Marine propeller integrated design
Influence of manufacturing strategy on bi-dimensional foil performance

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This paper presents a preliminary study of the influence of roughness due to marine propeller blades machining on their performance. A blade surface finish that has been roughened by corrosion, cavitation and other phenomena, leads to a power penalty. Thus propellers manufacturers tend to propose blades of great surface finish, even mirror-polished. However achieving such surface finish increases manufacturing costs. With modern manufacturing means, propellers can now be machined while preserving a good surface finish. We have studied the influence of manufacturing strategy on an aspect of hydrodynamic performance, cavitation.

Keywords: Roughness, Manufacturing Strategy, Cavitation, Integrated Design

1. INTRODUCTION

Propeller manufacturing involves stringent constrains depending on hydrodynamic. The performance of ship propellers is influenced by characteristics of shape and roughness, which can increase manufacturing costs. A very smooth finish, that involves long and costly hand-polishing process, is often requested by designers to avoid a loss of performance under the form of cavitation, despite the fact that not all propeller types necessarily require one.

Taking into account the modern means of manufacturing, manufacturing strategies could be defined to avoid a polishing phase while obtaining a relevant surface finish. Thus, experiments have been conducted on rough foils machined with specific tool path axis, in a hydrodynamic tunnel to observe the evolution of performances in terms of cavitation and therefore to define appropriate manufacturing parameters.

2. CONTEXT

Cavitation is a change of state of a liquid into a gas that occurs at the interface between a fluid and the structure (e.g. a propeller) when pressure drops. This phenomenon, which leads to erosion, vibration, and noise problems, is characterized by the number of cavitation given by equation 1.

$$\sigma = \frac{P_0 - P_v}{\frac{1}{2}\rho \times U^2} \qquad (1)$$

Where σ is the cavitation number, P_0 is the local static pressure (Pa), P_v is the vapor pressure, ρ is the mass density and U is the fluid velocity (m.s-1).

To observe cavitation, hydrofoils corresponding to a specific section of a blade are set up in hydrodynamic tunnel. By plotting σ, the cavitation number, against α, the angle of incidence on cavitation charts, particular aspects, such as inception or desinence of this phenomenon can be shown.

Experiments on artificial roughness such as sand, rough elements depot, or obstacles, have pointed out that a rough surface finish favors cavitation inception [1]. However, Grigson [2] has shown the limit of simulated roughness by pointing to the weaknesses of the use of sand depot. We have therefore carried out experiments to observe the effects of a machined rough surface on cavitation.

3. HYDOFOILS

3.1 Approach of the problem

The study of a propeller's behavior according to its blade roughness involves complex hydrodynamic and manufacturing parameters. We have therefore simplified our study by observing three rough 2-dimensional plane-convex hydrofoils.

Such hydrofoils provide two distinct surfaces that allow us to carry out our investigations of the roughness influence on the hydrodynamic performance, on the simplest geometry with which to study flows: a plane [3]. This surface will therefore have a specific surface finish, whereas the cylindrical surface will be mirror polished to limit its influence on our testing.

3.2 Definition of the hydrofoils

We have defined different tool paths on the plane surface of the hydrofoils to link manufacturing strategy and flow lines:

•Hydrofoil with longitudinal roughness: The roughness heights left by the tool are parallel to the flow lines

•Hydrofoil with transversal roughness: The roughness heights left by the tool are perpendicular to the flow lines

•Mirror-polished hydrofoil: a polishing phase is added to eliminate the roughness heights left by the tool

Both rough hydrofoils match a roughness average value of Ra = 2 μm. The hydrofoils have a chord length of 150 mm and a maximum thickness of 12% of this chord length at 75 mm of the leading edge. The rotation axis is set at 50% of the chord and 50% of the maximum thickness.

3.3 Manufacturing and control

To avoid corrosion, 316L stainless steel has been chosen as the hydrofoil material. The cylindrical surface has been machined using a endmill cutter to limit the roughness heights before the polishing whereas a ball-end tool has been used to machine the plane surface to obtain specific surface finish irregularities. This also makes it possible to match the cutting conditions of complex shapes such as propellers [4].

4. EXPERIMENTATION

The experiments were conducted in a hydrodynamic tunnel fitted with a 1 m long and 0.192 wide square cross test section. The velocity was set to 10 m.s-1 which corresponds, in our case, to a Reynolds number of 10^6. The foils were placed in the test section as shown in Fig.1 where a motorized system could rotate the profiles at the desired angle of incidence.

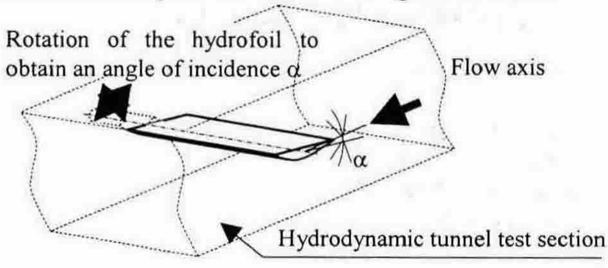

Fig.1: hydrodynamic tunnel test section

The cavitation inception and desinence conditions were observed by visual inspection of the flow field illuminated with a stroboscopic light. The inception condition ($\alpha_i(\sigma)$) was determined by progressively increasing the angle of incidence until cavitation appeared for a constant cavitation number
Then the desinence condition ($\alpha_d(\sigma)$) was determined by decreasing the angle of incidence until cavitation disappeared.

4. RESULTS

Fig.2 shows the inception and desinence conditions as a function of the cavitation number. Since the surface of interest is the plane, σ is only investigated at angles of incidence for which the cavitation occurs on that surface. It can be observed that there is an offset between the values of the angles of inception and desinence of the cavitation. It shows that once cavitation has appeared the angle of incidence needed to recover a non-cavitating flow (i.e. desinence of the cavitation) is not equal to the inception angle. This is often attributed to a change of the flow (laminar to turbulent) when cavitation appears. The different tests have shown that the hysteresis presence is independent of the fluid velocity and of the hydrofoil roughness. This gap, even small, is present along the full length of both curves, no matter what parameters are set.

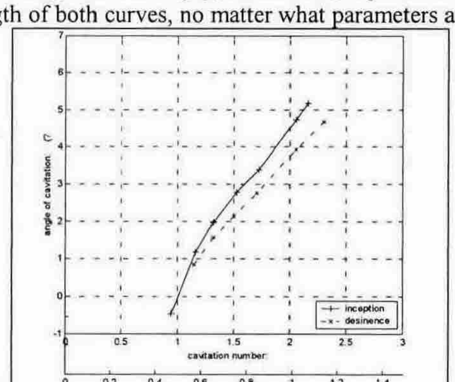

Fig.2: Cavitation chart of the mirror-polished foil at Re = 10^6

The comparison of the curves of inception or desinence of cavitation of the three foils for identical boundary limits (Fig.3) shows the influence of the surface finish. Contrary to what might have been expected the rough profiles provide the best performance by delaying cavitation inception. Thus a rough hydrofoil is able to support lower pressures and higher angles of incidence than a mirror-polished hydrofoil.

The comparison of the two rough profiles shows that the tool path has an influence on the behavior of the hydrofoils. Indeed the inception angles and the desinence angles are different. The foil that presents a roughness parallel to the flow delays both inception and desinence longer than the foil with a roughness perpendicular to the flow.

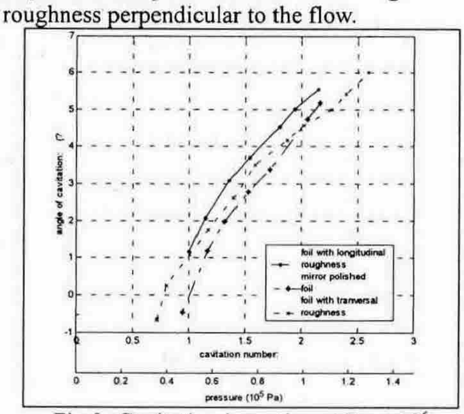

Fig.3: Cavitation inception at Re = 10^6

5. CONCLUSION

Experiments have been conducted to evaluate the effects of roughness due to different machining on the performance of hydrofoils. We have presented here the main results as a preliminary investigation. Although care must be taken with these results, the experiments conducted on rough foils have confirmed the influence of surface finish on cavitation inception. Even if it has no real impact on the hysteresis between inception and desinence, low roughness values tend to delay both transitions at pressure and angle of incidence values for which a mirror-polished foil would already be in a cavitating flow. Therefore attention must be paid to the surface finish, and thus the cutting tool parameters. As the two rough foils have different behaviors, we noticed that the roughness of the plane surface obtained by a machining tool path parallel to the flow delays cavitation inception. Thus the machining strategy is an important factor in the performance of hydrofoils and must be taken into account in the propeller design. Further studies on the lift and drag coefficient will bring more information on these phenomena.

It should be remembered that in our experiment roughness was observed on a plane surface. To apply our conclusions on propellers, experiments are being carried out on typical 2D-foils of the NACA 66 series. This geometry is often used to define a whole propeller by applying geometrical laws [5]. Therefore we will be closer to real conditions.

7. REFERENCES

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