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Procedia Engineering 167 (2016) 120 – 128

Procedia Engineering

www.elsevier.com/locate/procedia

International Symposium on Dynamic Response and Failure of Composite Materials, DRaF2016

Fuselage crashworthiness lower lobe dynamic test

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Abstract

The focus of this paper is to demonstrate the energy absorption capability of the lower lobe section of the aircraft, and to provide test data in support of validation of the LS-DYNA numerical model.
Following a national research program, a full scale drop test, of an airliner composite sub cargo floor fuselage, has been performed by the Italian Aerospace Research Center (CIRA) at their LISA (Laboratory for Impact testing of Structures in Aerospace field) facility.
The ultimate aims of research are design, size and evaluation of the crash behaviour of a specific concept of composite aircraft fuselage section linked to the full scale tests.
The results are based on pre-test simulations performed on coupon including representative elements devoted to the absorbption of the crash energy, and finally with the final drop test results and the corresponding post-test simulations.
Test provides validation of LS-DYNA analysis, and using the simulation tools it is possible to quantify different parameters as energy distribution, accelerations, dynamic structural efficiency, and structural deformations throughout the crash event, but above all the importance to define the real conditions of the constraints and loads in the attempt to reproduce the behaviour of the full scale aircraft fuselage, or section of it, during an emergency landing condition, partially reduced to the full scale subfloor. Then the simulation allows to develop geometries and size of the structures with stanchions and other structural elements in order to reduce the energy absorbing capabilities of the cargo subfloor.
Test data indicates the cargo subfloor can absorb an impact velocity of 22 feet/sec with typical payload, and the certification requirements about the emergency landing as satisfied. Finally, the decelerations and deformations are restricted in a survivable space for the passenger compartment.

Keywords: emergency landing; crashworthiness; drop test; fusolage lower lobe; aircraft certification.

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doi:10.1016/j.proeng.2016.11.678

1. Introduction

The paper describes the research activities which are of interest to the scientific community, with specific reference to an industrial application, for the research of new configurations and materials that can be adapted on the lower lobe of an aircraft fuselage in accordance with the certification requirements. Among the sizing requirements and as a result of certification program a critical point is the emergency landing, ref. [1] and [2].

These activities are dedicated to the design, sizing and crash behaviour evaluation of a specific concept of composite aircraft fuselage demonstrator with the objective to validate FE code on a subfloor cargo composite fuselage section drop tested by CIRA.

The goal of the research program is to develop some of the technologies required to enable the introduction of composite materials into aircraft primary structures. Actually, the use of composite material in airframe component manufacturing is becoming widespread and the trend will continue. The understanding of how composite materials behave as load-carrying material is being developed continuously.

The major difficulties are derived from the introduction of the composite materials in a field where the survivability has been and will continue to be the main theme in aircraft safety, considering that the certification specifications adopted from the authorities to certify an aircraft are not ready to define a complete transfer from metallic to composite materials.

The Federal Aviation Administration, FAA, is a national aviation authority in the United States, One of FAA’s major function is to define the standards regulating civil aviation. Composites are non-standard technology with limited shared databases, methods and guidelines. In past, FAA introduced the advisory circulars that present recommendations for showing compliance with specific requirements associated with composite materials, ref. [3] and [4]. These circulars are considered essential in the certification process for composite aircraft components as well as for establishing quality control provisions for material manufacturing and implementation.

This work presents the crashworthiness capabilities that a new concept of regional A/C must show under foreseeable survivable impact events, and the regulatory requirements imposed by EASA and FAA require to demonstrate the compliance to these rules by dynamic tests or analysis comparable to that achieved on previously certificated A/C of similar size, [6] and [7].

So one possibility is to examine the crashworthiness of composite structures and to develop a guidance certification analysis and test protocol for composite fuselage crashworthiness certification in order to increase the confidence and level of safety of composite components, [8]and [9].

In order to enable further implementation of composite structures in future crashworthy designs, a good way of modelling composite materials needs to be defined. Many composites exhibit energy absorption capability even during crushing, which is advantageous during a crash event, since this leads to a constant deceleration of an impacting object. This is what makes composite materials interesting in crashworthy structures, apart from the fact that composites exhibit a high stiffness-to-weight ratio. Damage in fiber reinforced polymers can occur with a combination of many failure mechanisms, such as delamination, fiber kinking, fiber pullouts and matrix crack propagation. During crushing of composites, most of these modes can be observed. There are many software using different techniques and material models for fiber reinforced polymers, consequently, the various methods need to be evaluated.

The study will be dedicated to design a three bay long section and in particular to design the cargo section and how to increase the ability of this structure to absorb energy and the level of passive safety. Finally, a preliminary prototype was designed, manufactured and tested at the experimental drop test. In this paper the numerical simulations are performed to analyze the partial fuselage (cargo section, stanchions) when it is subjected to a low velocity impact so to evaluate the impact responses of composite airframe structures, and to extend these responses up to the real condition obtained during an emergency landing. This paper provides the correlation between the experimental test at low velocity impact and the numerical analysis that are the final step of an extensive campaign of test performed on the coupon level and on model in small scale. The aim of this correlation offers multiple advantages:

- Improving the energy absorbing qualities in the event of an impact;
- Evaluation of the energy absorbing supports to distribute the contact force over a larger part of the body, so not only the lower lobe’s structural elements are involved in the energy absorbing process.

- Definition of the real constraints and loads about a portion of the fuselage that reproduce the similar condition obtained on the full scale aircraft fuselage during drop test.
- Definition of a guidance certification analysis and test protocol for composite fuselage.
- Assessment of methodology of modelling composite structure failures due to impact based on specimen tests and design guidelines.

2. Crashworthiness response extended to barrel section full scale

Certification specifications requires that a transport category airplane must show acceptable crashworthiness capabilities under foreseeable survivable impact events as described below. A way of showing acceptable capability is to demonstrate via a combination of test and analysis that the aircraft provides a level of crash survivability comparable to that achieved on previously certificated wide-body transports of similar size.

In general, the manufacturer should demonstrate either through analysis using validated analytical tools or by direct test evidence that the crash dynamics of the fuselage structure provides a level of occupant protection consistent with previously certificated large transport category airplanes (CLTA). Two potential approaches are acceptable for demonstrating the crashworthiness characteristics of the airframe:

- Drop test able to validate the analytical tools.
- Validation of analytical method by testing coupons and sub-elements.

The attention is focused on the barrel section in proximity of the forward cargo compartment, and simulating a drop test at 30 ft/s of the barrel section on the hard surface, the simulation exhibits the behavior of each component involved in the impact scenario and the study is concentrated on different parameters as energy distribution, time history of the accelerations, deformations, reactions force, and the vertical acceleration at the cabin floor in correspondence of the seat track of the passenger area.

When the energy levels are confident, the attention was dedicated at the LS-DYNA detail simulation about the dedicated composite testing on coupons detailed by an extensive campaign of tests dedicated to obtain the static and dynamic characteristics of different materials and layups. Then the experimental tests were dedicated to the evaluation on large elements as only stanchion according different installation solution or single frame assembly with stanchios and different joint solution as glue or fittings. Finally, sub-components (validation) and lower lobe assemblies and relative detail analysis effort linked to each test.

A detailed step by step procedure is listed in the following figures.

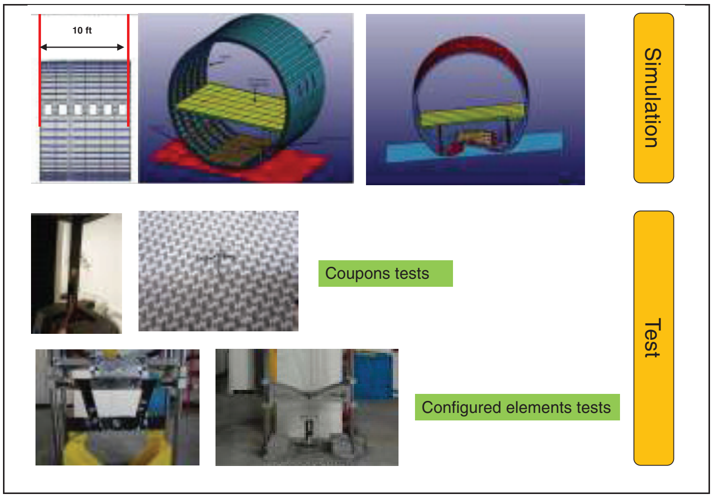


Fig. 1. Test/Analysis overview

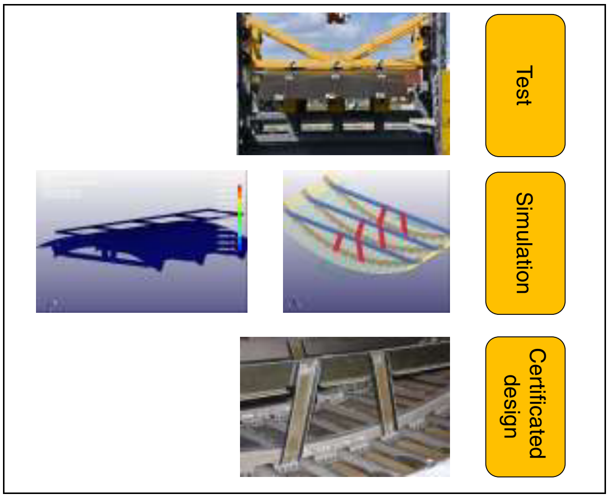


Fig. 2. Building block approach

3. Development of energy absorbing concepts

The front view of the FEM model fuselage subjected to vertical impact is shown in figure 3. The rigid wall is located in the XY plane under the structure. The distance between the fuselage and the wall is 0.1 m, this means that the structure hits the wall after traveling this distance at a speed higher than that initially set, because it takes into account the acceleration of gravity.

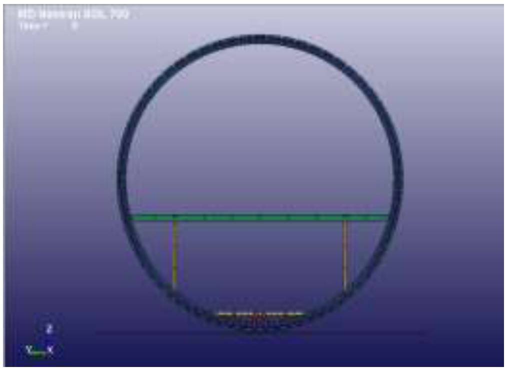


Fig. 3. Front view of the FE mode.

As soon as the structure impacts with ground the kinetic energy of the body decreases, [10], [11], and as the energy is absorbed by the inner parts of the structure that react. This shows that the structure hit the wall hard, and also shows that most of the energy at this time is absorbed by the structure as internal energy of the elements in proximity to the impact zone.

The front view of the fuselage is shown at time 0.1s in figure 4. The pavement passenger is involved in the phenomenon of impact. The deformation of the frame continues to be marked, while for the floor passenger appears to be small. It is noted that the area of attachment between the frame and the floor of the deformations presents very marked, because the structure of connection between the two parties has been modeled using a simple junction and then the floor is directly connected with the frame. There is no intrusion of components in the passenger area; the frame will not warp outwards by entering the passenger area. It has a significant decrease in the volume of the passenger area. The most stressed parts of the structure floor turn out to be the stanchions that act as beam column. This appears to be the most important moment of impact, because the affected area is occupied by passengers.

Fig. 4. The contact of the FEM fuselage and ground after 0.1 s

Analyzing the crash absorbing dynamic and failure characteristics related to the post-impacted fuselage it is possible to identify to the internal energy for each part involved in the impact as shown in fig. 5. The floor passenger (Part 12, 13, 14, 15) absorbs the maximum amount of energy compared with the other parts, such as: cargo floor (Part 8, 9, 10, 11), skin (Part 2, 3, 4), stringer (Part 5). Nextly the passenger floor frame (Part 6, 7) absorbs more energy than the other components.

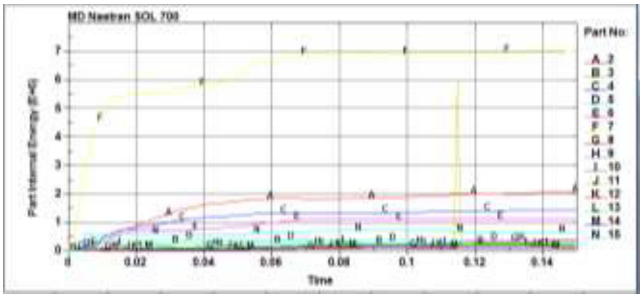


Fig. 5. Internal energy for each component of FEM fuselage.

The numerical results obtained on the fullscale fuselage subjected to the drop test, allowed studying and to define the best solution to scale a dedicated specimen as a portion of the fuselage, the final focus about this research project is define the design, the prototype ready to be tested at drop impact test.

The scaled prototype presents the partial fuselage, and modifying the structure, materials and layup it was possible to evaluate the parameter that influence the cash absorbing characteristics of the cargo component defining the best solution in terms of acceleration measured in correspondence of the possible attachments of the passenger seat.

These wide range variables about the different simulation allowed focusing the study about the layup and material focusing the attention on the ability to absorb energy. The correlation between the simulations about the full scale of the fuselage and the scaled component allowed to evaluate the parameter that influence the cash absorbing characteristics of the cargo component. For example, it was possible to identify the time histories of acceleration measured in correspondence of the possible attachments of the passenger seat about two different configurations.

The numerical results obtained on the fullscale fuselage subjected to the drop test, allowed to study and to define the best solution to scale a dedicated specimen as a portion of the fuselage, the final focus about this research activity is the definition of the prototype ready to be tested at drop impact test.

Materials used in these specimens are the best solution chosen between different layups of carbon fiber material. The rigidity of stanchions and design of subfloor structure, thicknesses and constraints have been defined by analysis.

4. Crashworthiness response extended to subfloor cargo full scale section

The structural model is dropped to a rigid flat base by the free-fall method in an impact machine. The item of interest of the lower lobe to be performed at the drop test consists of:

- Three cargo beam: C section with a thickness of 1,86 mm and 8 plies of CF.
- Skin: thickness of 1,604 mm with 1F+12plies.
- Three Frames: Zeta section with a pitch of 584,2 mm, thickness of 1,979 mm and 1F+15 plies.
- Six stanchions: C section with a length of 350 mm, thickness of 1,86 mm and 8 plies of CF, and with an installation angle of 18 degrees.
- Stringer: 15 stringers with a pitch of 170 mm. Omega stringer has thickness of 1,604 mm and 1F+12 plies

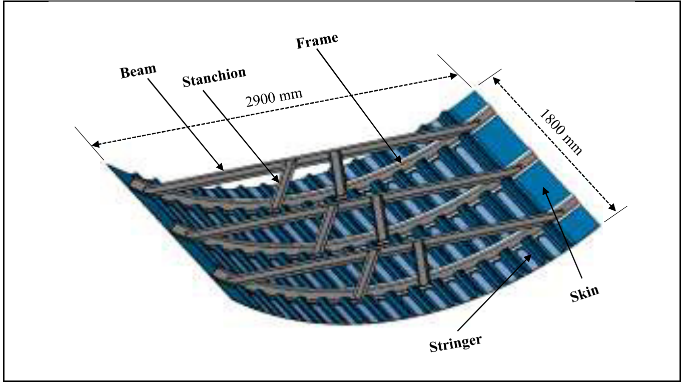


Fig. 6. Lower lobe item

The panel radius is 2403 mm, and the maximum height of 360 mm, the subfloor weight is 29 kg. The rigid truss weight is 150,3 kg and it free falls on the test article.

Fixing the height, the velocity obtained is 1.7 m/s.

The primary purpose of these tests is to provide test data in support of validation of the LS-DYNA analysis model.

Preliminary comparisons were presented and include:

- Total Energy vs. time
- Reaction at steel truss.
- Accelerations THS.

5. Design guidelines to scale loads and constraints

Development of the model was performed using two pre-processing software package, MSC.Patran and LS PrePost. A geometric model of the lower lobe fuselage section was developed containing the important structural features of the airframe. The geometric model was discretized, and element and material properties were assigned, all parts are modeled by two-dimensional elements. A database of composite materials and metal was implemented, to allow changing in the properties of each part to optimize the absorbing of energy. It is in fact thought to analyse the behaviour of non-homogeneous structures, creating models made entirely of composite material and other mixed composite material and aluminium, in order to highlight the structural solution faster in the event of a crash. All models have in common geometry, initial and boundary conditions.

The complete finite element model of the lower lobe fuselage section is shown in figure 7. Components of the model including the outer skin, fuselage frames, longitudinal stringers, stanchions elements.

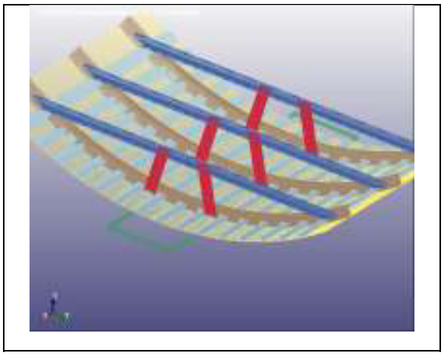


Fig. 7. Particular component of the fuselage section

The assignment of a consistent contact is important for the discussion of the crash event. This is essential to allow the transmission of the load between the structure and the rigid truss, also allows to predict the load transmission among the different parts of the structure that are in contact during the deformation, so as to avoid the interpenetration among the parts that are in contact. The distance between the elements of the structure and the impactor was introduced through the CONTACT tab, touch a master-slave type 'adaptive'. Furthermore, it has been used a self-contact, to avoid surfaces that fold back on themselves exhibit interpenetration of nodes, because of the large deformation on impact, the surfaces can turn in on themselves.

The problem of finding an appropriate formulation for the shell element for the prediction of damage on the composite material has been addressed using a model that predicts the progression of the damage reproducing an accurate coupling between the deformation modes. Assigning elasto-mechanical properties of the material using the card MATD54, that is a model for orthotropic materials, [5]. MATD54 also reduces the resistance of the fiber to account for the failure of the array and implements a model of progressive degradation after breaking. Optionally two types of failure are defined (Chang and Chang, 1984 (CRIT = 54.0) and Tsai and Wu, 1981 (CRIT = 55.0)). This model is valid only for thin shell elements. For all the shell elements this lamination theory is used. The theory of the laminate is properly applied uniformly to a constant shear strain through the thickness of the shell.

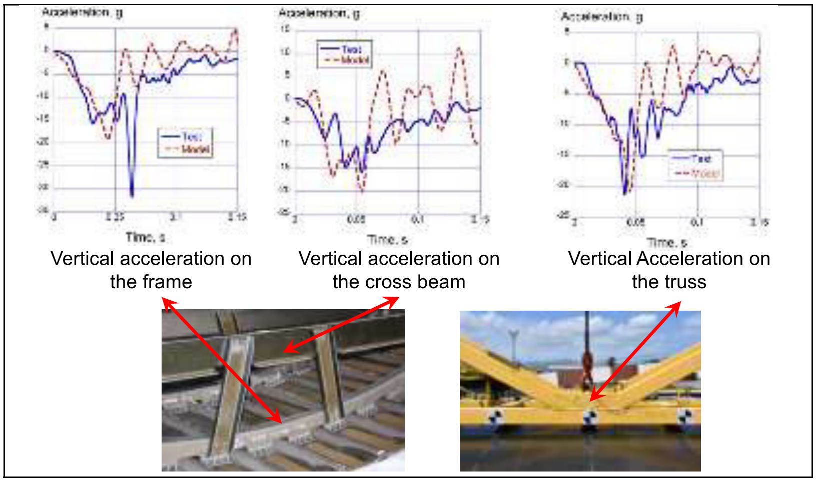
This preliminary experimental test was performed at low velocity impact (Kinetic Energy is 220 J), where the steel truss acceleration recorded a maximum peak of 31.8 g. On the skin is not visible a crush depth, and the test article doesn’t present a visible fracture.

The numerical-experimental correlation of the acceleration time-histories defines a good correspondence about the steel truss acceleration considering a piezoelectric accelerometer placed on the impact mass, which showed a local oscillation due to the truss, and which manifests itself during the initial part of the impact as damped oscillations.

The acceleration installed on the frame and cross beam produced a good correspondence with the numerical results, more the path less the peak, see fig. 8.

Test data allows to validate the analytical tool during the emergency landing conditions. The numerical simulation indicates lower lobe can absorb an impact velocity of 30 feet/sec with typical payload.

During the retrofit design onto the section barrel of the new A/C, the simulation exhibits, during a crash landing, in cabin floor a peak acceleration correspondence of the passenger seat track lower than 60 g, that is not a dramatic initial peak.



Vertical acceleration on the frame

Vertical acceleration on the cross beam

Vertical Acceleration on the truss

Fig. 8. Lower lobe dynamic test/Analysis

6. Conclusion

The numerical simulations aided to evaluate the part of the structure able to absorb the energy during the impact, have allowed to reproduce a similar scenario but on a partially “scaled” numerical component.

The design configuration of the cabin-subfloor section significantly affects the dynamic response of the airframe and then of the passengers, [13]. The development of structures with stanchions and other structural elements able to improve the energy absorbing capabilities of the cargo needs to be addressed in future crashworthiness requirements.

The typical transport category airplanes feature stanchions in the cargo floor structure, which can be designed to optimize crashworthiness of the airframe. Particular attention should be payed to the energy absorption mechanism through progressive crushing of CFRP stanchions which requires certain design features of the stanchion itself.

To increase energy absorption, the C-channel stanchions need to be separated from the structure on one side so that they may subsequently crush.

Simulation tools are able to quantify for all the components in the structure the Strain Rate, Loading Rate, Energy Distribution, Accelerations, Dynamic Structural Efficiency, and Structural Deformations throughout the crash event.

The detailed numerical demonstrator of the barrel section provides a predictable tool that can be used to evaluate the passenger’s risk of injury.

Acknowledgment

Authors would like to acknowledge that part of the research activity, whose main results are presented in this paper, has been conducted within the frame of the research project “MACADI” (DM 60703) granted to IMAST S.c.a.r.l. and funded by the M.I.U.R.

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