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FUSELAGE ADVANCED COMPOSITE DESIGN TO COMPLY WITH AN EMERGENCY LANDING TEST

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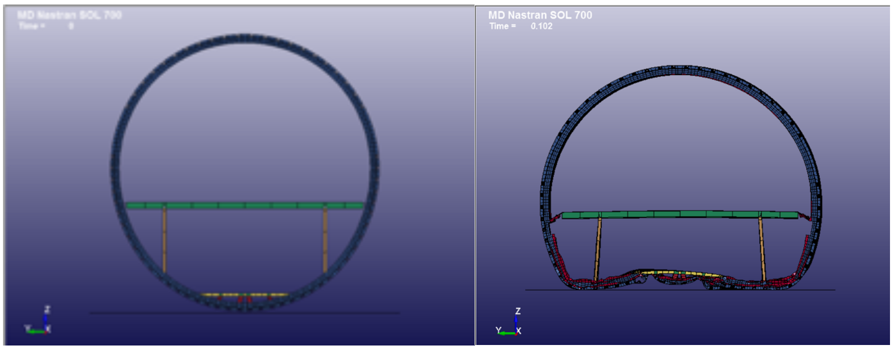
ABSTRACT

The emergency landing is an important design criteria in airworthiness certification. It is associated to the cabin safety and consequently to the risk of serious injury for the occupant. The loads transmitted to the passengers during a hard landing can be fatal both in terms of intensity and duration time, and the energy absorbing systems play a fundamental role to dissipate the energies unleashed during the impacts.

A barrel section was studied by the Finite Element Method to simulate the drop test consequences for the fuselage section of a wide body aircraft, and a medium velocity impact was applied to design devices and substructures able to dissipate the biggest amount of kinetic energy.

A validation process was obtained following three different steps: firstly, investigating the materials, layups and material characteristics changing with load's velocity, secondly different tests were performed on the demonstrators in order to verify the installation parameter of the devices devoted to absorb the energies, and finally the experimental results were extended on the lower lobe of the sub-cargo compartment tested at low velocity impact. These experimental results and the correlation with the numerical models allowed to extend the results on the barrel section and to evaluate the accelerations transmitted during the drop to the occupants. The satisfactory results estimated by the numerical solvers are able to aid the design and to reduce the experimental testing for the identification and the choice of different candidate solutions.



(a) – pre-test (b) – post drop test

Figure 1: Section barrel

Keywords: emergency landing, numerical and experimental test, FEM analysis, barrel section

1 INTRODUCTION

Occupant responses and injuries are important considerations in the design and assessment of aircraft safety. Although incorporating occupant responses and injuries into the design of safety devices is highly recommended by the current safety regulations, there are limited studies that directly consider occupant responses and injuries. Crash test dummies are equipped in the state-of-the-art crash testing and thus occupant responses and injury risks are evaluated directly based on occupant estimation responses. In the present work, the occupant responses and injuries in emergency landing events were investigated by positioning dummies into the barrel section of the fuselage model during a crash landing simulation. The FE models of a wide body fuselage and the Hybrid III 50th percentile crash test dummies were employed for evaluating the effects introduced by a new design of the lower lobe of the cargo section. The FE model was validated using existing experiments present in bibliography including a sled test and a normal drop impact test in full scale test. Simulations of the fuselage impacting a hard surface at a descent velocity of 30ft/s (10m/s) were conducted and the occupant responses were analysed. Furthermore, occupant injuries were estimated using occupant injury criteria based directly on dummy responses.

2 CRASH ANALYSIS SCENARIO

The scope of this study is to investigate the interaction of the crashworthy fuselage concept with the dummy occupant during the emergency landing on a hard surface in free drop. The starting initial step derives by an experimental drop test performed on the fuselage lower lobe carried out at low velocity impact and conducted at Italian Aerospace Research Center (CIRA) facility in July 2016. These results have been validated and then extended to a full-scale fuselage section simulating a vertical drop test, in order to evaluate the acceleration histories transmitted in correspondence of the passenger seats' attachments. Finally, these values are the input data to study the injury on the passengers during a vertical drop.
The fuselage section is 4-m in diameter and is approximately 5-m in length, impacting on the hard surface with 10 m/s of velocity. The section of the fuselage has been completely redesigned as a new aircraft single aisle 6-abreast in CFRP material. The numerical drop test defined the acceleration histories in correspondence of the attachment seat, that are transmitted directly to the passengers, that are 50th Hybrid III anthropomorphic test dummies (ATDs) with a weight of 80 kg.

3 VALIDATION OF A LOWER LOBE SECTION

The full lower lobe section was designed, manufactured and tested at low velocity impact. The Figure 2 shows the representative section of fuselage fully manufactured of CFRP.
To validate the development process of a crash sized structure, the lower lobe is subjected to a drop test addressed to estimate the energy absorbing devices, to evaluate the dynamic global behaviour of the sub floor structure, to record the structure time history deceleration, and to assess survivability level offered by composite structure.

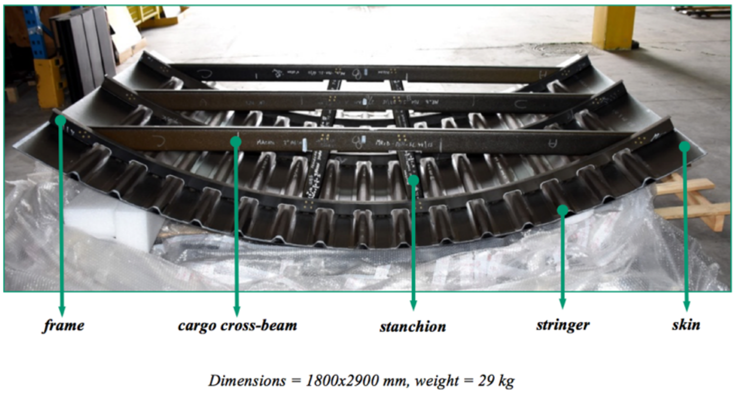


Figure 2: Lower lobe item

The lower lobe is impacted using a rigid truss drop tower of 150,3 kg in free falls, and with a velocity of 1.7m/s so to obtain an impact energy of 220 Joule. The primary purpose of these tests is to provide measurement data in support of validation of the Ls-Dyna analysis model. The test article was monitored by accelerometers, camera and strain gauges. In addition, the delamination area was observed with Non-Destructive Evaluation (NDE) systems of the impacted specimens using ultrasound methods.

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, additionally the final experimental test on the lower lobe allowed to define the peculiarities of the crush absorber and to produce a final sizing of the stanchion. Afterwards, the finite element model used to simulate the drop test of the barrel section has been updated with accurate geometry and material properties and the updated model was used in this study.

4 FULL SCALE SIMULATION OF A COMPOSITE SECTION BARREL

The following step was to upscale the lower lobe section extending the study not only to small portion of the fuselage directly impacted during a free fall, but considering a complete model of the fuselage section.

The model geometry has been developed from technical drawings of the fuselage section containing the important structural features of the airframe. The geometric model has been discretized, and element and material properties properly assigned. All parts were modelled by two-dimensional elements. A database of composite materials and metal was implemented, to allow changing of 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 faster highlight structural solutions in the event of a crash. All models have common geometry, initial and boundary conditions.

The complete finite element model of the fuselage section with cargo section and passenger floor is shown in Figure 3. Components of the model including the outer skin, fuselage frames, floor, longitudinal stringers, cargo and stanchions elements are shown in Figure 4.

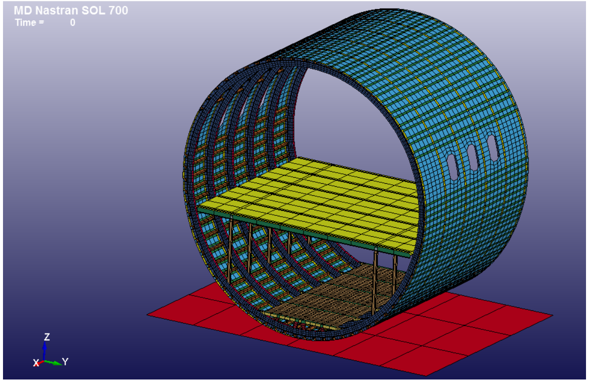


Figure 3: FE model of the section barrel

The section of the skin panel has a constant thickness and a mesh of CQUAD4 shell elements has been implemented. The surface was created following the two curves representative of the section of the lobe fuselage structure, in particular for the lower lobe the equation of an ellipse is used while for the upper lobe that of a circumference. The material of the base plate is an IMS with a specifically designed symmetrical lay-up, which has the distinction of being considered a quasi-isotropic material. The panel has a lay-up consisting of 10 plies.

The stringer has omega-section with constant thickness, extending in the longitudinal direction and has been modelled using CQUAD4 shell elements. The base material of the lamina is again an IMS, featuring symmetrical lay-up and made up of 10 plies.

The frame has "F" section with constant thickness. It extends along the circumferential direction in the YZ plane. The elements used are planar CQUAD4. The base material of the lamina is an IMS. The lay-up is unidirectional and is made from 5 plies.

The elements used to model the floor cargo are CQUAD4 and CTRIA3. The floor is composed of several parts connected by rigid elements. For all parties, longitudinal beam, cross beam, stanchion, skins, it is used as a base material of the foil IMS, but each of these parts has a different lay-up.

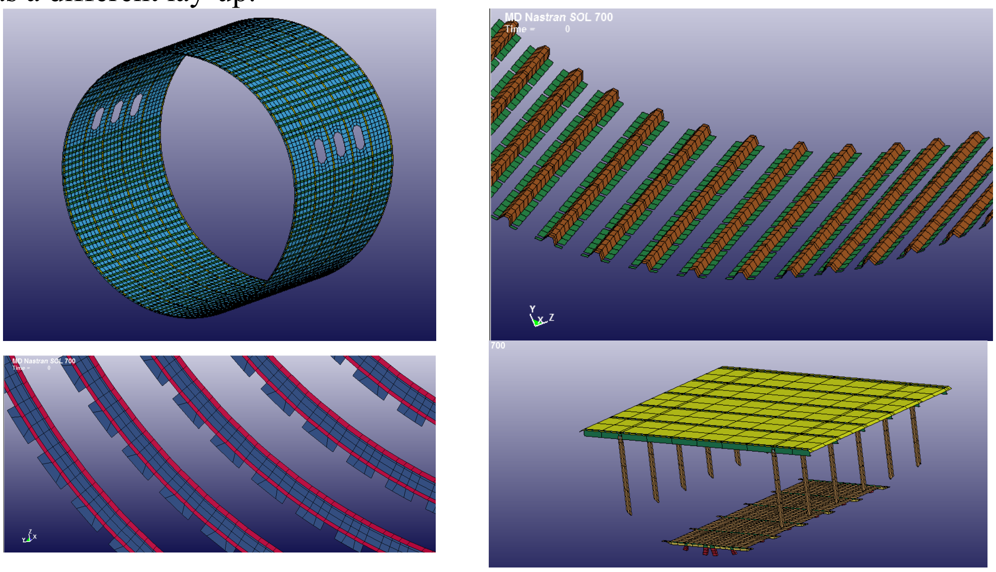


Figure 4: Details of the fuselage section.

The fuselage is subjected to drop with a descent velocity so the constraint conditions have been applied only to the ground, which is modelled as a rigid plate fixed along the outer edges, since the structure must be free to impact the ground. A 10 [m/s] descent speed was assigned uniformly to the fuselage structure. Furthermore, since the structure is subjected to the action of gravity, for a better simulation of the post-impact dynamics, a time constant acceleration equal to the acceleration of gravity, has been considered applied to the whole structure.

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 ground, 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 ground was introduced through the CONTACT tab, through a master-slave type 'adaptive'. Furthermore, it has been used a self-contact, to avoid surfaces that fold back on themselves exhibiting 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. Orthotropic materials has been employed assigning elasto-mechanical properties of the material using the card MATD54. This material card also reduces the resistance of the fibers to account for the failure of the array and implements a model of progressive degradation after breaking. Optionally two types of failures 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.

5 INTEGRATED OCCUPANT AIR CRASH SIMULATION WITH THE FEM

Known the overall behaviour of the fuselage and how the energy is absorbed from different parts during a ground impact, the next step was to retrieve the accelerations transmitted to the floor, so to be used to study the passenger injury.
The FE model of a Hybrid III 50th percentile male dummy was used to obtain occupant responses in crash simulations. It consists of 228,000 nodes, 210,439 shell elements, 242 beam elements and 186,800 solid elements. Elastic materials for the skeleton, viscoelastic material (MAT_006 in LS-DYNA) for the polyvinyl skin, simple rubber model (MAT_007 in LS-DYNA) for rubber parts, and viscous foam (MAT_062 in LS-DYNA) for foam parts, are adopted. Accelerometers installed on the head, chest and pelvis of the dummy allows to measure parameters like chest compression and axial force in the femur bones.

6 OCCUPANT INJURY CRITERIA FOR FULL-DOWN TEST

In order to provisionally place the dummy on the seat, a first numerical simulation of the model shown in figure 6 has been developed, by considering only the gravity load applied on the pelvis model, whose mass has been considered equal to the total mass of the dummy. Then, the dummy model was first validated using experimental data of a sled test during down and forward condition.

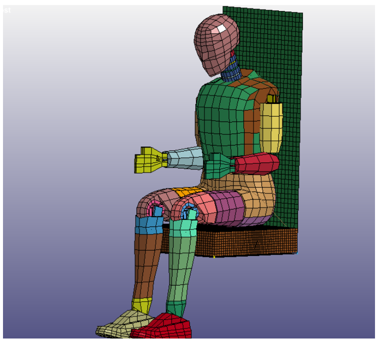


Figure 5: Hybrid III dummy model

In the attempt to define the contribution of the lower lobe in absorbing the impact energy involved in an emergency landing, the numerical analysis was defined to compare the floor-

level accelerations and head and pelvis accelerations on the dummies. The passenger seat represents the first interface element between the loads/accelerations which are transmitted from structure to the passengers, but the estimation of the accelerations (intensity and duration), in correspondence of the seat tracks, change completely modifying the structure design involved in the impact.
With regard to this last aspect, obtained FE results can be considered useful to carry out an adequate overview, from both a qualitative and a quantitative standpoint, of the dummy kinematic and dynamic behaviour of the seat during the impact event, as shown in figure 8.

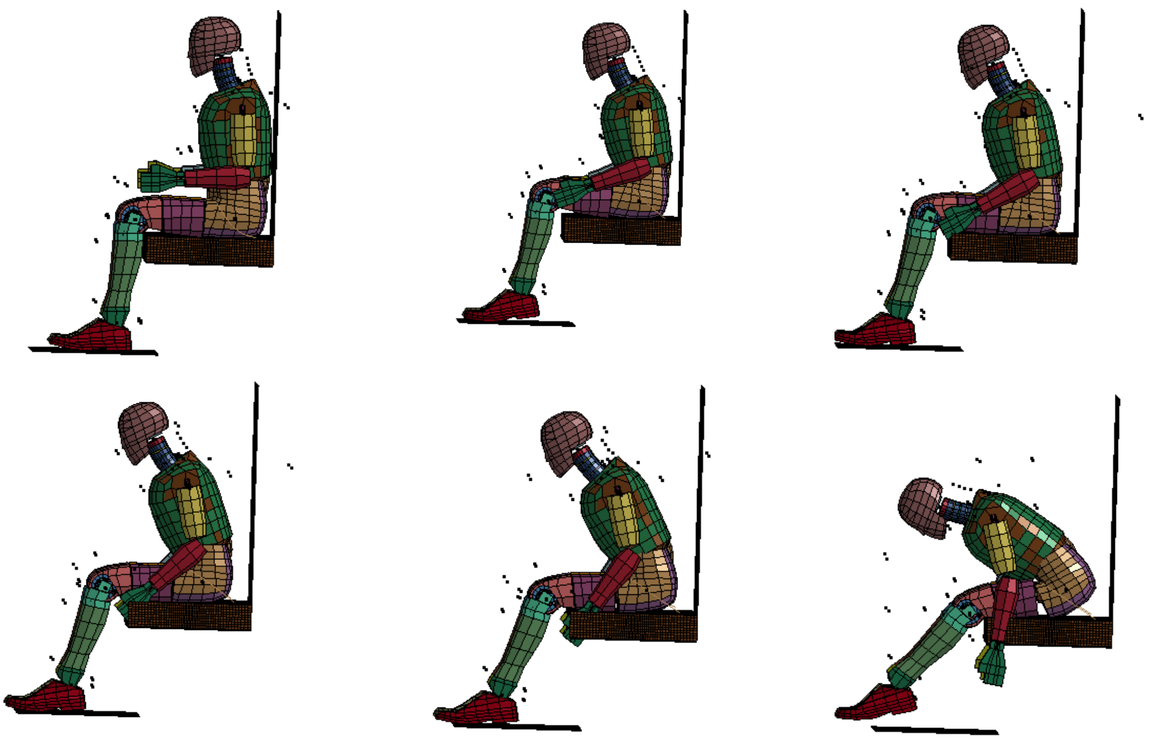


Figure 6: Kinematic results of the down test simulation.

The resultant acceleration vs. time of pelvis and head are illustrated in figure 9.

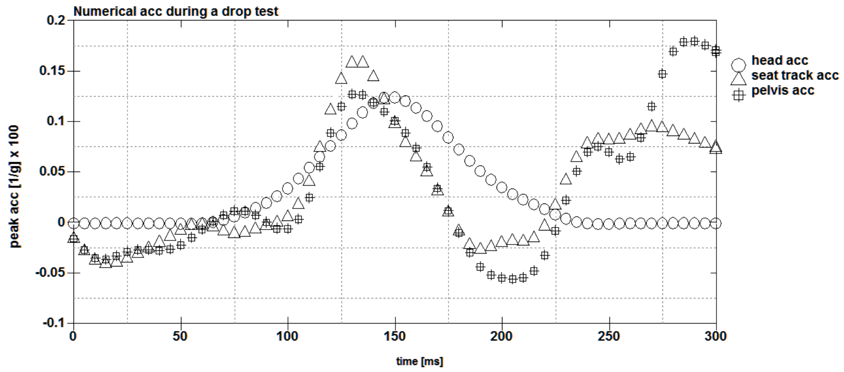


Figure 7: Accelerations histories during the impact.

Note that the floor acceleration pulse duration is approximately 0.035 - 0.04 seconds. The onset of the dummy pelvis and head accelerations lagged the onset of floor acceleration by approximately 0.005 seconds, and the acceleration duration is about 30% longer than the floor acceleration. The floor acceleration initially peaks around 17g and then levels off are 13-g.
In the next figure 10, is shown the calculated lumbar load measured at the base of the spinal column can be used to predict spinal injury. To prevent or limit injury to the spine, FAR Part

27.562c stipulates that the lumbar load should not exceed 1,500 pounds (680 kg). The peak lumbar load measured in the pelvis of the right dummy is slightly less than 1,500 pounds, consequently, the objectives of FAR Part 27.562c were met.

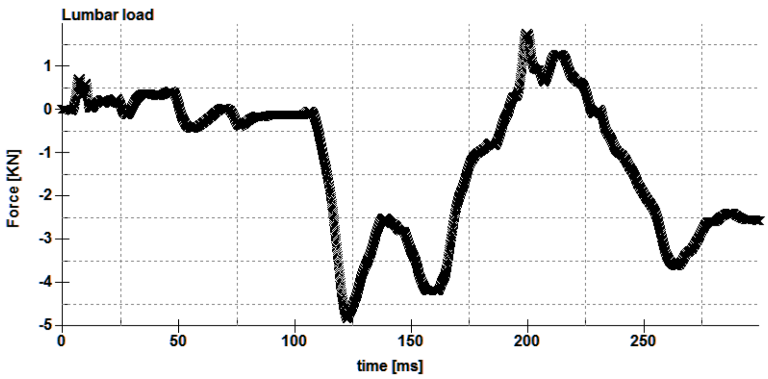


Figure 8: Lumbar load history during the impact.

7 CONCLUSION

It was agreed that the structural analysis of an aircraft seat, like a FE one, is necessary to determine whether the seat requires to be stiffened to support seatbelt overloads. Structural additional analyses would be also necessary to characterize more precisely the energy absorption capability of the seat components, with reference to the global stiffness of the frame, and also with reference to the local contact response of the areas impacted from passengers around.

The better way to obtain meaningful numerical results, without falling into prohibitive calculation times due to the extreme complexity of the model, is to start by considering a quite simplified model, up to obtain preliminary results consistent with the physics of the studied phenomena, in terms of kinematics, contact load magnitude, contact stiffness parameters and restraining system characteristics.

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