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More safe and less expensive design strategies in the composite A/C certification process: numerical-experimental crashworthiness evaluation for composite regional aircraft fuselage

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Abstract

The aim of the paper is to describe the advancement on the aeronautical crash simulation and test reached in CERVIA project, funded by Italian Minister of Research, and developed by an industrial/research center/university working group. The main Italian A/C maker (Finmeccanica Aircfrat Division ex AleniaAlermacchi) coordinates the research; crash activities are developed by CIRA (Italian Aerospace Research Center), by Second University of Naples and by SRS Engineering Design s.r.l. The activities cover important certification crashworthiness tasks to improve the global safety of A/C. Regarding the crash analysis the adopted numerical procedures are been borrowed from those ones well known in automotive filed, in order to set the numerical analysis of a large structural element of a regional A/C (barrel of fuselage). The geometrical data as well as guidelines about crash scenario are been agreed with the OEM (Original Equipment Manufacturer). One of the core activity is to set a numerical methodology able to predict the behavior of the aeronautical large composite structures during crash event with a good agreement with experimental tests. The goal will be achieved through experimental-numerical correlation of typical structures with increasing geometric complexity. The activities of correlation have been performed on floor beams with a good agreement between numerical and experimental data. Now the tests on stiffened panels are planned with the use of specific test bench. On the other hand, the simulations on the fuselage barrel has been performed in the case of Aluminum Alloy manufacturing materials. The biomechanics of the occupants have been evaluated during these simulations. The final crash test of the full scale fuselage barrel (3,05 mt in diameter and 6 mt in length) will be execute by CIRA at LISA (Laboratory for Impact testing of Aerospace Structures). The ambitious goal will be performed within 2016.
The good results of the first numerical-experimental correlation put the basis for the ambitious goal to set methodologies able to predict the crash behavior of large composite structures as well as the bio-mechanical parameters on the passengers. All that, in the future, could be lead to develop crash-resistant structures.

Keywords: Composite Materials, Impact, Airworthiness, Regional Aircraft, Crashworthiness

Introduction

The use of composites in aerospace as primary structures is steadily increasing, thanks to the many advantages that these materials offer compared to the traditional ones (less weight, high specific static and fatigue strength, etc.). The carbon fibers reinforced plastic materials (CFRP) mainly used in aviation are fragile and usually exhibit an elastic linear response up to failure with very limited plastic deformation and/or virtually absent. For this reason, the composite structures are particularly vulnerable to damages caused by highly dynamic loads for which must meet very stringent certification procedures (passenger injury, [3][4]). The "crashworthiness" of an aircraft is dominated by the response to the impact of the fuselage structures [5]. The Regulations generally evolve based on experience gained through accidents of aircraft in operation or anticipating security problems arising from new designs not previously experienced. Current Regulations consider sufficient the capabilities to protect the occupants of the traditional aeronautical structures (made of Aluminum Alloy) under crash conditions [6]. This assumption is derived by the analysis of existing fleets and historical accidents. This approach was considered satisfactory for traditional A/C but with the advent of composite fuselage structures and innovative design concepts, it is no longer sufficient to demonstrate the same level of protection for passengers. The response to the impact of a fuselage composite structure should be evaluated to ensure that survival is not significantly different from that assured by traditional fuselage. The impact loads and deformations of the primary structure and the floor must be carefully evaluated and its behavior taken into account during the different stages of design. Considering the need to investigate various crash scenarios and to perform comparative studies with respect to metal structures, the design of large composite structures should must necessarily widely use simulations that usually are in support of an extensive number of experimental tests [5], [1]. The numerical analyzes require an equally extensive study to assess the sensitivity of the results with respect to the modeling parameters (mesh density, modeling of the joints, of materials data, failure model, etc.) and the evidences coming from tests. The reduced number of previous example of correlation during crash [5] makes the goals of the present research very ambitious.

1. Crashworthiness scenario

In the EU, EASA CS-25 provides specifications to protect large airplane occupants from serious injuries in case of emergency landing. These specifications are CS 25.785, CS 25.561 and CS 25.562 [4] and, are applicable to the certification of new large airplane and to some major changes to existing ones. In the USA, FAR Part 25 provides similar specifications as CS-25 for new Type Certificate. The introduction of seat standards improvements was done in 1988. FAA in January 1996 provides guidance to industry on the dynamic testing of seats. Paragraph 25.561 of EASA CS-25 and FAR Part 25 provides seat static load testing instructions up to 9g in the forward direction. Seats meeting these testing requirements are commonly called '9g seats'. This paragraph already existed before but was upgraded at the time of FAR Part 25 Amendment 25-64 and JAR-25 Change 13. Paragraph 25.562 of EASA CS-25 and FAR Part 25 provides for dynamic seat testing instructions with acceleration levels up to 16 g in the forward longitudinal direction and seat occupant protection criteria like the Head Injury Criterion (HIC). Seats meeting these testing requirements are commonly called '16 g seats'. The specific objective of this proposal is to improve the protection of occupants onboard the large airplanes operated for commercial air transportation (CAT) of passengers, when they are involved in a **survivable accident impact**. From these standards, it will be derived the general requirements to identify the conditions at which the entire fuselage should be subjected in case of survivable event (*A change in downward vertical velocity (Δv) of not less than 10.7 m/s (35 ft/s) …. Peak floor deceleration occurs in not more than 0·08 seconds after impact and reaches a minimum of 14 g; A change in forward longitudinal velocity (Δv) of not less than 13.4 m/s (44 ft/s) ... Peak floor deceleration must occur in not more than 0·09 seconds after impact and must reach a minimum of 16 g)*
Analyzing this scenario, it can be posed the basis for another "step beyond the state of art" in the safety improvement of A/C trying to increase the *percentage of survivals* (PoS) during *fatal accident*. The yearly reports of the main Civil Aeronautical Organizations such as ICAO, EASA, FAA and IATA ([6], [7]) show a constant value of PoS (20-25% depending on the observing year) from '50s today. The same organizations have identified the improvement able to increase the PoS. From one hand, the response to the impact of composite fuselage structure have to be evaluated to ensure that PoS were not significantly different from that secured by a plane of similar size manufactured in metal. On the other hand, to make in practice suitable improvements to reach high value of PoS, the primary structure of the fuselage (skins, stiffeners, floor and sub-floor) must redesigned in order to increase the impact energy absorption with the final goals of:

- Reducing the acceleration peak (**bio-mechanical requirement**)
- Reducing the deformation of floor, doors and surrounding structures (**escaping requirement**)
- Reducing the fuselage deformation (**anti-crush requirement**).

2. Crash Simulation

The starting point has been the long experience gained in the automotive field where the level of crash simulation (methodologies, materials properties, software, filters atc…) is so high that the experimental-numerical correlation is a standard activities. From aeronautical point of view, this represents an advantage not only for the wide available literatures, but also for the readiness of numerical SW's used for the simulation. The simulations are performed with typical FEM SW's in their explicit formulation due to the phenomena duration and speed involved. The most widely used software for this kind of application are: MSC Nastran, Abaqus and Ls-Dyna. In order too improve the confidence with the obtained results, problems with growing grade of complexity has been simulated and successively experimentally correlated. Typical composite laminates were well characterized (especially from static point-of-view), nevertheless no a lot of information was available regarding the dynamic behaviour. It was assumed that the material had a negligible strain rate behaviour. Much attention has been given to the mechanism of energy dissipation of assembled CFRP structures. Contrary to the steel, the CFRP does not show any yield phenomena and the impact energy dissipation is deputed to the material failure (i.e. delamination, matrix-fiber de-bonding, fiber and matrix failure) and connections failure modes. The FE simulations have been set to take into account not only the impact loads but also the progressive failure of the composite excepting delamination that would require too fine model. In the planned activities, also the failure of riveting, bolted, bonded and co-cured parts will be taken into account.

3. Experimental and numerical Test Matrix

The planned test matrix of the simulations and dually of the experimental tests are specified in the following table (N= numerically tested; E=Experimentally tested; M=Modelled with functional tests):

Table 1: Numerical-experimental test Matrix

Test case	*Materials*	*Status**
Sub-floor beam	CFRP	N & E
Sub-floor assembly	CFRP	N & E
Stiffened Panel T1 (only one stringer - mono-bay)	CFRP	N
Stiffened Panel T2 (from 2 up to 5 stringers multi-bay)	CFRP	N
Stiffened Panel T3 (Frame and stringers)	CFRP	N
Barrel of fuselage T1 (without dummies)	CFRP	M
Barrel of fuselage T2 (with dummies for bio-mech.)	AA (1st model) CFRP (2nd model)	N M

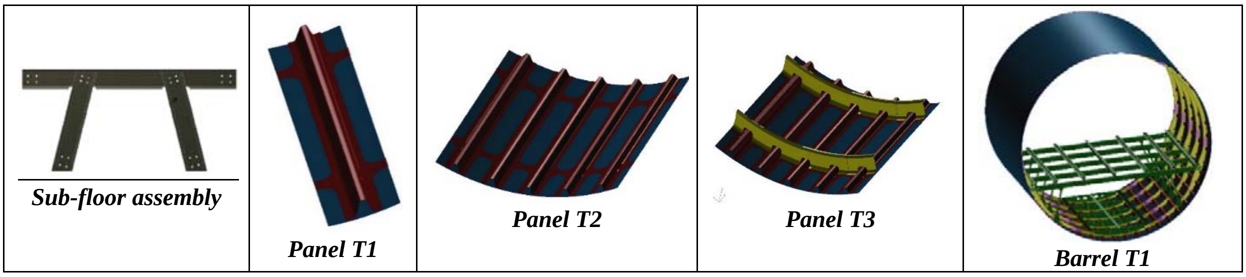

Figure 1 – Sub components – FE models

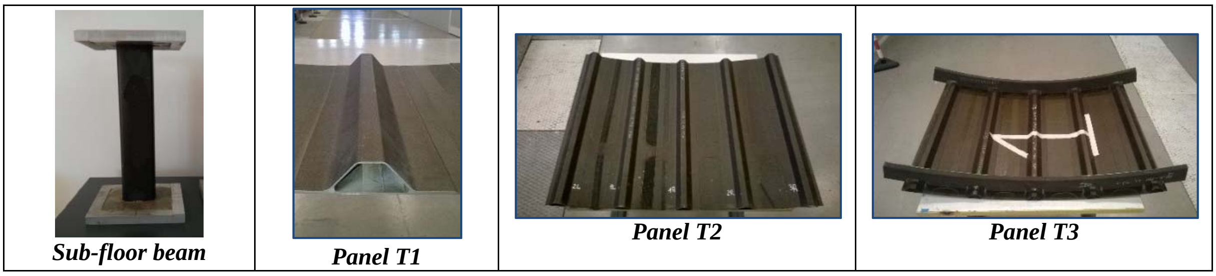

Figure 2 – Sub components – Experimental models

The CFRP material used for the entire barrel and for the sub components is a typical unidirectional pre-preg used in aeronautical field. The test matrix was structured in such a way that the complexity of the

tests were increasing. Further, all subcomponents were defined in order to limit, as much as possible, the uncertainness regarding the final crash test. Numerically all sub-components are/will be tested in quasi-static load conditions (to verify their stiffnesses) and under impact loads. The same tests are/will be experimentally replicated.
Figure 1 shows some numerical test articles. Figure 2 shows some sub-components before testing. The entire experimental test campaign will be completed within 2016.

4. Numerical results regarding barrel of fuselage T2 – 1st model.

One other ambition is the evaluation of the several kind of injuries that an aircraft passenger can be affected during a crash landing event; few experimental tests are available from literature ([5]). One of the test is the fuselage drop test. The aim of the simulations has been the development of a numerical procedure, multibody and mixed FE/Multybody based, useful to simulate the aforementioned test. Numerical analyses have been carried out respectively by means of LSTC-LsDyna® and TNO-Madymo® codes. In this case, while the shape of the barrel has been consistent with the fuselage barrel reference, the manufacturing materials has been treated as a metallic one (aluminium alloy). In a next step the bio-mechanical evaluations will be performed considering a CFRP fuselage (also experimentally). Hybrid III 50th dummy has been used in the simulations to focalize the behaviour of the passengers. Detection of forces and accelerations acting on the most sensitive areas of the human body such as head, neck, chest, pelvis and femurs have been evaluated. Figure 3 illustrates the drop test time evolution obtained through numerical simulation. The biomechanical injuries have been evaluated through the injury criteria described in the [3].

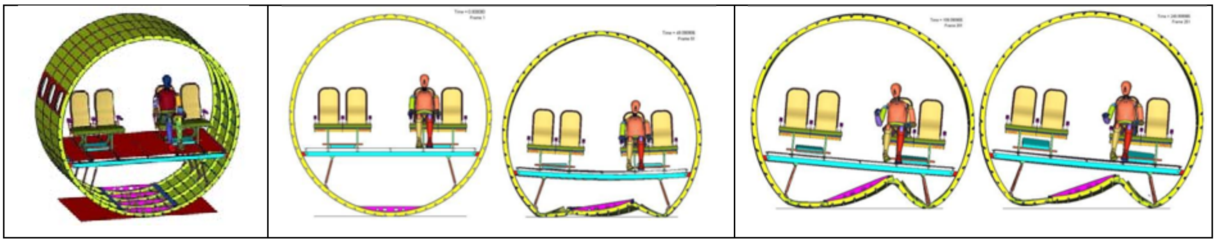

Figure 3 – Simulation of aircraft drop test.

5. Conclusions

The good results of the first numerical-experimental correlations put the basis for the ambitious goal to set methodologies able to predict the crash behavior of large aeronautical composite structures as well as the bio-mechanical parameters on the passengers and finally the development of crash-resistant composite structures.

6. References

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