SIMULATION OF IMPACT ON COMPOSITE FUSELAGE STRUCTURES USING ABAQUS/EXPLICIT

José Luis San Vicente <sanvi@principia.es>, **Francisco Beltrán*** <fbg@madrid.idom.es>**,**

Francisco Martínez <martinez@principia.es>

Principia Ingenieros Consultores, SA,

Velázquez 94, 28006 Madrid.

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Abstract: *Numerical modelling has been carried out involving a new type of impact absorber for an aircraft fuselage structure. This work is a part of the CRASURV Project in the context of the BRITE-EURAM 4th Frame-Work Programme funded by the European Union. The role of Principia has been to carry out numerical simulations with ABAQUS/Explicit before and after a physical test was performed. In order to capture the complex mechanism of collapse in composite frames, equivalent isotropic materials have been used. The paper describes the simulations and the procedures employed for representing the materials, the comparison between pre-test calculations and test results and the improvements introduced for the post-test calculations. Conclusions are also offered in respect of the modelling strategies adopted in analyses.*

*presently at IDOM SA, José Abascal 4, 28003 Madrid.

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1.- INTRODUCTION

1.1.- Preamble

Principia is an associated partner in the project “Commercial Aircraft/Design for Crash Survivability” (CRASURV), within the BRITE-EURAM program of the European Union. The project is split into several tasks that are assigned to the different partners in the consortium. The partnership includes the main aircraft manufacturers of the continent .The goal is to validate methodologies and numerical tools for the design of composite material fuselages. The focus of the project is on impact loading and it includes numerical simulations of physical tests.

The role of Principia within the project has been to simulate a vertical drop test of a commuter subfloor structure. This included a first set of simulations before the test was performed (“pre-test simulations”), whose results were compared with the test results. Afterwards, a second set of simulations was carried out (“post-test simulations”) trying to match the outcome of the drop test. All the analyses were performed with the commercial code ABAQUS/Explicit.

1.2.- Description of the problem

A fraction of fuselage of a commuter aircraft was designed and built in composites by other partners in the CRASURV project. The guidelines for the design were: to preserve a minimum survivable space inside the structure, to limit the transmitted forces to the passage and, to find the simplest configuration of the components in order to obtain a light structure as well as to reduce manufacturing costs.

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The previous guidelines led to the concept of a collapsible component, placed under the floor of the cabin. This component was a sinusoidal web beam (SWB). The upper flange of the SWB was riveted to the seat tracks, whereas the lower flange was fixed to the skin of the fuselage. The configuration of the specimen is shown in figure 1.

All the components of the structure were built using carbon fiber composite materials. The SWB was made of a combination of layers with unidirectional carbon fibers and carbon-aramid hybrid fabrics in epoxi matrix. Besides the self-weight of the specimen (30 kg), lumped masses representing the weight of the passengers and the rest of the structure loaded the seat beams. The total weight of the specimen was 710 kg.

The test was a vertical drop test, with an impact velocity of 7 m/s. A guiding system was provided in order to assure the verticality of the specimen while the impact. The instrumentation mounted on the specimen provided records of forces, accelerations, strains and displacements. This data were intended to validate the numerical results. The purpose of pre-test simulations was to predict the outcome of the test and to help the selection of instrument locations. Post-test simulations were intended to refine the approach to pre-test analyses.

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2.- PROPERTIES

2.1.- Geometry

Starting from the drawings and CAD geometry supplied by other partners[1], a mesh enough to capture the expected behaviour in the test was built. Taking into account the symmetry of the commuter and the conditions of the test, Principia decided to model only half specimen. Appropriate boundary conditions were placed at the mid-plane of the structure. The model had a total of 30,000 shell elements and 220,000 degrees of freedom. The mesh is depicted in figure 2, where all the pieces were modelled, as well as the interactions and connections between them.

2.2.- Materials

All the pieces of the commuter were made of composite materials, except the rivets and some fittings in aluminium. The SWB was built of unidirectional carbon (Hexcel T6F190-12”-F155) and hybrid carbon-aramid plies (Hexcel 73210-F155-45%) in epoxi matrix. The mechanical properties are presented in table 1. These materials were tested in previous tasks of the project. The rest of the components of the specimen were layered in a quasi-isotropic way, and also tested within the programme.

The expected mechanism for energy dissipation consisted in the debonding and splitting of the plies and the fibers of the SWB. This was proved in several component level impact tests. Such physical phenomena are very complicated to simulate with the conventional finite element techniques. Therefore, the first step of the modelization was to find out a way to represent the failure of the

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composites. The strategy chosen by Principia was to capture macroscopically the failure of the material. instead of representing every composite ply in the pieces. It was necessary to develop an equivalent material characterised by a few parameters. After several attempts, it was decided to introduce a failure criterion based on the plastic equivalent strain of the material. Such constitutive models are available in the material libraries of ABAQUS/Explicit: elasticity, plasticity and failure. In such approximation, the involved parameters of the models had to be calibrated. Such calibration was performed differently, depending on the expected importance of the piece.

The SWB was considered the most important part of the structure and, therefore, the main object of study. It was calibrated using the results extracted from a previous test with an identical SWB [2]. The conditions of this test were simulated, and the parameters were tuned until the measured results were matched. The main indicator was the force reaction against the ground, and the result of the calibration is shown in figure 3. An elastic-plastic law was defined for the materials. Once the yielding stress was reached, stress grow until a stress peak at 2.7% of strain. The SWB behaviour model included also a failure criterion that decreased the stress to zero at 9% of strain. Figure 4 depicts the obtained constitutive behaviour of the material.

On the other hand, the rest of the components were considered of lesser importance, and they were calibrated using one element numerical tests, matching the quasi-isotropic properties gathered from previous tasks. After a stress peak the elastic-plastic branches, the stress was decreased up to a residual value that was held. The properties eventually used are presented in table 1.

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3.- PRE-TEST ANALYSIS

Once the material properties were calibrated, pre-test simulations started. The results of the analyses were a sequence of deformed shapes, as well as histories of accelerations and forces. The simulations were carried out until a problem time of 70 ms. At this point, the most important events were considered to have occurred. The most characteristic results were:

- In the first 18 ms, the frames of the fuselage break and the reduction of velocity is rather small.
- Between 18 and 24 ms the lower flange of the SWB hits the ground and the collapse of the lower part of the SWB is triggered. After 24 ms a continuous contact between SWB and skin is established.
- Between 24 ms and the end of the simulation at 70 ms, there is a sliding of the SWB outwards. The friction between components allows the collapse of the web.

Figure 5 depicts the deformed shape at 50 ms.

4.- TEST

On November the 27th of 1998 the drop test was performed at the Centre d'Essais Aérospatiale de Toulouse (CEAT) facilities. In addition to the records of velocities, accelerations, displacements and forces, a high speed film of the impact was taken, as well as many photographs. Some months later, CEAT issued a report containing the data recorded during the test[3]. Figure 6 shows the final deformed shape of the structure. The floor beams of the commuter have been lifted in order to get a better

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viewpoint of the structure.

After the test performance, it may be said that the first milestones of the test had been matched, but a weak spot not detected in the design phase appeared in the seat track. SWB did not crush, but slided outwards and consequently broke the seat track web were the SWB was anchored. Since the composites are hardly ductile materials, the dissipation of energy was much lower than showed in pre-test simulations. Therefore, the severity of the impact was higher than predicted. The outcome of the commuter was symmetric, as expected.

5.- POST-TEST SIMULATIONS

Once the results of the test were documented, pre-test simulation results were reviewed. The deformed shape and main milestones of the deformation process had been captured, nevertheless, a much higher level of force in the SWB web was predicted. This was due to an excess of ductility in the calibrated material, as well as an overestimate friction between the components.

The calibration of the materials was done with a compression test. Nevertheless, during the test, the SWB showed compressive as well as flexural response. This latter mechanism introduced a variation in the behaviour that ought to be translated to the model.

It was decided to slightly embrittle the material properties and to fix the friction between components to more realistic values. Figure 7 compares the stress-strain curves for the material representing the

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SWB in the pre-test and post-test simulations, where the resistance is lowered for strains greater than 4.0%.

Such modifications were introduced in the model and a new set of simulations was carried out. The deformed shape sequences were similar to the obtained in pre-test simulations and in the test. But these modifications reduced the amount of dissipated energy mode to more realistic values. In figure 8 the reaction force measured in the test and that obtained in the post-test simulations is compared. Note that numerical and actual values compare acceptably.

6.- CONCLUSIONS

The general deformed shape was successfully predicted in pre-test simulations. It might be concluded that the general modelling assumptions, such as symmetry and mesh size were valid.

However, the level of energy absorbed was overestimated, because the triggering mechanism in SWB was thought to be activated. This was not the case in the test. On the other hand, post-test simulations showed that if the brittleness in the equivalent isotropic material is increased, the actual results were nearly matched. Hence, the second conclusion is related with the validity of the developed material model in the first part of the work. Once the collapsing way of the material is known, it is not necessary to develop highly sophisticated models to capture the macroscopic behaviour in composites, but it is feasible to utilise simple models accurately calibrated. Brittleness and elastic response are the main features that should be carefully calibrated.

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Nevertheless, even with a calibration of a component similar to the mounted on the specimen, the obtained results in pre-test simulations were slightly different from the measured data in the test, because of the different failure mode. So the third conclusion is that in the absence of shell elements able to represent delamination of plies the materials have to be calibrated in just the same failure way than expected in the actual test. If the deformed sequence shows another collapsing way, the material has to be re-calibrated in this second failure mode.

7.- REFERENCES

1 - Alenia (1998). "Commuter CAD drawing – L/O-LWR Fuselage Structure". CRASURV Project Deliverable D.3.1.1.

2 - DLR (1998). "Crash Behaviour of Composite Commuter Sub-floor Components; Report on Dynamic Tests". CRASURV Project Deliverable D.4.1.9.

3 - CEAT (1999). "Results of the Commuter Sub-passenger Floor Structure Drop Test". CRASURV Project Deliverable D.4.3.2.

4 - Principia (1999). "Post-test Simulation of the Commuter Sub-floor Structure Drop Test". CRASURV Project Deliverable D.3.5.6.

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7.- TABLES

Material	Carbon fiber	Hybrid carbon-aramid
Thickness (mm)	0.19	0.28
Young modulus Exx (GPa)	114.0	36.3
Young modulus Eyy (GPa)	9.3	36.3
Shear modulus Gxy (GPa)	4.6	2.1
Poisson ratio	0.25	0.05
Tensile failure stress Xt (MPa)	1610	372
Compressive failure stress Xc (MPa)	-818	-310
Tensile failure stress Yt (MPa)	36	372
Compressive failure stress Yc (MPa)	-218	-310
Shear failure stress Sxy (MPa)	109	114
Deformation at failure X (%)	1.0	1.0
Deformation at failure Y (%)	1.0	1.0

Table 1 - Mechanical properties of materials in SWB

Component	Young modulus (GPa)	Poisson ratio	Yielding stress (MPa)	Maximum stress (MPa)	Strain at maximum stress (%)	Residual stress (MPa)	Strain at residual stress (%)
Skin	37.8	0.3	720	740	2.8	50	10.0
Frames	37.8	0.3	720	740	2.8	50	10.0
SWB	33.8	0.3	239	346	2.7	0	9.0
Floor beams	37.8	0.3	720	740	2.8	50	10.0
Seat beams	37.8	0.3	720	740	2.8	50	10.0
Stringers	37.8	0.3	720	740	2.8	50	10.0

Table 2 - Equivalent isotropic materials

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8.- FIGURES

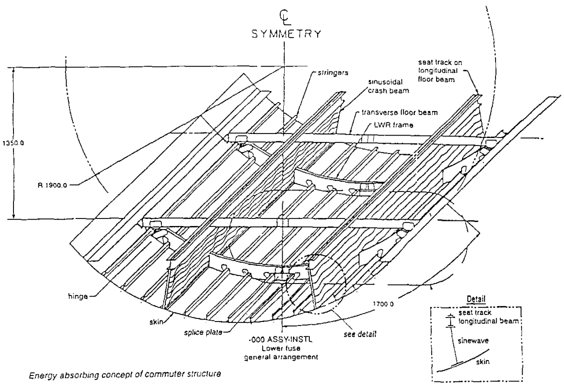

Figure 1.- Design of the specimen

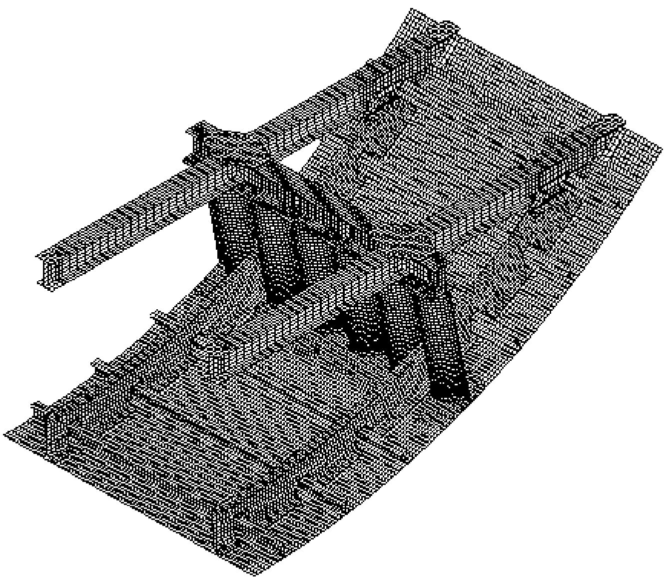

Figure 2.- Mesh of the model

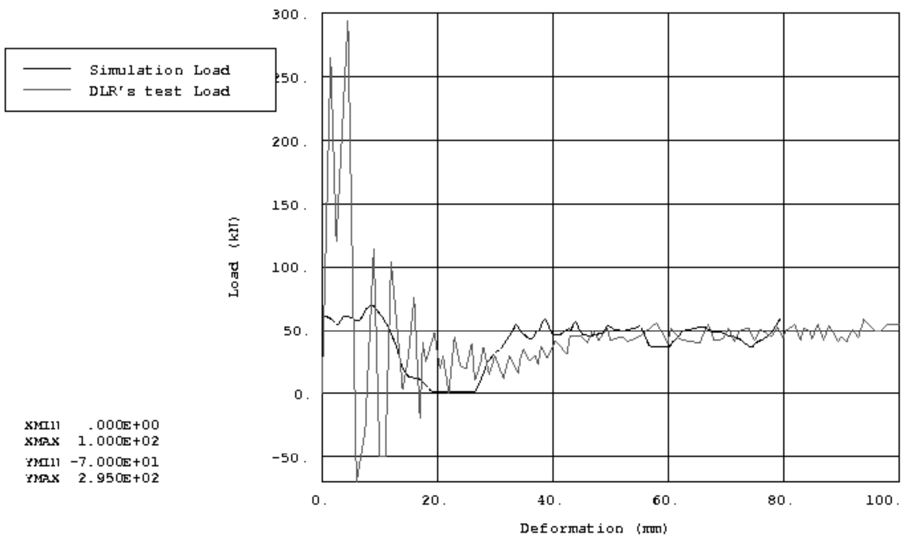

Figure 3.- Results in equivalent properties calibration test

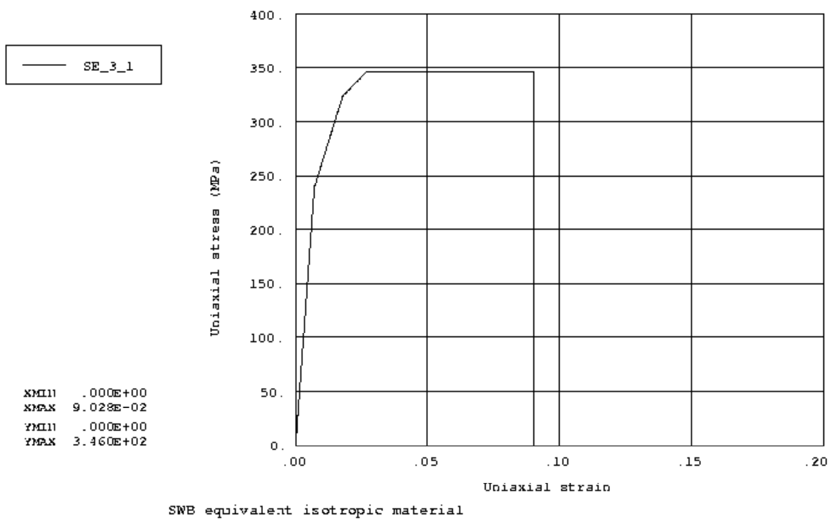

Figure 4.- Behaviour model after calibration

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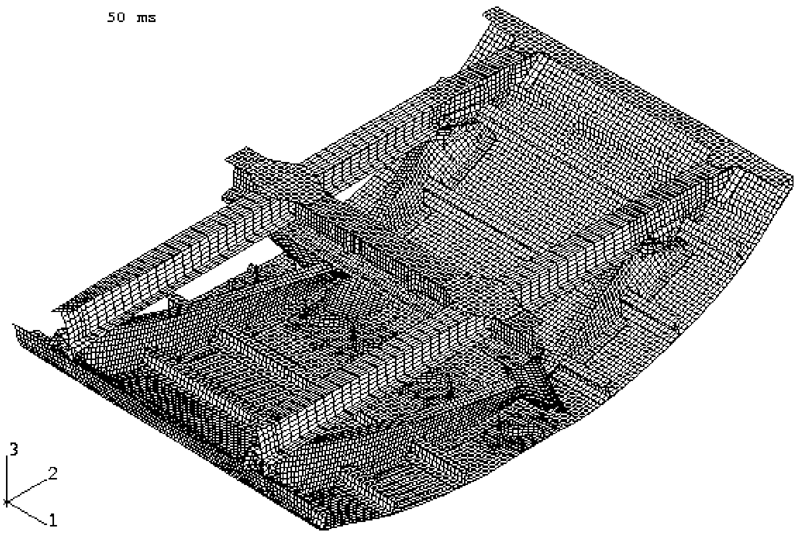

Figure 5.- Deformed mesh at 50 ms in pre-test analyses

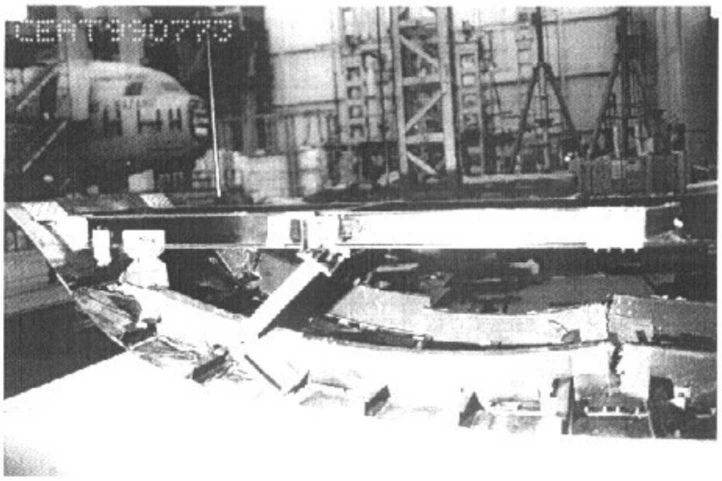

Figure 6.- Specimen collapse in the test

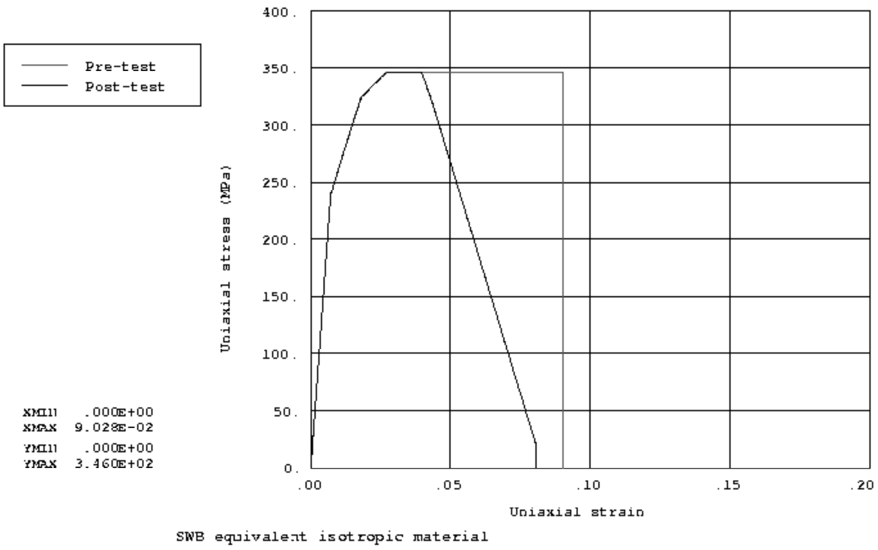

Figure 7.- Comparison of pre and post-test constitutive models

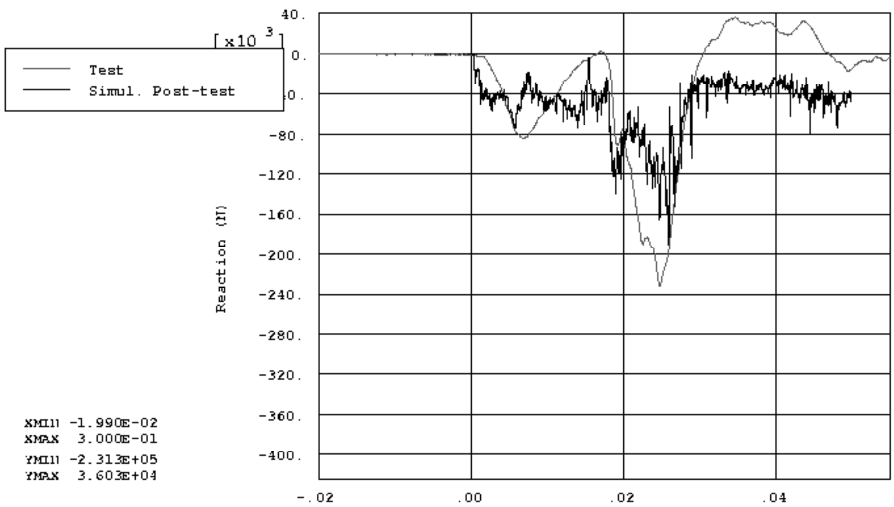

Figure 8.- Reaction on the floor

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