures for WED free version is 2,72e5 Pa whereas the WED retrofitted version is 1,077e5 Pa.

At the same time the shape of pressure fields is different for the two versions, the inner zone of the WED has bigger pressure fields.

Fluid velocities on control planes P1 and P2

a.

b.

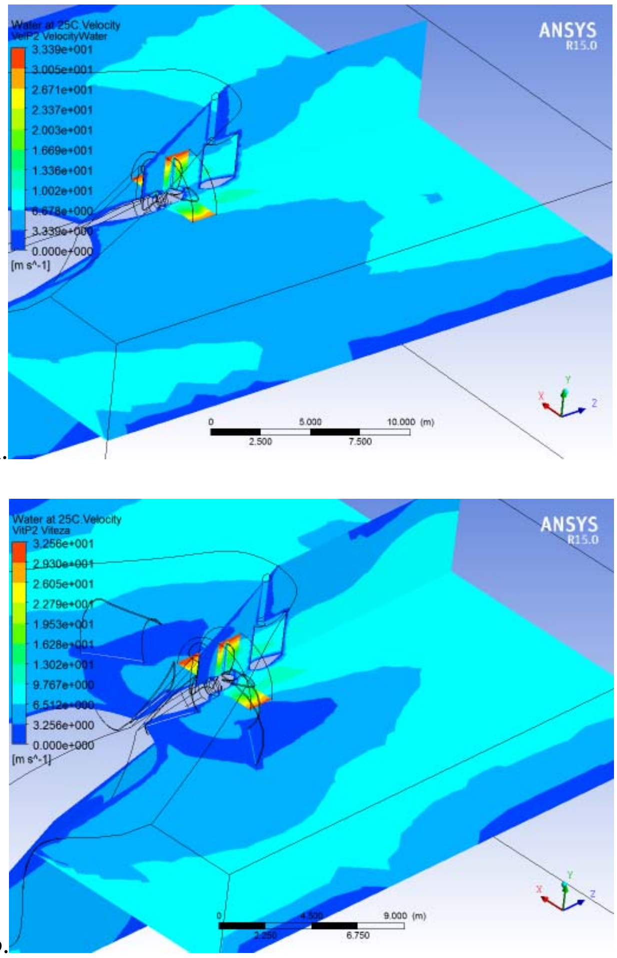


Figure 7. Velocity fields for P1 and P2
a-without WED; b-with WED

Velocities for P3 control plane

a.

b.

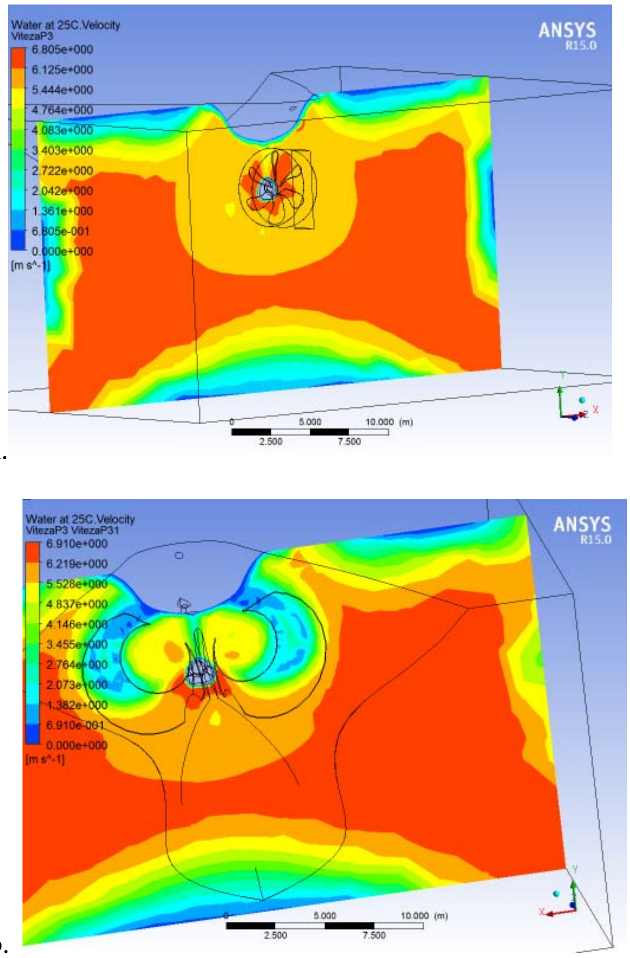


Figure 8. Velocity fields for P3, a-without WED; b-with WED

The maximum velocities are bigger for the afterbody with WED (33.56 m/s). Near and after the WED devices the fluid velocities are smaller indicating a “screening effect”.

This P3 plane is near to the Target Plane (1200 mm away) so that the influence of the propeller rotation motion is not so obvious here. As seen above the maximum velocity in both cases is the same (6.8..6.9 m/s) but field distribution is altered, the WED devices concentrating the mass flux toward their centres and , implicitly, toward the Target plane. In plane words, the WED is “stealing” streamlines of fluid from the besides of the body and is concentrating them over the Target Plane at the upper part of the propeller.

Pressure Fields over the Target Plane

The target plane as mentioned is positioned exactly on the entering zone of the propeller fluid domain where no doubt, the influence of propeller motion is the most pregnant. In order to quantify the variation of pressure induced by WED, a new variable is defined to calculate the average fluid pressure on the target Plane:

Area Ave(Pressure)@Target

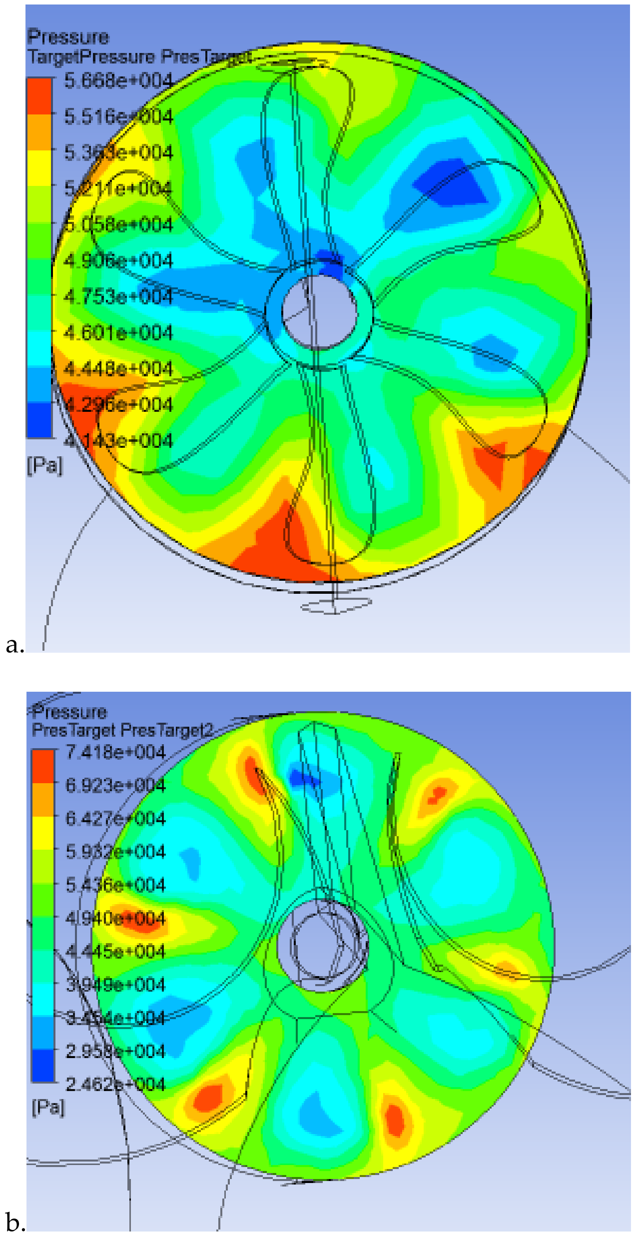


Figure 9. Pressure fields for target Plane
a-without WED; b-with WED

The average pressure calculated is 48,213 Pa for the WED free version and 49,823 Pa for the WED version meaning that is 103%.

Velocity Fields over the Target Plane

For the velocity fields the situation is quite reversed as compared to the above results. Introducing again a new variable to enable us to calculate the average velocities for the target plane:

areaAve(Velocity)@Target

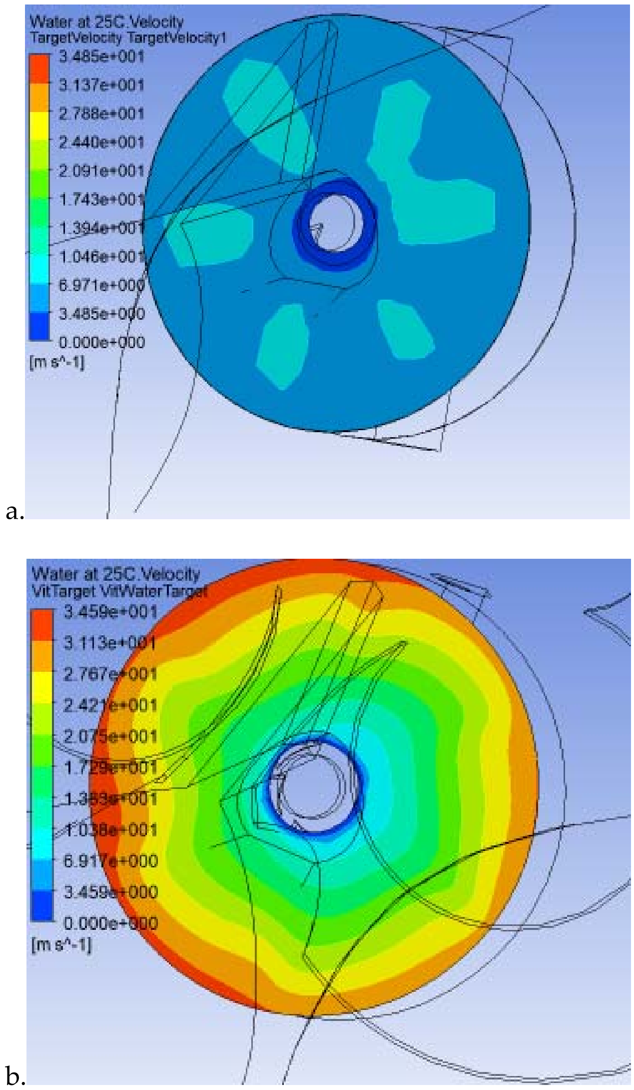
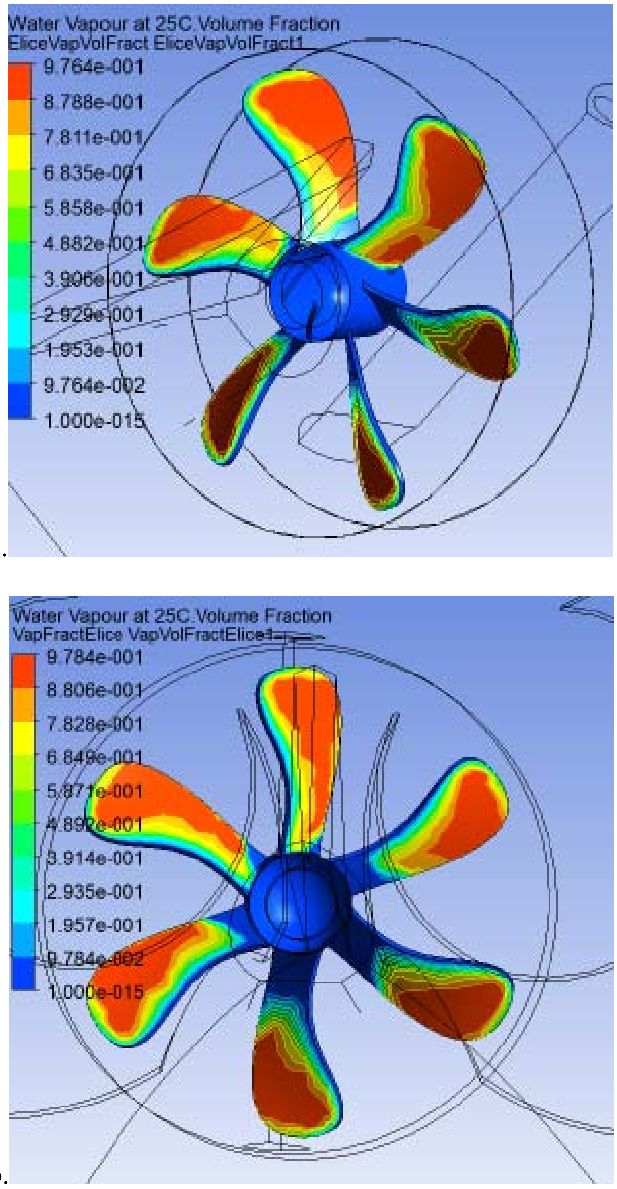


Figure 10. Velocities fields for target Plane
a-without WED; b-with WED

The WED free version is giving an average of 6.25 m/s whereas the WED version is giving 23.2 2m/s average velocity, meaning that the WED version is increasing with 363.2 % the mass flux over the target plane.

The vapour volume fraction for propeller blades



a.

b.

Figure 11-The volume of vapor fraction over the propeller a-without WED; b-with WED

The vapour volume fraction is the first and almost the best indicator of the cavitation appearing in that propeller zones. Whether the conditions for vapour development are good, then the formation of those vapours and their subsequent implosion is almost certain. By analyzing the above figures, it is becoming obvious that on the back of the blades (the blade's sides toward the ship) the vapour fraction has a maximum of 97.7 % for both cases and therefore, at first sight, there is no positive influence of WED over the cavitation conditions of the propeller. In order to quantify this we will need a new variable as below.

The average pressure coefficient on the blade surfaces

To have a certain picture over the average pressure coefficient causing the cavitation, a new variable is introduced as follows:

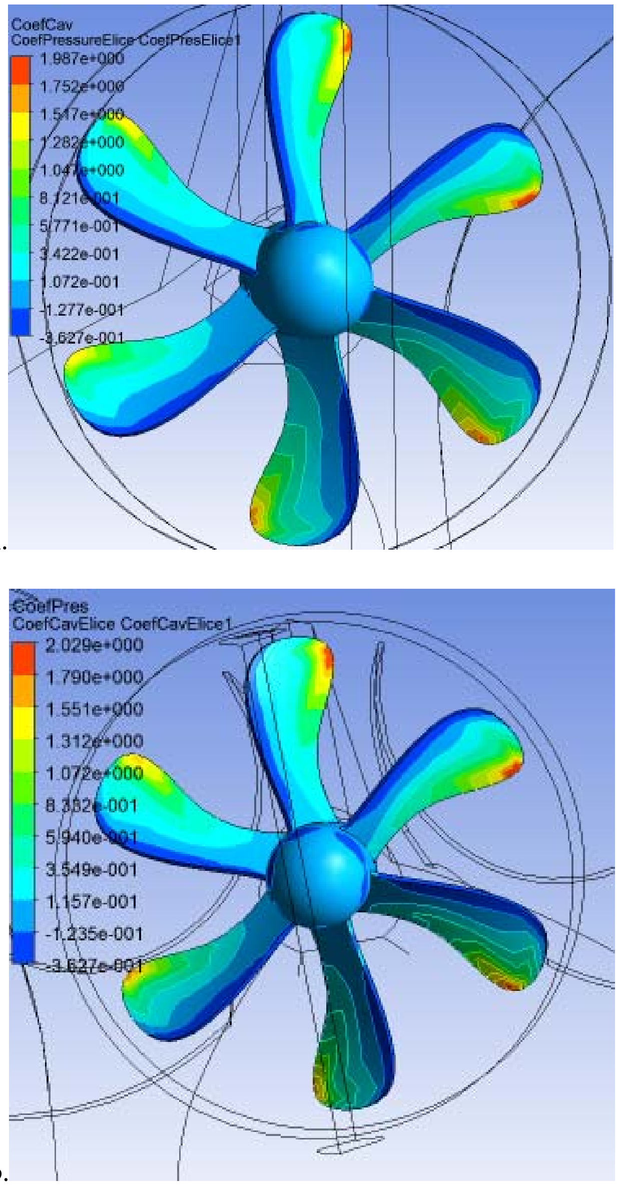
Coef Pres=(Pressure-51957[Pa])/(0.5*1002[kg m^-3]*16.91[m s^-1]^2)

where "Pressure" is extracting the pressure calculated for each and every cell of the propeller blade, 5195 Pa is the relative pressure, 1002[kg m^-3] is the sea water density and 16.91[m s^-1]^2 is the average velocity of the propeller.

The above formula is as per the equation:

$$C_{p\min} = \frac{p_{\min} - p_{\infty}}{\frac{1}{2}\rho V^2} \tag{1}$$

where p_{min} is the minimum pressure belonging to the propeller.



a.

b.

Figure 12. The pressure coefficient over the propeller a-without WED; b-with WED

The maximum values for this coefficient is 1.98 for WED free version and 2.029 for WED retrofitted version. The difference is so small that without chances of being wrong, the obvious conclusion is that WED device has no influence over the cavitation of the propeller. To decrease the cavitation we have other choices, including a sound design of the propeller biased to improve the propeller behaviour in cavitations. WED is clearly not a choice.

4 CONCLUSIONS

The wake equalizing duct (WED) is one of the most commonly used energy saving devices for improving the propulsion performance of a ship and reducing the propeller-excited vibrations and viscous resistance forces.

In this paperwork two versions of an existing ship in normal version and retrofitted with WED device were analyzed in order to demonstrate the influence of the WED device on the propeller cavitation (if any). It was demonstrated that the maximum values for the pressure coefficient is 1.98 for WED free version and 2.029 for WED retrofitted version. The difference is so small that without chances of being wrong, the obvious conclusion is that WED device has no influence over the cavitation of the propeller. To decrease the cavitation we have other choices, including a sound design of the propeller biased to improve the propeller behavior in cavitation. WED is clearly not a choice.

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