Cavitation/ventilation phenomena during the water impact with horizontal velocity of double curvature shaped bodies

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SUMMARY

The role played by the rear body curvatures on the generation of cavitation and ventilation phenomena during the water impact at high horizontal velocities is investigated experimentally. Pressures and loads are measured during the tests and the interpretation of the data is supported by underwater images.

Different cavitation/ventilation modalities have been observed, with the change from one to the next occurring with velocity variations of few m/s.

It is found that the phenomenon is mainly governed by the longitudinal curvature. For the sharper curvature shapes cavitation starts around 30 m/s whereas smoother shapes shift the transition to about 40 m/s. Based on the hydrodynamic loads measured at fore and aft positions, it is seen that the occurrence of cavitation and ventilation affect the position of the center of loads, thus implying that in free fall conditions the occurrence of cavitation or ventilation may influence the body dynamics.

1. INTRODUCTION

The present paper continues the study on the water impact with high horizontal velocity which was already addressed in previous editions of the workshop (Iafrati and Calcagni, 2013; Iafrati et al., 2014; Iafrati, 2016*a*). The motivation stems from the need of achieving a better comprehension of the phenomena taking place during the aircraft emergency landing, referred to as ditching, as well as to build up a reliable dataset to be used for the development of computational models to be used by aircraft manufacturer in design and certification.

At the last edition the effects of the body curvature were discussed but the study was limited to body shapes with transverse curvature only (Iafrati, 2018). However, as discussed in Tassin el al., (2013), the actual aircraft shape has a double curvature and that implies that, at least within a 2D+t assumption, the rear portion of the fuselage is actually exiting rather than entering the water. As a consequence, negative pressures are generated which, in certain conditions, may also trigger cavitation or ventilation phenomena. Even forgetting the effects of the pressure on the structure, an accurate prediction of the pressure distribution is very important for the precise reconstruction of the aircraft dynamics (Climent et al., 2006).

Generally, free flight ditching tests performed in the past (e.g. Climent et al., 2006; Zhang et al., 2012; McBride et al., 1953) were conducted at model scale, and thus the velocities might have been too low to induce cavitation or ventilation. In this study, experiments are conducted at the High Speed Ditching Facility available at CNR-INM enabling test speed up to 46 m/s, which is a nearly full scale value, and thus those phenomena, if occurring, should be properly captured.

In this paper some preliminary results of pressure and loads generated during the water impact with horizontal velocity of double curvature bodies are presented and the role played by the longitudinal curvatures are also discussed.

2. EXPERIMENTAL SETUP AND INSTRUMENTATION

Tests were performed at the High Speed Ditching Facility available at CNR-INM which was already presented in Iafrati and Calcagni (2013), whereas a detailed analysis of the test repeatability features is provided in Iafrati et al. (2015) and Iafrati (2016*b*).

In order to investigate the role played by the body curvatures, four different fuselage shapes were designed, based on purely analytical equations, and the specimens to be tested are taken as rear portions of the full fuselage (Figure 1).

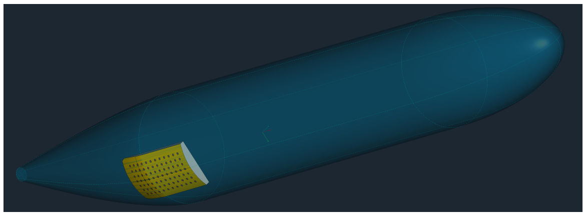

Figure 1: Fuselage shape: the portion used to build the specimen for the high speed ditching tests highlighted in yellow.

Here results are presented and discussed for fuselages with circular cross section which are defined in terms of the longitudinal equation of the local radius and of the position of the center of the circular section. Let B denote the breadth of the fuselage in the central portion, the expression of the local radius is

$$\begin{aligned} r(x) &= 0.5B\sqrt{1-\left(\frac{x-F_B\cdot B}{F_B\cdot B}\right)^2} \ , \ x/B\in(0,F_B) \\ r(x) &= 0.5B \ , \qquad x/B\in(F_B,L_B-R_B) \\ r(x) &= 0.5B+O(x) \ , \ x/B\in(L_B-R_B,L_B) \ . \end{aligned}$$

In the above equations L_B is the total length of the fuselage scaled by the breadth whereas F_B and R_B are the scaled lengths of the forward and rear portions where the fuselage shrinks. The circular section is centered at $(y,z)=(0,0)$ for $x<x_H$ and at $(y,z)=(0,O(x))$ for $x>x_H$, where $x_H=B(L_B-R_B)$. The offest function $O(x)$ is defined as follows:

$$O(x)=-0.5B\sin\left(\frac{x-x_H}{KR_BB}\right)\left[\frac{x-x_H}{\sin(1/i)R_BB}\right]^{1/i} \quad .$$

The coefficients of the fuselage shapes considered in the study are the following:

	L_B	F_B	R_B	K	i	B (mm)
S1B	8	1.5	2	2	1	1000
S2	7.5	1.5	2.5	1.55	2.6	1500

The specimens are limited in the y direction in the range $y\in(-330,330)$ mm. Longitudinally, S1B has $x\in(5700,6940)$ mm whereas S2 has $x\in(6710,7950)$ mm. More details about the fuselage shapes are provided in Iafrati and Olivieri (2017).

The specimens are equipped with a total of 30 pressure probes as shown in figure 2. The interest being primarily on the effect of the longitudinal curvature, most the probes are located at the rear. In addition to pressures, also the forces in the longitudinal and vertical directions are measured. The vertical component is measured at the rear and at the front so that the center of loads can be estimated. Tests have been performed by varying the horizontal velocity, the vertical to horizontal velocity ratio and the pitch angle.

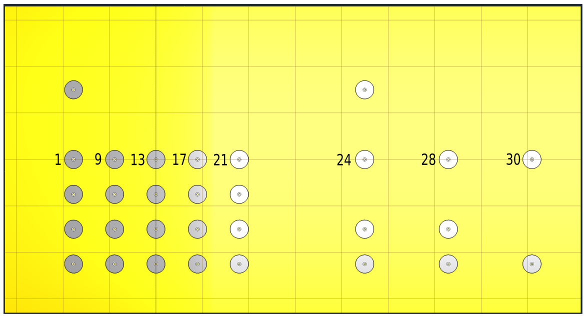

Figure 2: Position shape and specimen portion used for the high speed ditching tests highlighted in yellow. The leading edge is on the right. Sensor 13 is located at the point which touch the water surface first at 8 degrees pitch angle.

3. ANALYSIS OF THE EXPERIMENTAL DATA

Rather interesting information concerning the hydrodynamic phenomena taking place beneath the specimen can be obtained by the underwater images. The picture in figure 3 refers to the tests performed on shape S2 at $V/U=0.0375$ and $U\simeq 30m/s$, 6 degrees pitch angle. The image, which is at the end of the impact phase, displays the presence of a cavitation bubble. The cavitation bubble is formed shortly after the initial contact, but it does not spread much behind. Tests performed in other conditions indicates that this can be considered as an incipient cavitation condition, as no cavitation is observed when the horizontal speed is reduced by 1 m/s (Iafrati et al., 2019).

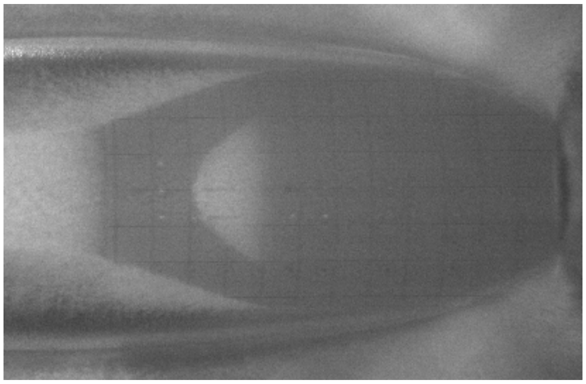

Figure 3: Underwater image taken about the end of the impact phase of the tests performed on shape S2 at $U\simeq 30m/s$. The figure highlights the formation of a cavitation bubble, which oscillates without reaching the backward step. Such a condition is referred to as an incipient cavitation condition.

By increasing the horizontal speed to 35 m/s, the cavitation bubble propagates and reaches the backward step of the specimen (figure 4*a*). There, it gets in contact with the air at the ambient pressure and the pressure in the cavity rises due to the ventilation. The phenomenon is not stable, though. As shown in figure 4*b*, as soon as the ventilation reaches the sharp curved point, a new cavitation bubble is shed. At that time and for that conditions, the impact phase, which depends on the ratio between the height of the leading edge with respect to the still water level, has passed already.

The velocity at which cavitation starts is strongly dependent on the shape, and more specifically on the longitudinal curvature. In figure 5 the underwater images taken during the tests on shape S1B at 35, 40 and 46 m/s are shown. There is no cavitation at all at 35 m/s, and something appears only at 40 m/s, although a clear cavitation bubble is visible only at 46 m/s.

Whereas the above results confirm that the test velocity may induce significant changes to the hydrodynamics, they do not explain the practical consequences on the ditching problem. The latter can be better inferred looking at the time histories of pressures and loads.

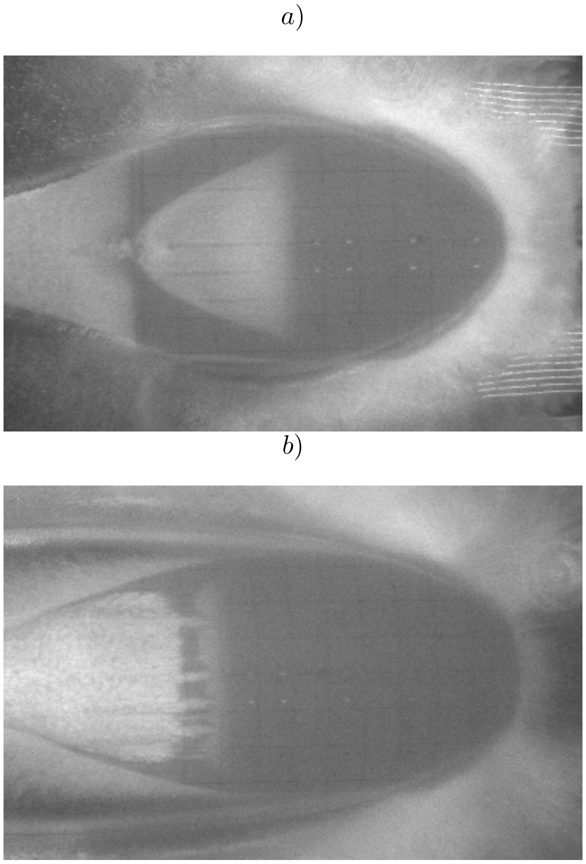

Figure 4: Images of the tests performed on shape S2 at $U \simeq 35 m/s$. The upper image is taken about the middle of the impact phase when the cavitation bubble reached the backward step and the ventilation starts. The lower image is taken near the end of the impact phase and it shows the detachment of a second cavitation bubble.

Pressures measured by probes located along the midline of shape S2 during the tests at 30 m/s are shown in figure 6 togheter with the corresponding loads in the vertical direction. The pressure data clearly highlight the pressure drops to the vapor pressure. But more interesting, concurrent with the drop in the pressures there is a negative load measured at the rear, thus implying a shift of the center of loads in the forward direction.

A similar comparison is presented in figure 7 for the tests on shape S2 at 35 m/s. In this case the occurrence of ventilation can be recognized by the rise of the pressure to the ambient value. Concurrent with the rise in the pressure, there is an increase in the load measured by the rear cells, and thus a backward shift of the center of loads.

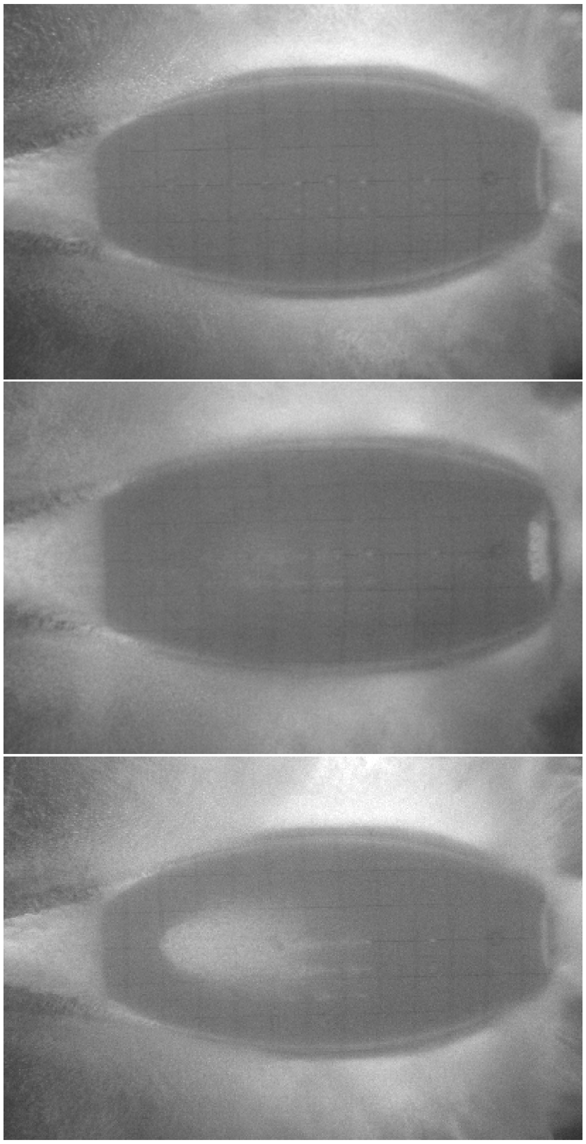

Figure 5: Underwater images of the impact of shape S1B at (from top to bottom) 35, 40 and 46 m/s. The milder longitudinal curvature shift the onset of cavitation to 40 m/s although cavitation is really evident only at 46 m/s.

4. CONCLUDING REMARKS

The occurrence of cavitation and/or ventilation conditions during the water entry at high horizontal velocity has been discussed based on experimental data. The results confirms that such phenomena occur only at high speeds and couldn't be found in scaled model tests. An important role is played by the longitudinal curvature, with milder curvature shifting the cavitation to higher impact velocities. The occurrence of cavitation and ventilation conditions is also analyzed based on pressure and loads. It is observed that cavitation and ventilation phenomena have significant effects on the center of loads which, in the case of the aircraft ditching, governs the dynamics of the aircraft.

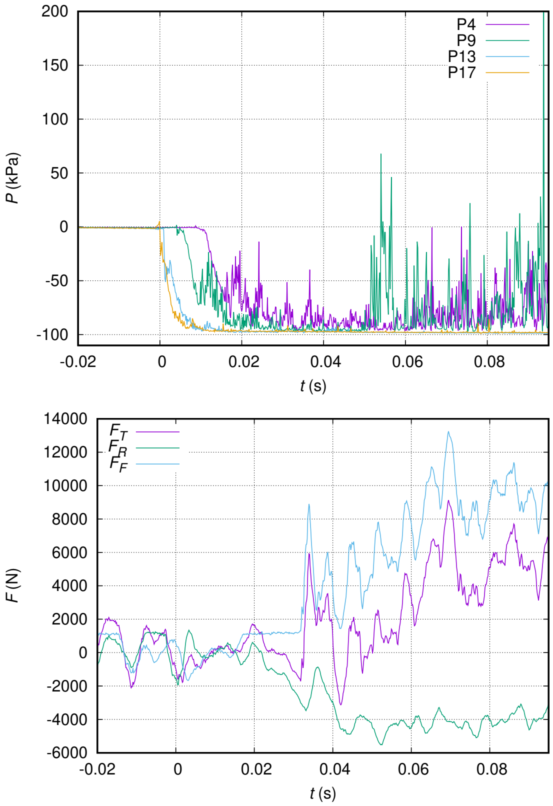

Figure 6: Time history of the pressures (*top*) and normal forces (*bottom*) measured in the tests performed on shape S2 at $U \simeq 30$ m/s.

ACKNOWLEDGMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 724139 (H2020-SARAH)

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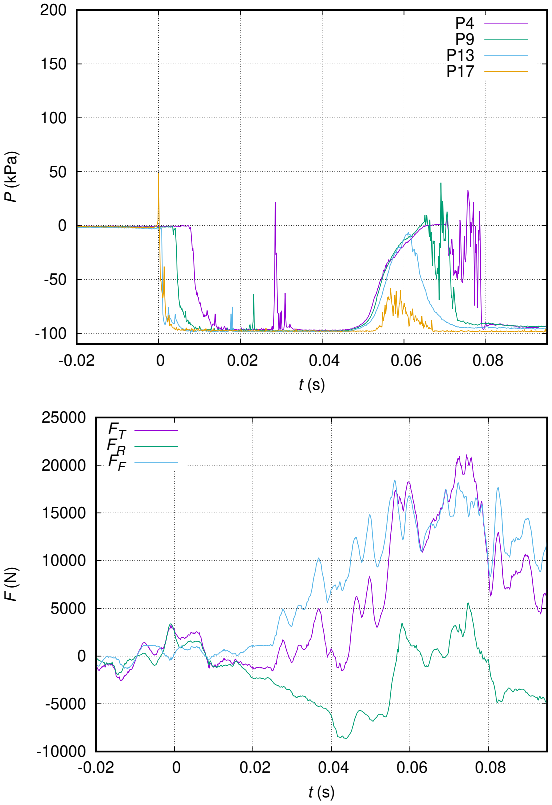

Figure 7: Time history of the pressures (*top*) and normal forces (*bottom*) measured in the tests performed on shape S2 at $U \simeq 35 m/s$.