Experimental study of high speed plate ditching

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SUMMARY

In the present paper experimental results of the water entry of a flat plate with a high horizontal speed are presented. The activity is part of an extensive study, still ongoing, aimed at achieving a deeper comprehension of the physical phenomena involved in the aircraft ditching problem. Measurements are conducted in terms of velocity, acceleration, pressures, strains and total forces acting on the plate. In order to avoid any misleading effect due to the scaling, experiments are carried out at quasi-full scale velocity. This required the construction of a new experimental facility at INSEAN-CNR. In this work an analysis of the data of two different values of the pitch angle of the plate is conducted along with an estimate of the test-to-test dispersion. Furthermore, the effect of entrained air is discussed.

1. INTRODUCTION

In this paper results of an experimental activity on the water entry of a plate at high horizontal speed are presented. The motivation stems from the need of developing more reliable simulation tools for the aircraft ditching analysis. An important step in the design stage of aircraft is the assessment of the ditching capabilities. To this purpose the industry needs simulation tools which can model, in a reliable manner and with limited computational effort, the fluid structure interaction taking into account the elastic/plastic structural behavior, including failure. Accounting for all these aspects in a computational model is rather challenging owing to the difficulties in capturing the highly localized pressure and velocity distributions, air cushion effects, hydroelastic coupling, as well as cavitation and ventilation phenomena (Climent et al., 2006). The development of those tools requires a reliable set of experimental data to be used for validation. Due to the difficulty in scaling all the parameters involved, experiments have to be performed in full scale conditions. To this purpose a new experimental facility has been built and installed at the end of towing tank # 1 of INSEAN-CNR. The facility and some preliminary results were presented at the previous Workshop edition (Iafrati and Calcagni, 2013).

In the experimental campaign, which is conducted within the SMAES-FP7 project, the influence of several parameters is analyzed. These are: velocity, pitch angle, plate curvature, plate thickness, material. In this work results are presented for a flat plate, 15 mm aluminum alloy.

Without any experience on the facility, an important step in the test campaign concerned the estimate of the test-to-test dispersion. It is worth noticing that, as discussed in Iafrati and Calcagni (2013), the model is accelerated by a set of elastic cords which make a precise control of the velocity at the impact essentially impossible. Furthermore, although rather rigid, the guide undergoes some oscillatory motion during the test and it is important to understand how those effects influence the measurements. In order to evaluate the dispersion of the measurements, ten repeats of the same test have been performed. This is done for two different pitch angles, which are 4 and 10 degrees. In both cases the vertical/horizontal velocity ratio was 1.5/40.

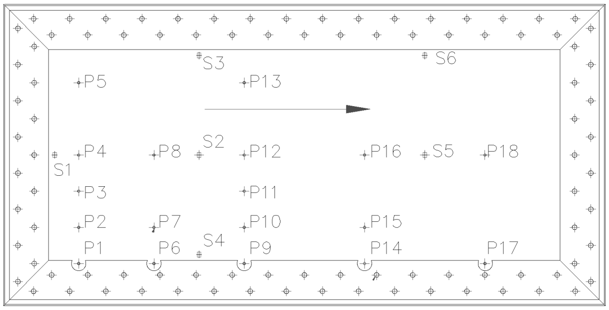

Figure 1: Position of the pressure probes and strain gauges as seen from the back of the plate. The trailing edge of the plate is on the left and the plate is moving to the right.

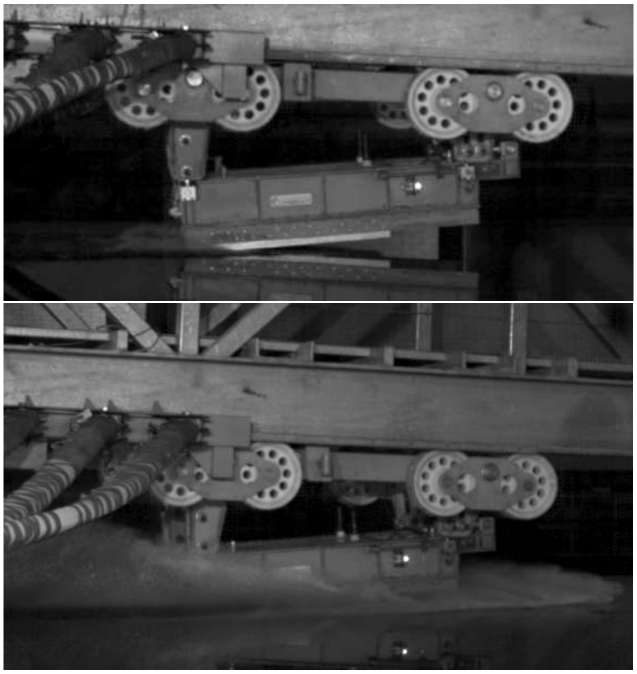

Figure 2: Entry of the plate in case of 4 degrees pitch angle. The two figures refer to the same test and have a time delay of about 0.045 s. The plate and the aluminum frame appear in light gray beneath the steel frame.

2. EXPERIMENTAL SETUP

In the following a short description of the instrumentation installed on the plate is provided. A more detailed description of the experimental facility and of the on board instrumentation can be found in Iafrati and Calcagni (2013) and it is not repeated here for the sake of space.

The plate, which is thick enough to remain in the elastic regime, is instrumented by 18 flush mounted pressure probes and six biaxial rosettes for the strain measurement. The positions of the pressure probes and strain gauges are illustrated in Fig. 1. The plate is installed onto an aluminum frame which is connected to carriage by a more rigid steel frame (Fig. 2). The connection between the steel frame and the trolley is made by a total of six piezoelectric load cells, four of them measuring the force acting normal to the plate and two measuring the force along the plate.

3. EXPERIMENTAL RESULTS

In Fig. 3 the pressure measured by the probes located at different longitudinal positions along the centerline are shown for the case with 4 degrees pitch angle. The figure highlights the time delay occurring between the sharp rises of the different sensors, which is the time needed for the jet root to move from one position to the next. Note that for each run we assume as reference time the time at which the sharp rise occurs at probe P4 (see Fig. 1). Figure 3 also shows a variation in the pressure peak recorded at the different positions. For a rigid plate in uniform motion, we had expected the peak to be constant (Iafrati and Calcagni, 2013), and thus we believe that other phenomena are acting. One point to be checked is the dispersion of the data.

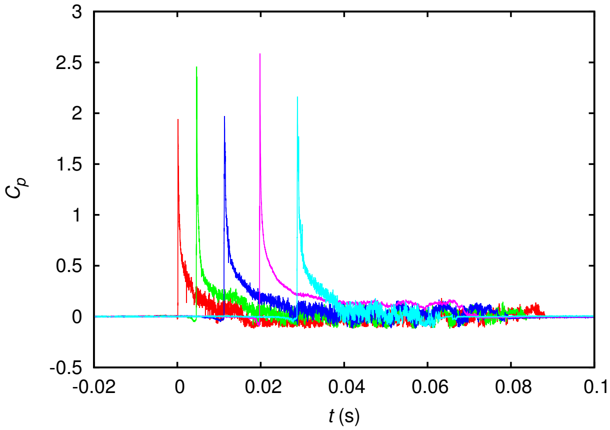

Figure 3: Pressure recorded at the pressure probes located at the centerline (i.e. P4, P8, P12, P16, P18) during the run 1 of the test for 4 degrees pitch angle. Results are given in terms of the pressure coefficient $p/(\frac{1}{2}\varrho(U^2+V^2))$.

In Fig. 4 the time histories of pressure recorded at probe P4 in different runs are drawn. It is found that in some cases the pressure behaves as a classical water entry problem (Fig. 4, top) whereas in other cases an oscillating behavior occurs about the peak. We do believe that this is a consequence of the wind blowing onto the free surface ahead of the impact point which roughens the free surface (see Fig. 5), thus probably leading to the entrapment of air bubbles. In order to get a better understanding of this aspect, an underwater visualization is going to be used for the next tests. It is worth noticing that the pressure front remains rather straight, with some bending denoting possible 3D effects occurring at the last probes position (Fig. 6).

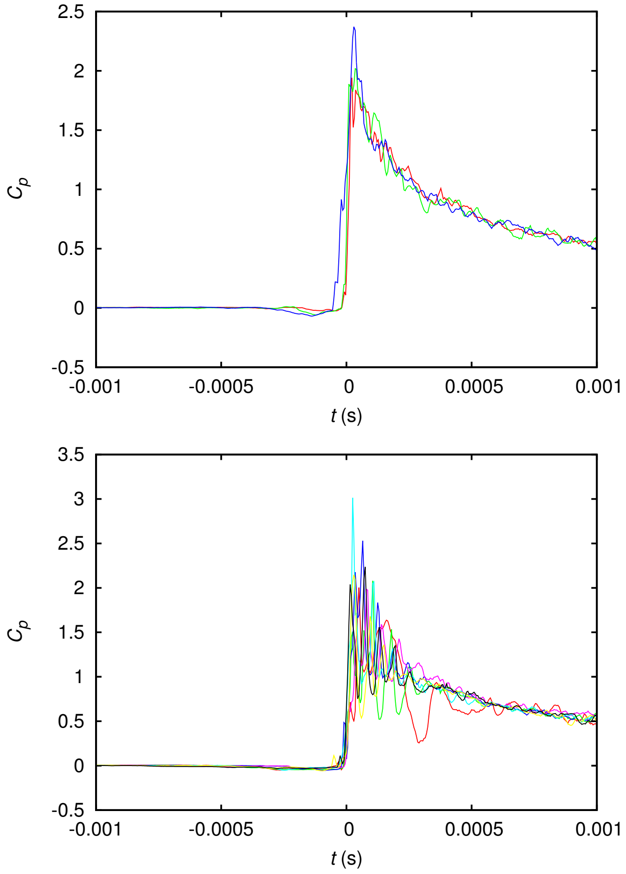

Figure 4: Test-to-test dispersion of the pressure data. In the two figures the time histories of the pressure measured at probe P4 during the ten repeats are shown. The origin of the time is set at the instant at which the sharp rise occurs at probe P4. For three cases given in the upper figure the pressure exhibits the classical impact behavior. For the other seven cases the pressure exhibits an oscillating behavior, which is presumably due to entrainment of air bubbles beneath the plate.

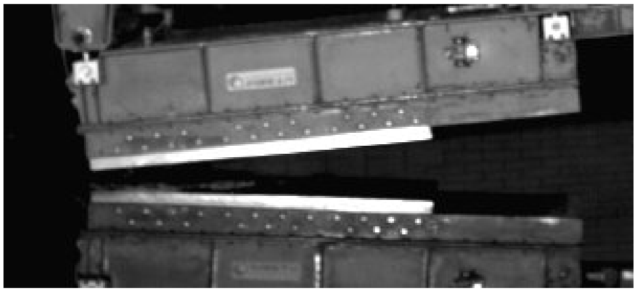

Figure 5: Free surface perturbations induced by the wind action beneath the flat plate. Some bubbles can be recognized at the side about the end of the plate.

In Fig. 7 strains in x and y direction are shown. The comparison between S3 and S4 displays a rather good agreement, indicating a nearly symmetric impact. Of course the largest values occur at the center of the plate, where S2 and S5 are located. In all cases the strains go back to their initial values, i.e. only elastic deformation occurs in this condition.

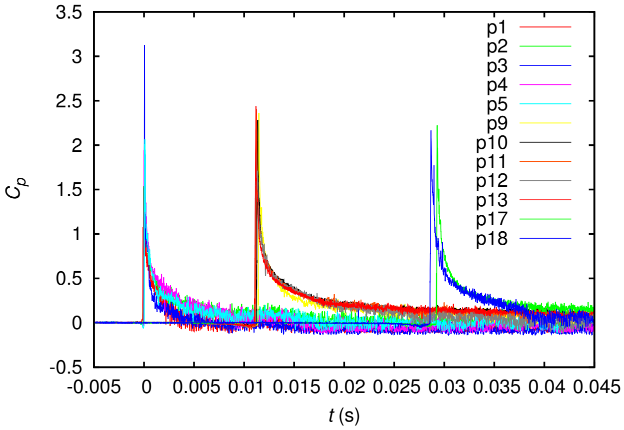

Figure 6: Time histories of pressure recorded at different sensors located at three longitudinal positions. It is seen that a delay occurs for probes P17 and P18, which identifies possible 3D effects.

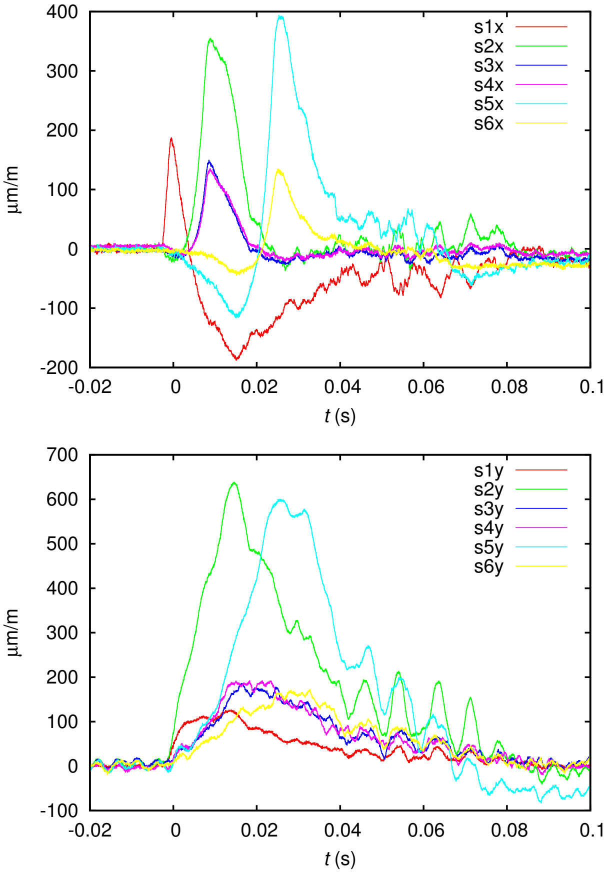

Figure 7: Time histories of the strain in x (*top*) and y (*bottom*) direction for run 1 of the 4 degrees pitch angle case.

An indication of the dispersion of the strains can be derived from Fig. 8. The curves display a rather good overlapping about the peak. Some differences can be noticed in the late stage which seem mainly related to a phase shift in the oscillations rather than in the amplitude.

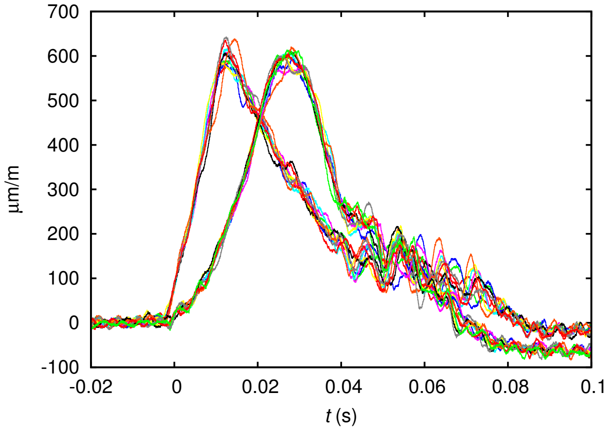

Figure 8: Dispersion of the strains measured by S2y and S5y for ten repeats of the 4 degrees pitch angle condition.

The coefficient of the force normal to the plate is computed as $C_F = F_z/(\frac{1}{2}\varrho(U^2+V^2)BL)$, where B and L are the breadth and the length of the plate, respectively, which are 0.5 m and 1 m. The time histories for the tests at 4 degrees pitch angle are drawn in Fig. 9 for several repeats. There is a good agreement among the different repeats although some scatter characterize the data after the sharp rise in the interval $t \in (0.02, 0.04)$. At about $t = 0.04$ s the jet leaves the plate and the force diminishes but does not go to zero as the plate is still entering into the fluid.

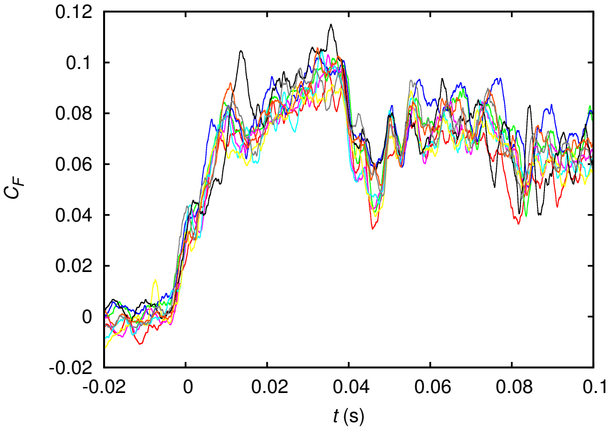

Figure 9: Time histories of the total force coefficient acting normal to the plate of the ten repeats for the tests in the 4 degrees pitch angle condition.

Similar results can be shown for the 10 degrees pitch angle case. In Fig. 10 the pressure history at probe P4 is shown for the ten repeats. It is worth noticing that in this case the curve are well overlapped each other and there are no oscillations. This is because at larger pitch angles the wind can exit on the side of the plate and the impact is onto an almost undisturbed free surface. In Fig. 11 the time histories of the pressure measured at different probes located at the same longitudinal position are shown. Differently from the 4 degrees case, the peak arrives earlier at the probes located closer to center, which means that the wetted line is curved due to some three dimensional effects. This time delay grows while moving forward. Compared to the 4 degrees case, the pressure peak exhibits a more evident reduction moving forward. An interesting aspect concerns the occurrence of a time interval with negative pressures before the peak. Note that the pressure gets the same negative value for different probes, but the time interval grows moving forward.

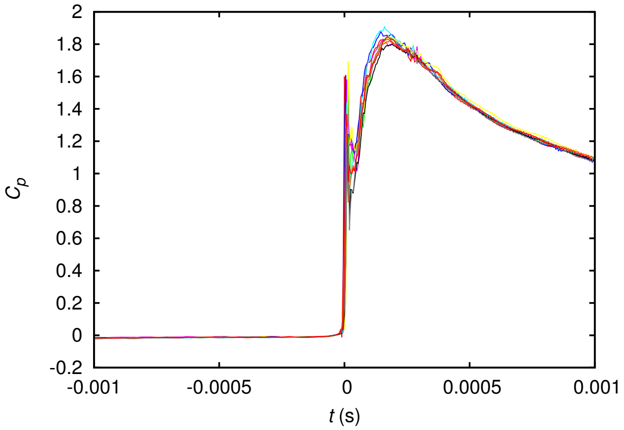

Figure 10: Test-to-test dispersion of the pressure data for the 10 degrees pitch angle condition. As in Fig. 4, the time histories of the pressure recorded by the probe P4 in ten repeats of the test are displayed.

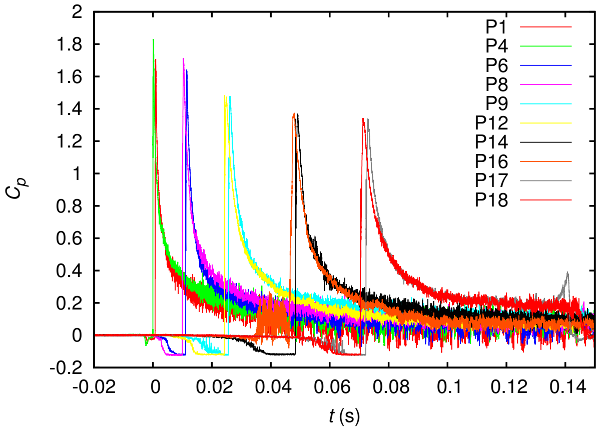

Figure 11: Time histories of the pressure at different probes for the 10 degrees case. Negative pressure occurs at several probes before the sharp rise, duration of which grows moving forward.

The time histories of the strain are drawn in Fig. 12. It can be seen that the values are about 30% larger than the ones measured in the 4 degrees case. This is because, due to the larger pitch angle, in average the pressure is higher than in the 4 degrees case. Similar considerations can be drawn also looking at the force coefficient provided in Fig. 13. Note that, also in terms of forces, the dispersion is much smaller compared to the 4 degrees case.

4. ACKNOWLEDGMENTS

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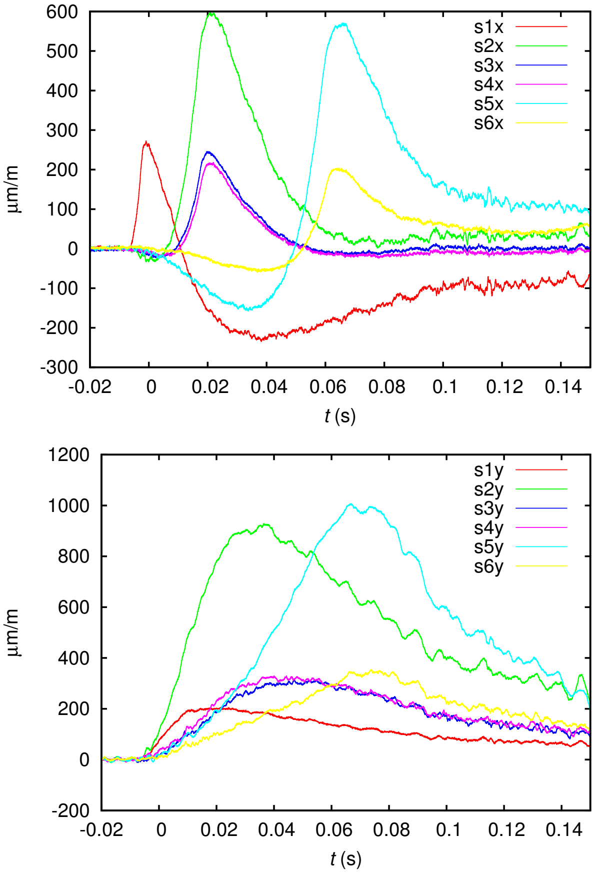

Figure 12: Time histories of the strain in x (*top*) and y (*bottom*) direction for run 1 of the 10 degrees pitch angle case.

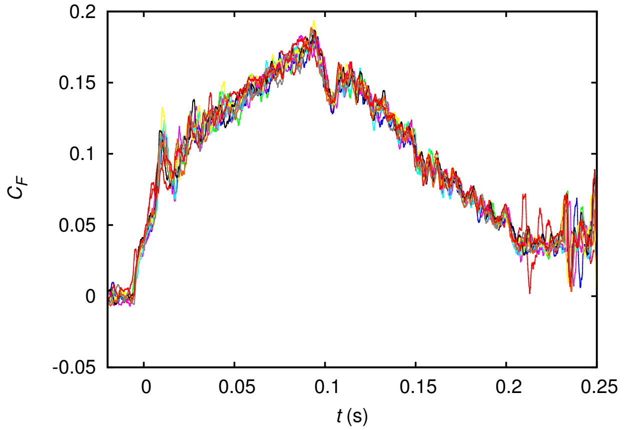

Figure 13: Time histories of the total force acting normal to the plate of the ten repeats for the tests in the 10 degrees pitch angle condition.

5. REFERENCES

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