CRP POD PROPULSION FOR FAST ROPAX SHIP

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SUMMARY

In the last decade POD propulsion applications have significantly been growing mainly in the sector of cruise and ferry ship. Together with the development of Pod propulsion application, new interest arose about innovative solution of podded propulsor by the study of hybrid solutions.
Among different possible configuration, the concept of CRPP arrangement obtained by mounting an azimuthing pod immediately behind a standard propeller seemed to be quite promising as demonstrated by early real applications of this new propulsive arrangement.
Within the INTEGRATION(*) project the application of this propulsion system to a fast Ropax ship (30 knots) is investigated as an alternative to the traditional twin screws solution.
In order to explore the advantages that the CRPP solution should provide the performances of this new solution were analysed by means of a comprehensive campaign of model tests including resistance tests, 3D wake measurement, self propulsion tests and cavitation tunnel tests.

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NOMENCLATURE

υ	Kinematic viscosity (N s m^{-2})
ρ	Density of water (kg m^{-3})
P	Pressure (N m^{-2})
J	Propeller Advance Coefficient
D	Propeller diameter (m)
K_T	Propeller Thrust coefficient
K_Q	Propeller Torque coefficient
η_o	Propeller Open Water Efficiency
n	Propeller round per minute (RPM)
Kp	Pressure pulse coefficient
C	Single amplitude pressure fluctuation (Pa)
P05	Mean value of 5% highest pressure pulse (kPa)

1. INTRODUCTION

Steady increase in pod propulsion application may be justified by some certain advantages offered by this propulsion system such as extremely good manoeuvrability in harbours and freedom to the general arrangement.

Among different pod installation the concept of the CRP pod solution has recently witnessed a growing interest.
Of course the installation of one conventional propeller limits the freedom in the general arrangement offered by traditional pod solutions, but contrarotating solutions can offers high propulsive efficiency. Moreover the large pod unit introduces some resistance and transforming mechanical power into electrical take normally 10% of the total efficiency (considering to substitute traditional twin propellers with two pods), but in the case of CRP pod only a loose of 5% in the efficiency can be expected being the forward propeller mechanically driven.

In this context the present research work was primarily addressed to assess the advantages and potential risks of this propulsive solution. To this end it was decided to investigate the limiting case of a single screw fast Ropax having a maximum speed of almost 30 knots, expecting that for a less extreme design the hydrodynamic problems posed by this system would be amenable to an optimal solution.

The research was based on a comprehensive campaign of model tests involving:

Towing Tank Tests:
- Bare hull resistance tests
- 3D wake measurements with five hole spherical tube at one draft and one ship speed. Measurements will be taken at four radii and every 15°
- Self propulsion tests

Cavitation Tunnel Tests:
- Open water test with pod unit and main propeller combination for two RPM-ratio
- Thrust and torque measurements at varying tunnel speeds
- Cavitation observation at different pod rotation angles
- Pressure pulse measurements at two speeds at 8 positions above the propellers.

The manufacturing of the models (ship, main and pod propellers, pod and rudders) and the performance of the tests have been made by SSPA.
All the model tests have been performed at the design draft (6.80m).

2. DESIGN OF THE CRPP SYSTEM

2.1 MAIN CHARCTERISTICS OF THE SHIP

The main characteristics of the ship were defined taking as reference a traditional twin screws Ropax vessel previously designed; (Figure 1)

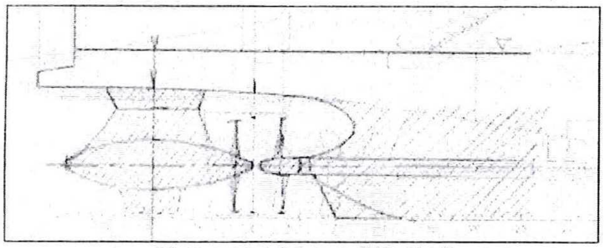

Figure 1: Aft part of the hull

The main characteristics of the ship are reported in the Table I and the body plan of the hull is shown in the Figure 2.

Length PP	181.20 m
Beam	27.20 m
Draft	6.80 m
Displacement Vol.	18040 m^3
Design Speed	29 knots

Table I: Main characteristics of the ship

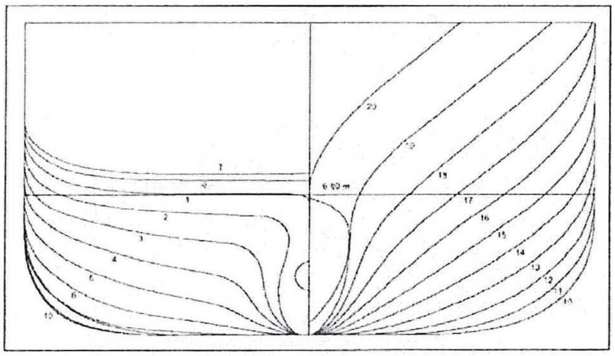

Figure 2: Body plan of the hull

2.2 MAIN CHARACTERISTICS OF THE PROPULSIVE DEVICES

The propellers used were designed by using SSPA's in-house lifting line and lifting surface code for contra rotating propellers (CONTRA), Ref. [1]. In order to reduce the amount of cavitation and vibration excitation the blade tip and root are relatively unloaded. Both the forward and aft propeller is designed using the same circulation distribution.

The propellers were designed with moderate skew blade shapes from families that have successfully been used at SSPA earlier. The blade sections are from a family developed at SSPA and are designed to give best possible cavitation performance. The propeller strength was calculated according to DNV rules.

The propeller designs are a 5-bladed forward propeller of 5.5 m diameter, with a blade area ratio of 0.87 and a pitch ratio at r/R=0.7 of 1.502 and a 4-bladed aft propeller of 5.15 m diameter, with a blade area ratio of 0.76 and a pitch ratio at r/R=0.7 of 1.455.

The main problem with the current propeller designs was the risk of cavitation erosion on the aft propeller. The induced velocities from the forward propeller make the cavitation on the aft propeller very unstable, especially when applying rudder angles to the POD. In order to achieve a reasonable power density on the propellers the power distribution between the propeller and POD was initially set to 50/50.

The figures below show a photo of the propulsive arrangement and the total propulsion characteristics, e.g both forward and aft pod propeller and including the drag of the pod housing.

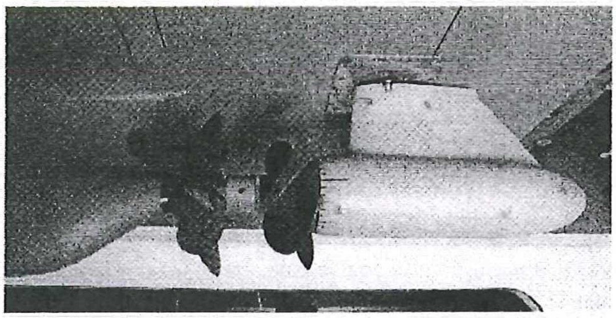

Figure 3: Propulsive arrangement

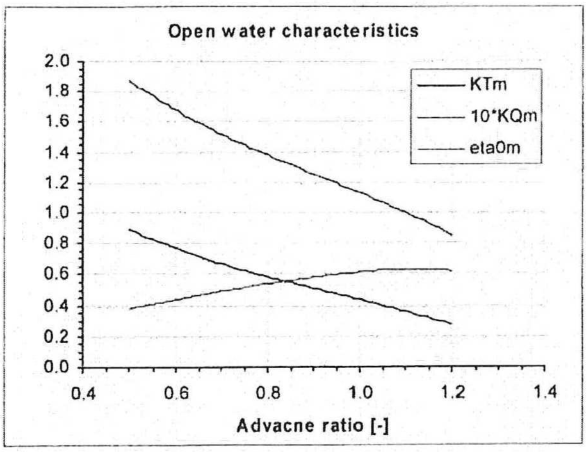

Figure 4: Propeller characteristics

3. EXPERIMENTAL TESTS

3.1 TOWING TANK TESTS

Resistance tests, wake measurement and self propulsion test were performed in the towing tank.

3.1 (a) Test Arrangement and Procedures

The model was loaded to a corresponding full scale volume and the corresponding drafts at the fore perpendicular and aft perpendicular were measured. The model was longitudinally connected to the carriage with a rod and an electrical transducer measuring the force between the model and the carriage. The rod was adjusted to be parallel to the base line at all tests and thus the force was measured in the horizontal direction.

The model was kept on course by two trim devices, one at AP and one at FP. The model was fixed to the carriage in surge, sway and yaw motions, while it was free to heave, roll and pitch.

The ship model was towed at the same Froude number as for the full scale ship. At the desired speed, model speed, towing force, vertical trim change at FP and AP, shaft rate , torque and thrust at shaft (main and POD propeller) were measured.

The wake field was measured at the propeller plane using 5-hole spherical probes. The measurements were made at four radii and at every 15° for each radius.

3.1 (b) Test Results

Resistance and self propulsion tests
At the self propulsion test a rpm ratio between the main and POD propeller of 1.19 was used.

The effective power and delivered power are plotted in Figure 5. 52% of the delivered power was contributed by the main propeller and 48% was contributed from the POD propeller. These data were evaluated starting from the experimental test following the ITTC'78.

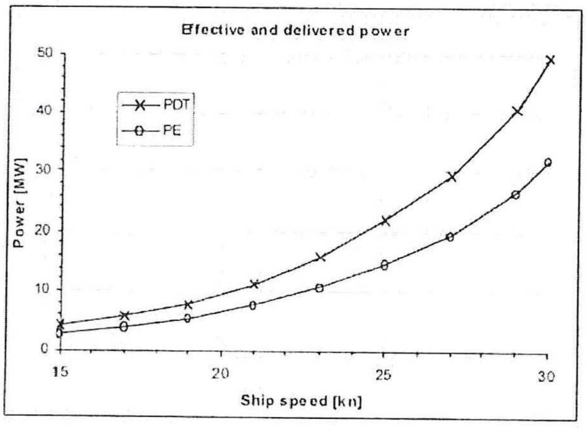

Figure 5: Effective and delivered power

Wake measurement
The wake measurement shows a symmetric wake field with low gradients and low peaks (Figure 6). The nominal wake factor was calculated to 0.22.

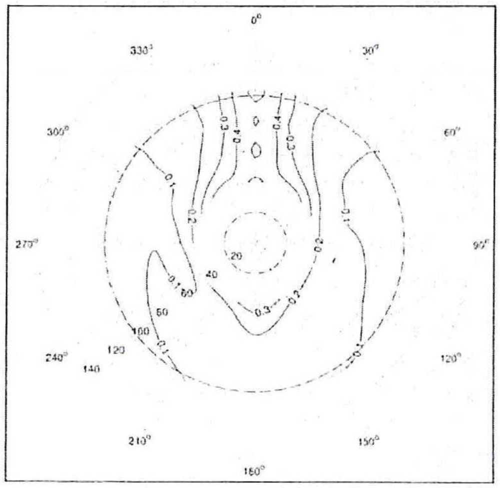

Figure 6: Wake measurement

3.1 CAVITATION TUNNEL TESTS

3.2 (a) Test Arrangement and Procedures

The complete ship model used in the towing tank was mounted in SSPA large cavitation tunnel (section no. 3, width 2.1 m, height 1.22m). The distance between the base line and the plywood sheet representing the water surface was corresponding to a draft of 6.8 m with allowance for the stern wave height.

Figure 7: Ship model installed in SSPA's large cavitation tunnel

The propeller models were powered by AC motors and the thrust and torque on the conventional forward propeller were measured by an Kempf & Remmers type dynamometer. The torque of the POD propeller and the POD thrust were measured using specially designed dynamometers. The motors and dynamometers are immersible and were mounted inside the water filled model. The tunnel water speed was kept constant at 7.5m/s during most of the tests. The propeller force measurements in behind condition at atmospheric pressure were mainly performed for determination of the effective speed of advance using KT-identity. The shaft rate was varied to cover the loading range of interest.

At the cavitation observation test the propeller cavitation was studied at a number of different loading conditions, and the cavitation extension and character at different blade positions were recorded by sketches, still photos and by video recordings. The relation between rpm's on the forward and aft propeller was always kept at the optimum value of 1.19 except at some loading cases where it was varied in order to study the effect of the load distribution on cavitation and pressure pulses.

The propeller induced pressure pulses were measured in eight positions on the hull surface. Measurements were performed for both cavitating and non-cavitating conditions. The signals were recorded by a digital measurement system and analysed by a Digital Fourier Transform (DFT) method developed at SSPA.

3.2 (b) Test Results

Force measurements
Except for conventional force measurements also force measurements performed at different tunnel water speeds were carried out. This comparison gives an impression of the effect of different Rn-numbers (scale effects), which affect the power distribution. It was shown that the difference in efficiency is considerable when varying tunnel water speed, but when comparing to towing tank results the measurements taken at the higher water speeds show relatively little difference to the towing tank results. The influence of the Reynolds number on the power distribution is relatively small for this ship and no special correction for this is necessary.

Cavitation extension
For the design loading 29 knots, back sheet cavitation occurred on the forward propeller from 310° through 0° to 200° revolution angle. The maximum extension occurs near the 12 o'clock position. The cavitation is mainly uneven sheet cavitation with mixed in small bubbles. The tip vortex seems to leave the blade near r/R=0.9 instead of the blade tip. There is no face cavitation and the hub vortex cavitation is suppressed by the small clearance between the forward and aft propellers.

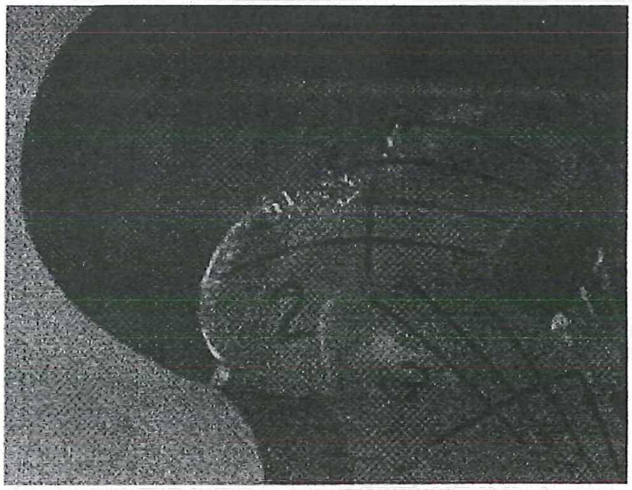

Figure 8: Cavitation extension on forward propeller at design speed 29 knots

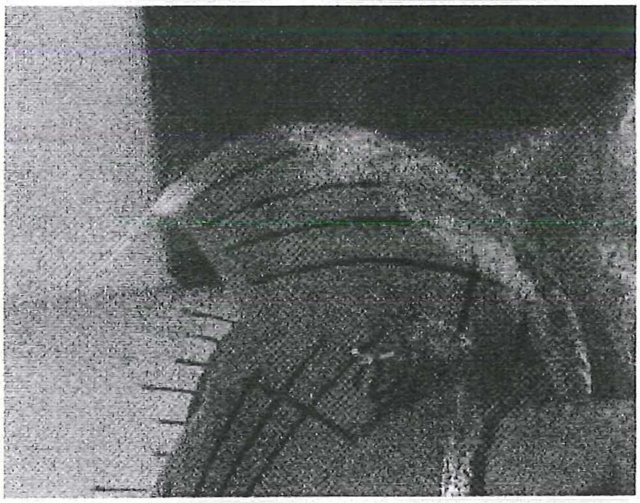

Figure 9: Cavitation extension on forward propeller at design speed 29 knots

Pressure pulses
The pressure measurements were carried out with the pressure transducers arrangement shown in Figure 11.

The results from the pressure pulse measurements are given below as predicted double amplitudes and also as narrow band (400 lines) spectra of measured model source pressure levels.

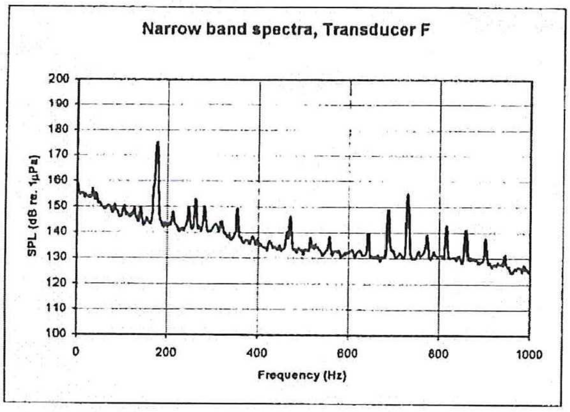

Figure 10: Example of narrow band spectra

It is evident from the spectra that the pressure pulses from the forward propeller are the dominant source. It is essentially impossible to detect the pulses from the aft propeller, partly due to the fact that the blade frequencies on the two propellers are almost the same. Thus it is only interesting to evaluate pressure pulses using the forward propeller as master. The peaks around 800 Hz is gear noise from the upper and lower POD gears.

The scaling of pressure pulses to full scale is obtained by presuming

$$K_P = \frac{2 \cdot C}{\rho \cdot D^2 \cdot n^2}$$

(where C is the single amplitude pressure fluctuation) to be the same in model and ship scale. Corrections for the influence of the free water surface and ship size according to Ref. [2] are also applied in the full-scale prediction.

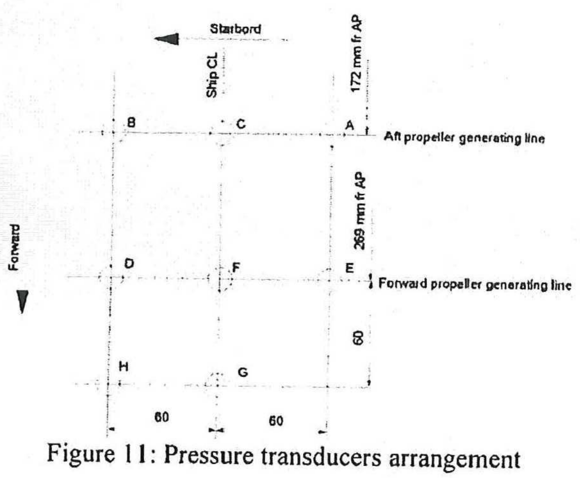

Figure 11: Pressure transducers arrangement

The pressure pulses are of a relatively high magnitude compared to the values seen on twin-screw ships of similar size and speed. The magnitude of second and higher harmonics is low compared to the first order pulses as could be expected from the limited tip vortex cavitation.

A prediction of vibration velocity acc. to Ref. [2] was also made. The resulting predicted vibration velocity is high and it can be expected that vibration problems would occur in full scale with the present propeller design. The prediction is however somewhat uncertain as the experience from full-scale CRP installations are limited and the results should therefore be taken with care.

4. ANALYSIS OF MAIN RESULTS

Cavitation extension

In order to understand the propulsive cavitation behaviour, the mutual effect of the ship wake, the forward propeller and the POD propeller had to be understood. As it can be seen in Figure 13, at the J design condition, the forward propeller shows to be affected by sheet cavitation especially close to the 0° position, where the wake field is higher. Then, in each angular position a forward propeller blade works in a different advance condition and this surely influences the hydrodynamic behaviour of the POD propeller. Averaged J values vs angular position are plotted in Figure 14. Because of the J value variation vs the blade angular position, the thrust, and then the slipstream acceleration and the fluid velocity, is different for a single blade in each angular position. For this reason, when the forward propeller works at the higher J values, the POD propeller blade is affected by a lower fluid velocity and then an higher angle of attack. In this condition back sheet cavitation occurs.

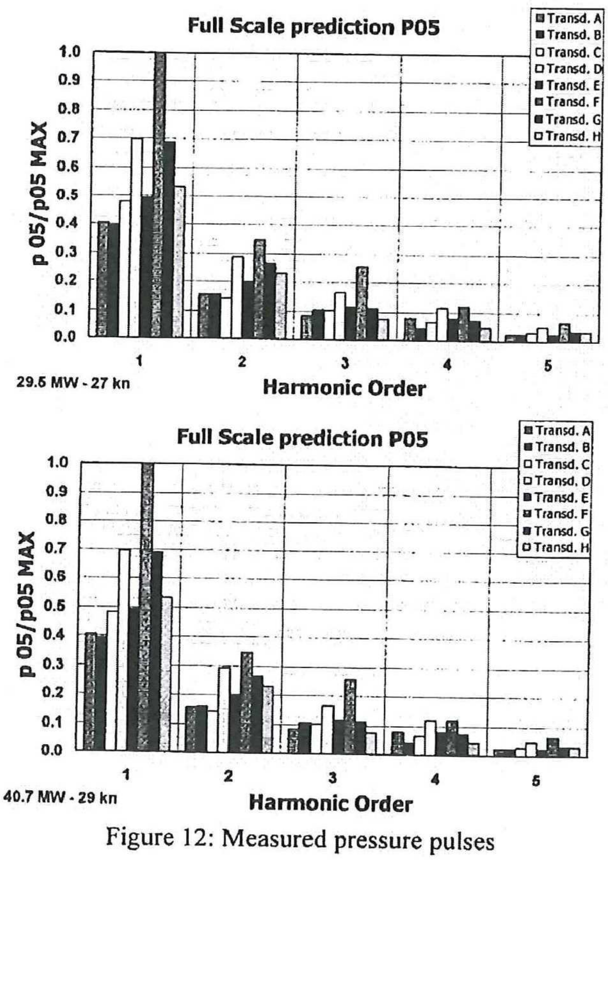

Figure 12: Measured pressure pulses

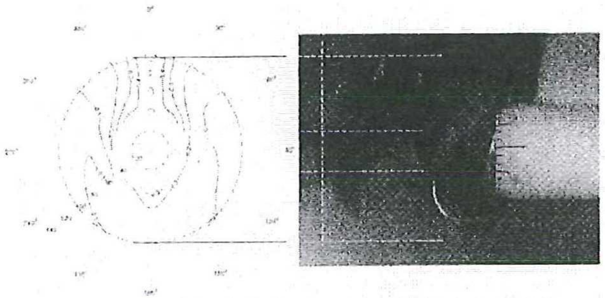

Figure 13: Ship wake measurements vs cavitation phenomena

The sheet cavitation on the aft propeller is very complicated with different parts that together extend through the whole revolution. The breakdown of the different parts of the cavitation is affected by the induced velocities from the forward propeller, which makes the cavitation unsteady and thus more erosive. This behaviour is considerably worse when the POD unit is used for steering. Rudder angles as small as 3 deg. have a significant negative influence on the cavitation patterns. No face cavitation was noticed on the aft propeller.

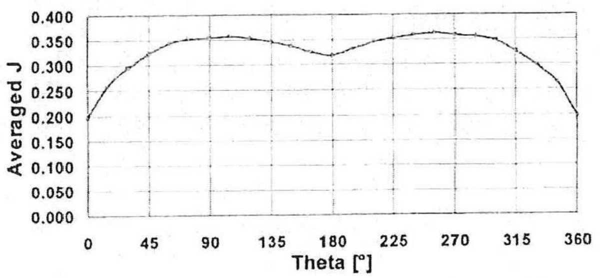

Figure 14: Forward propeller advance coefficient distribution on the wake field measurements

The effect of the POD angle on the cavitation pattern is quite important especially on the sheet cavitation behavior of the POD propeller. The small clearance between the forward and afterward propeller hub caps leads to no hub vortex phenomena with 0° steering angle. However, also for small POD angles the combined effect of the forward propeller sharp hub cap's geometry and the small clearance leads to the generation of a blade root vortex starting shedding from the edge of the hub and moving on the POD hub. It is important to highligh that when the POD blade passes behind the shedding point of the hub vortex, the root vortex induces the development of the sheet cavitation on the back side of the POD blade. In Figure 15 the cavitation phenomena and the steering angle effect are highlighted by the negative color scale.

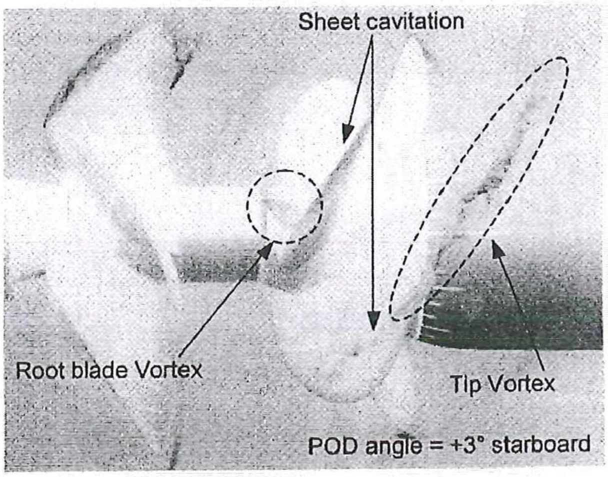

Figure 15: Effect of steering angle on cavitation pattern

Tip vortex effect on the POD housing and strut

At the J design value, the POD tip vortices show to be extended afterward for about one diameter in propeller axis direction. As it can be seen in Figure 16, they are developed along the POD housing and their intensity depends on the relative blade position. The photo is taken during propeller open water tests from the bottom high speed cavitation tunnel test section window, therefore the strut is hidden by the pod housing.

The generation of tip vortices has shown to influence significantly both the pressure pulses measurements and the POD housing and strut erosion. During the cavitation tunnel experiments, the hitting of the tip vortices on the POD housing and strut surfaces has to be considered as the main cause of the paint removing, and then structure erosion in full scale.

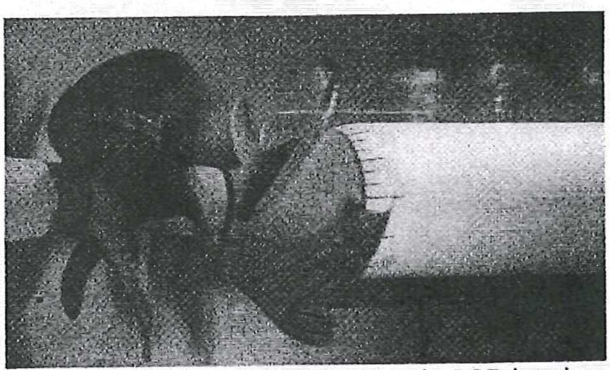

Figure 16: Tip vortex behavior along the POD housing

Load distribution configurations

As mentioned before, the two propellers were designed assuming 50%-50% load distribution. Then, in order to understand the effect of the load distribution on the hydrodynamic performances of the entire propulsive unit, three different load configurations were checked.

The results obtained by this experiment show that a little bit change in cavitation pattern occurs, and that moving the higher load from the forward to the after propeller the cavitation is reducing on the first propeller and increasing on the last one. As described before, this is

due to an averaged decreasing J value for the forward propeller and then an increasing KT and fluid acceleration.
Looking at the effects of the tip vortex on the POD strut and housing and the pressure pulses, it could be considered to change the load distribution in order to minimize the effect of POD propeller cavitation phenomena in terms of pressure pulses and erosion, but in this case a new propeller designs would be required.

5. CONCLUSIONS

As stated in the introduction the primary target of the present work was to explore the limits of CRP pod solution taking as reference ship the rather extreme case of a 29 knots single screw fast Ropax.
It must be understood that this is a first investigation of the potential hydrodynamic problems and not the end result of the design process. It is furthermore expected that for a less extreme ship concept it would be easier to find the optimal hydrodynamic solution.

As a matter of fact the actual propellers give reasonably good efficiency but unsatisfactory cavitation properties and high pressure pulses. There are, however, some possibilities to improve the designs and the conclusions about the propeller designs are:
- The power absorption of the two propellers is essentially correct which shows that the design method works rather well despite the approximations made.
- The extended hubcap on the forward propeller works well in eliminating the hub vortex cavitation from the forward propeller, at least at 0° rudder angle.
- The cavitation on the aft propeller is very unstable due to the influence from the forward propeller. This means that the amount of cavitation on the aft propeller must be minimized.
- The forward propeller is too unloaded towards the tip and it has too small blade area ratio, which gives poor cavitation properties. The relatively large cavitation volume gives high pressure pulses. In order to reduce the specific blade load it is recommended to increase the number of blades to 6.
- The aft propeller appears to have the correct load distribution but also has too low blade area ratio. In order to reduce the amount of cavitation as much as possible it is recommended to increase the blade area ratio by increasing the number of blades to 5.

The tests carried out with steering angle show that the cavitation pattern just behind the forward propeller is strongly influenced by the sharp shape of the hubcap and the mutual effect of the forward blade root vortices and the after blade sheet cavitation. So, in order to minimize both these negative effects during normal operation, the introduction of alternative course keeping devices could allow to keep the POD and the main propeller aligned and to steer the POD only for maneuvering actions, related at quite low ship speeds. Therefore, the adoption of movable flap on the POD strut or of small rudders could be considered a good solution.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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