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Survey of numerical approaches to analyse the behavior of a composite skin panel during a water impact

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ABSTRACT

Water impacts may have tragic consequences for the passengers of helicopters. Most of the passive safety devices developed for helicopter crashworthiness is designed for ground impact. The loading that characterizes the impact with hard and soft surfaces is different and therefore energy absorption devices developed for ground impact are not effective during a water impact.

Various researches focus on the use of composite materials for aircraft and helicopter fuselage. In this paper, in particular, it is investigated the behavior of a composite panel during the impact with water and the approaches to study the event by means of finite element codes.

In order to collect reliable data for numerical model validation, water impact drop tests were carried out. A sample panel, made with a Carbon Fiber Reinforced Plastic material similar to those used for modern aircraft skin panels, was manufactured. A specific test device was created and used in the tests. Impact decelerations and deformation of the panel were measured.

Numerical models of the tests were created. Meshless approaches were used, in addition to Lagrangian and Eulerian Finite elements, to model the water region. Eventually, a close experimental–numerical correlation was obtained for each model in terms of impact dynamics, decelerations and composite panel deformation. The main features of the event and the differences between the four numerical approaches were discussed. Guidelines for further investigations were also drawn.

1. Introduction

Water impact is an issue of great importance for rotorcraft and aircraft crashworthiness. Statistics [1] has shown that 10% of civil aircraft accidents and 25% of military aircraft accidents involve impacts with water.

While remarkable progresses in crashworthiness design have been achieved in recent years, most of the passive safety devices have been developed considering ground impacts [2]. Analyzing the structure behavior during a ground impact versus a water impact, experience shows that the load paths are completely different (Fig. 1). Therefore, it is not unusual that energy absorption devices designed for ground impact are not effective during a water impact.

Impact loads during a water impact are usually lower with respect to equivalent ground impact scenarios, but the impact duration is longer and load distribution involves parts of the structure not designed to carry impact loads [3].

When an aircraft is involved in a ground crash landing the load is transferred through subfloor structure (frames and spars), which absorbs part of the impact energy by progressively deforming. Since ground deformation can be considered negligible with respect to the structure, the load entity and path is more predictable and a crashworthy design of the aircraft subfloor can be developed to limit the loads transmitted to the occupants.

On the contrary, when an aircraft is involved in a water landing, the water pressure impinging on the skin panels leads to panels collapse and consequent failure of the load transfer mechanism between skin panels and subfloor structure, affecting the energy absorption capabilities of the subfloor. The skin panels collapse leads to two potentially critical consequences: reduction of the energy absorption capability of subfloor and water inrush with consequent cabin flood and reduction of floating time.

The analysis of the event before the failure of the panel is complicated by the fact that the entity of the impact loads also depends on fluid–structure interaction.

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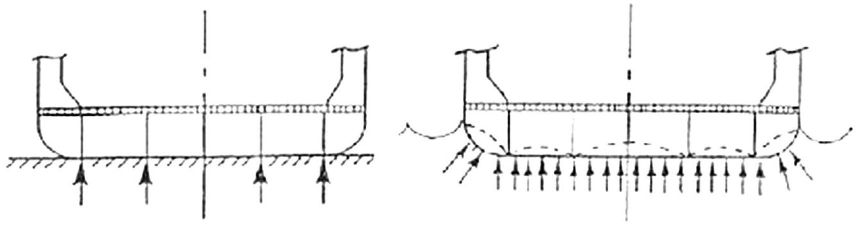

Fig. 1. Ground impact (left) vs. water impact (right) [3].

At Politecnico di Milano Laboratory for Safety in Transports (LAST) research activities on fluid–structure interaction and helicopter ditching have been performed since 1994. Between 2005 and 2008 it joined the Group for Aeronautical Research and Technology in Europe (GARTEUR) AG15 was established to improve the Smoothed Particle Hydrodynamics (SPH) method for application to helicopter ditching.

Following previous research work on non-deformable bodies impacting water [4], the activity was focused on fluid–structure interaction between water and a composite Carbon Fiber Reinforced Plastic (CFRP) skin panel.

The research work consisted of two phases: the initial experimental phase and the subsequent numerical phase.

In the experimental phase, water impact drop test were carried out to collect test data to develop and validate numerical models. An instrumented CFRP flat panel was mounted on a specifically built test frame, during the tests both decelerations on the frame and deformations of the panel were measured.

In the numerical phase the tests were reproduced modeling the fluid region with different numerical formulations; two finite elements approaches, Lagrangian and ALE, and two *meshless* formulations, SPH and EFG. LSTC LS-Dyna 971 [5], a proven and commercially-available nonlinear explicit finite element code was used. The results obtained were compared against experimental tests and to evaluate different formulations performances in terms of correlation and computational efficiency, providing important guidelines for modeling fluid–structure interaction in water impact events.

2. Experimental tests

The intense test campaign carried out in the first part of the research consisted of performing water impact drop tests using a CFRP skin panel.

A solid test frame was built to investigate the impact behavior of the panel. During the tests impact decelerations and deformations were acquired. Besides, high velocity movies of the tests were recorded to evaluate the impact dynamics of the event.

2.1. The specimen

The specimen (Fig. 2) was a flat 400 × 400 mm CFRP panel. The panel was made with Vicotex 914/42%/G803 (carbon fiber woven 42% in resin epoxy) and a stacking sequence $[90°, 45°, 0°, -45°]_{SYM}$ typical of some aircraft skin panels were used. The nominal thickness of the panel was 2.00 mm.

2.2. The test article

The test article (Fig. 3) consisted of a massive base frame, four lateral flat Aluminum alloy panels and L-shaped corner stiffeners. The base frame, in particular, was a 400 × 400 mm, 40-mm height Al 6082-Ta16 plate machined to have a square hole of 320 × 320 mm. The CFRP panel was bolted on the base frame so that the actual impact region was 320 × 320 mm.

The test article was provided with a cap to avoid water inrush. The global dimensions of the test article were 400 × 400 × 500 mm and the test mass was 16.9 kg including instrumentation, cap and cables. Most of the weight of the test article was due to the frame so that the center of mass was located at the bottom of the test frame. The lateral panels were added to avoid sinking after the water impact and to provide a more solid connection to the guide used to guarantee a constant, zero-angle incidence of the test article during the fall. These panels, 2.0 mm thick, were designed to provide the necessary stiffness to the structure and to be lighter than the base frame.

The test frame was designed to test panels of different materials and thicknesses and to focus the analysis only on the panel behavior.

2.3. Test facility

The dimensions of the test article allowed performing the drop tests using the indoor facilities of LAST. A 3000 kg bridge crane was used as hoisting system and a 1.5-m diameter and 1.4-m depth PVC round pool was used as water basin.

The test article was hanged to a quick-release system and four steel cables were used to guide the test article during the fall and to maintain the impact incidence of the test article within acceptable limits (i.e. smaller than 3°). The test facility is shown in Fig. 4.

2.4. Instrumentation

Impact decelerations and deformations were measured during the tests because they are quantities of great interest in designing structures safe in water landing.

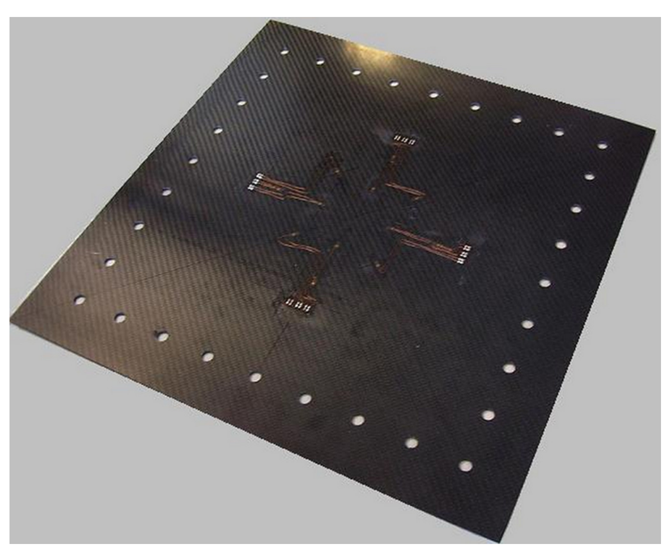

Fig. 2. The CFRP skin panel.