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High-speed ditching of a flat plate: Experimental data and uncertainty assessment

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ABSTRACT

The water entry of a flat plate with a high horizontal velocity component is investigated experimentally. The objective is to achieve a better understanding of the physical phenomena occurring during aircraft ditching. The study is a part of the SMAES-FP7 project, which was aimed at developing simulation tools for aircraft design and certification. The experimental data are used to support their validation. In order to perform the tests, which are done at realistic ditching speeds, a new facility has been designed and built at CNR-INSEAN. The use of quasi-full scale velocity allows to overcome the troubles of scaling the structural behavior in such a complicated fluid–structure interaction problem. In this paper two test conditions are considered for which several repeats were performed allowing to assess the uncertainty of the data. Results are presented in terms of pressures, strains and loads and an interpretation of the measured data on the basis of theoretical solutions of the problem is provided.

1. Introduction

The water entry flow is known to originate large hydrodynamic loads (Korobkin and Pukhnachov, 1988). It is of interest in many different contexts. The most obvious are probably those related to the naval field in connection to both displacement ships (Kapsenberg, 2011) and high speed planing crafts (Stenius et al., 2013). However, the phenomenon is also relevant in the aeronautical field in connection to the aircraft emergency landing on water, which is known as ditching. Ditching must be analyzed by aircraft manufacturers in order to obtain certification of the airframe by airworthiness authorities, e.g. EASA (European Aviation Safety Agency) or FAA (Federal Aviation Administration). A review of the activity done in the field is given by Seddon and Moatamedi (2006) whereas some more recent activities, e.g. Climent et al. (2006), Streckwall et al. (2007), Guo et al. (2013), Zhang et al. (2012) testify the relevance of the topic.

The ditching problem is made quite complex by the many different physical parameters which enter into play. The most evident is the high horizontal speed, but also size and weight of the aircraft, aerodynamic aspects, hydrodynamic phenomena and structural flexibility with inherent fluid–structure interaction have significant effects. In the past, ditching certification involved experimental campaigns with rigid sub-scale aircraft models. An example of this approach is the EADS-CASA CN-235 ditching test campaign (Climent et al., 2006). Tests were conducted using a 1:8 scale model, which underwent ditching into water. A total of 112

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runs were performed in order to analyze different parameters of the aircraft configuration: aircraft weight, position of center of gravity, vertical and horizontal velocity, pitch angle, landing gear (retracted/extended), sponsons (with and without) and water state (calm and rough water). This approach generally provides good results concerning aircraft stability, pressure loads and flotation characteristics but it faces known limitations due to the scaling and to the lack of flexibility. Indeed, some phenomena like ventilation, air cushioning and cavitation phenomena cannot be properly reproduced at low (scaled) speed and, furthermore, the fluid–structure interaction cannot be captured with a rigid model test (Climent et al., 2006).

Flexibility is accounted for by the computational approaches which are employed for ditching simulations (Siemann and Groenenboom, 2014). However, the solution of the problem is quite challenging owing to the need of capturing the sharp pressure and velocity gradients, the thin jet layer, the fluid–structure interaction as well as the hydrodynamic phenomena which may occur at full scale. Such a complexity requires a continuous development of the numerical models and a careful validation is needed.

In the SMAES (SMart Aircraft in Emergency Situations) project which was done within the European Union's 7th Framework Programme, an extensive experimental campaign of guided ditching tests was conducted (Campbell, 2012). The campaign was aimed at achieving an improved understanding of the fundamental physics and of the fluid–structure interaction and, in parallel, at building up a large dataset to be used for validation purposes. Bearing in mind the limits of scaled model tests discussed in Climent et al. (2006), guided ditching tests were performed using quasi-full scale conditions, with horizontal velocity at impact in the range of 30–46 m/s. The horizontal to vertical velocity ratio is governed by the inclination of the guide which varied from 30/1.5 to 45/1.5. Rectangular panels of different material, thickness and shape were used.

It is worth noticing that a similar experimental campaign, albeit at lower velocities and for narrower plates, is presented in Smiley (1951). Although the work has to be commended for the extraordinary effort, the availability of more sophisticated technical devices nowadays was expected to provide a much deeper and complete investigation of the problem. Also note that in Smiley (1951) only rigid specimen were considered, and thus the important role played by the flexibility and by the fluid–structure interaction is completely missing.

For the execution of the recent test campaign a new facility was designed and built at CNR-INSEAN, which uses a catapult to accelerate the trolley bringing the specimen. Due to the complexity of the facility and the lack of any previous experience on it, a preliminary estimate of the test-to-test dispersion was deemed necessary in order to assess the reliability of the data. Such an estimate was considered strongly needed for tests on thin plates undergoing permanent deformation for which only few test repetitions were possible. To this purpose ten repeats of the test at the same condition were performed by utilizing a flat plate thick enough for the deformation to be well within the elastic range. Two test conditions were selected, one at 10° and one at 4° pitch angle.

In this paper the facility and the experimental setup are illustrated first. Hence, a detailed analysis of the test-to-test dispersion of the data is presented in terms of pressures, strains and loads. Finally a detailed discussion of some of the phenomena observed in the measurements is provided along with comparisons of the data of the two test conditions.

2. Facility and experimental setup

2.1. Guided ditching facility

As aforementioned, for the execution of the guided ditching tests a new facility was designed, built and installed onto the CNR-INSEAN towing tank, which is 470 m long, 13.5 m wide and 6.5 m deep (Iafrati, 2012). Conceptually, the facility is composed by a guide suspended over the tank by a total of five bridges (Fig. 1). Aside from the first bridge on the right, which is fixed, the other bridges can be positioned at different heights, thus allowing to rotate the guide achieving different horizontal velocities while keeping the vertical component constant and equal to 1.5 m/s downward, according to the requirements of the airworthiness authorities.

Differently from the ditching tests discussed in Climent et al. (2006), in this case the specimen is guided till the end of the test. The choice was motivated by the wish of achieving more controlled entry conditions in terms of horizontal to vertical velocity ratios, pitch and heel angles during the impact. Furthermore, it has to be reminded that the tests are supposed to be as close as possible to the full scale conditions. In that sense the rigidity of the guide, preventing its upward motion, mimics the inertia of the full aircraft during the initial phase of the impact and allows more representative loading conditions.

The trolley bringing the plates to be tested is accelerated by a set of elastic cords which are connected to a U-shaped bar which encompasses the trolley. As shown in Fig. 2, the cords exert their action up to the point where they become aligned to the fixed supports, which gives a maximum length of the acceleration path of about 28 m. Starting from that point the U-shaped bar is slowed down by a braking system located on the wings of the guide beams. The braking system has enough power to reduce the speed of the U-shaped bar and to leave the trolley run freely along the guide up to the impact point. The total mass to be accelerated is about 1100 kg, whereas the mass which undergoes the impact is 835 kg. As discussed in the following, thanks to the large mass of the impacting system, the velocity reduction during the significant part of the test is less than 2 m/s (Iafrati et al., 2014b). During the test campaign, velocities in the range of 30–46 m/s were achieved.

The specimen to be tested are attached to a box structure which contains the electronic instrumentation and the onboard acquisition system. In order to measure the total hydrodynamic loads acting on the plates, the box structure is connected to the trolley through a total of six single axis load cells (Fig. 3). Four Kistler piezoelectric load cells type 9343, full scale range of 70 kN each, are used to measure the loads acting in the z direction whereas two cells type 9363, full scale range of 120 kN, are used for the x components. Here z denotes the axis normal to the plate, whereas x and y are the longitudinal and transverse directions,