Experimental Support of Numerical Models for Verification of High-speed Impact Resistance of Composite Airframe

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Abstract: The composite structures are often subjected to impact damage during production, in-service operations, or maintenance. Testing all impact scenarios into a real structure is very expensive and time-consuming. The aim of this paper is to present an improved calibration and verification of numerical models by standard and non-standard experiments. The results were applied for analyses of bird strike simulation on a composite engine cowling of a newly developed high-speed helicopter.

Keywords: experiment; impact; high-speed; bird; composite.

1 Introduction

Safety is the ultimate aim in civil aviation. Therefore, the international civil aviation system evaluates with an acquired experience in the operation of aircraft, but of particular importance here are air accidents [1]. They are milestones for the new approaches to the operation of aircraft and demonstrate their resilience to the impact. The risk of foreign object impact that can decrease local strength property must be taken into account in the design of primary structures. Testing all impact scenarios onto real structures is expensive and impractical. Foreign object damage (FOD) such as bird, hail, debris etc. are important phenomena that must be taken into consideration when designing aircraft. The critical parts of planes or helicopters are windshield, nose, fuselage panels, wing and empennage leading edges, rotor blades, fan blades, engines cowlings or inlets [2].

However, the design of the aircraft structures usually involves many iterations of design-manufacturing-test and conducting bird impact experiments is not only time consuming but also costly.

The flat and simple curved test specimen used in the high-speed impact resistance verification tests was designed to provide confirmation of the performance of the selected composite material and to assist in the finite element modelling of the global structure [6]. All numerical models were calibrated based on experimental results gathered with an eye toward damage initiation and propagation behaviours. Fig. 1 shows the building block diagram (BBD) for the proposed approach.

2 Materials and methods

The test program aimed to obtain inputs for verification of simulation technique of complex composite airframe design from point of view of high-speed impact resistance. The test program was adapted to obtain inputs in terms of application of simplified models for explicit solver analysis (large size of FE elements for a decrease of critical calculation time) and also from point of view of easy production of the test specimen.

The standard and non-standard uniaxial tension and compression tests were used for input material properties onto numerical models on specimen level (see Fig. 1). The main focus was on inputs for simulation of honeycomb sandwich core and mechanical fasteners of composite parts of the airframe. The influence of high-speed load and inputs for the FE model of airframe and bird projectile was verified by flat and simple curved test specimens on an element level (see Fig. 1).

The results from calibration and simulation on specimen and element level were used for simulation and optimization of the real airframe on full-scale level of proposed BBD (Fig. 1).

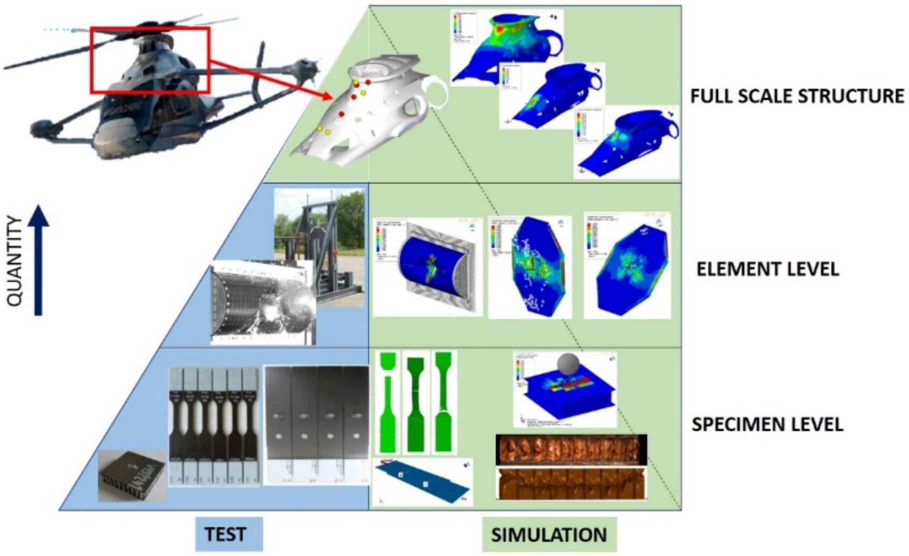

Fig. 1: Building block diagram for bird strike resistance analysis of composite cowlings.

2.1 Specimen level

The specimen level aimed to obtain mainly static material properties for input to the FE material models. In addition to standard tests of the properties of composite materials, attention was focused on the calibration of simplified replacement models of the honeycomb sandwich core and mechanical fasteners.

In the case of the design of the simplified model of a sandwich structure with honeycomb core for impact analysis in the explicit solver, attention was focused on the compression behaviour. The compression tests according to ASTM C365M standard [3] were performed in the VZLU test lab (Fig. 2), and the results of the tests were used for verification and calibration of the FE model (Fig. 3). The simplified FE model of honeycomb sandwich structure was proposed for simulation of complex airframe based on solid elements with ABAQUS crushable foam material model. The results from the tests and simplified FE model were also compared with the detailed FE model of the honeycomb core (Fig. 3).

Fig. 2: Compression test set-up with additional displacement measurement.

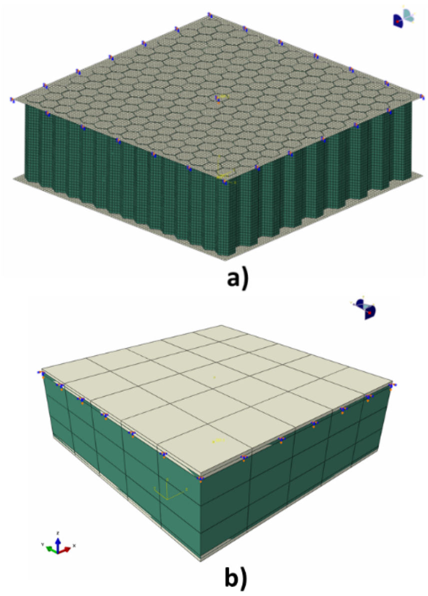

Fig. 3: FE models of test specimen – (a) detailed, (b) simplified.

Fig. 4 shows the schema of crushable foam hardening properties calibration for the simplified FE model based on known test results. The hardening parameters are changing in the three significant points:

1. Initiation of buckling.

2. Start of collapse phase.
3. Onset of densification.

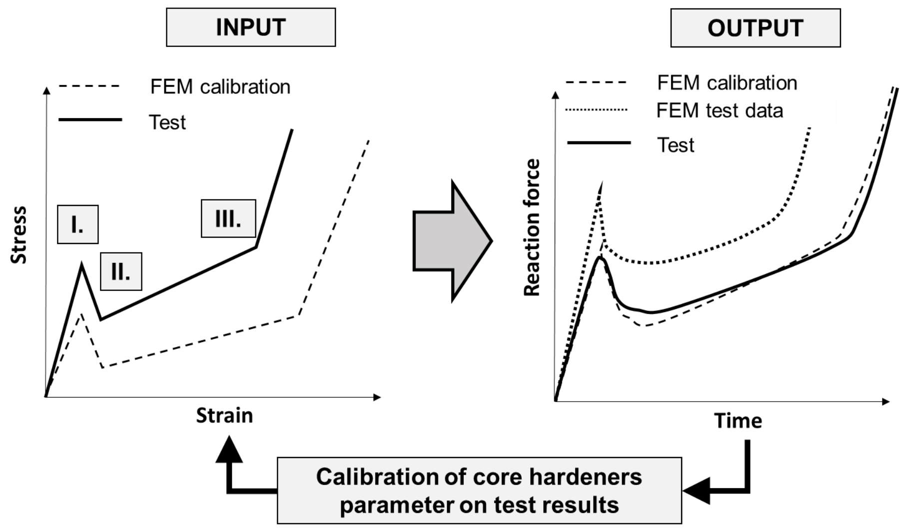

Fig. 4: Scheme of core material model parameter calibration for simplified FE model.

In terms of simplified modelling for the analysis of complex structures in the ABAQUS [4] explicit solver, attention was further focused on modelling and analysis of mechanical joints of composite parts. The results of the high-speed test of mechanical joints (Fig. 5) were used for verification and correlation of the simplified FE model of mechanical joints. Two types of 1D FE elements were compared from point of view of strain rate behaviour – BUSH and BEAM elements. FE model consists of shell elements (S4R) with mesh size 10 mm (size of global FE model), see Fig. 6. Mean unnormalized values at quasi-static load rate on the base of material equivalency test results [8] were used for high-load rate tests of mechanical joints.

Methodology for combined load fastener analysis is based on Bruhn [7].

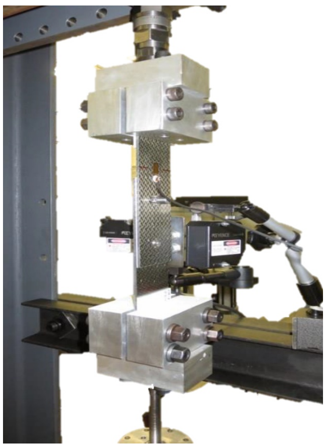

Fig. 5: High-load rat test of mechanical joints.

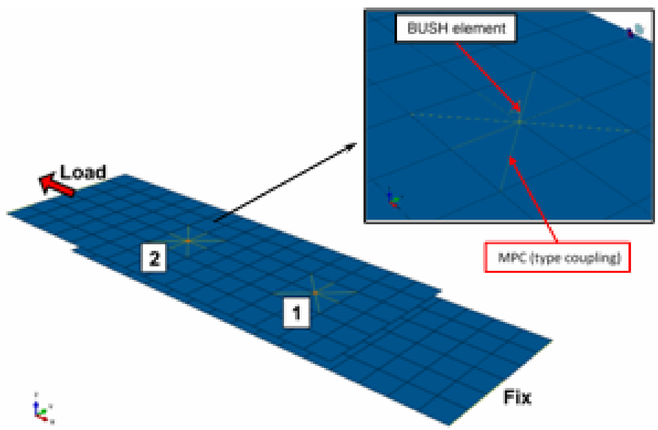

Fig. 6: Simplified FE model of mechanical join test.

2.1.1 Element level

Based on the input data from the specimen level and preliminary design of the structure, test specimens were designed to verify the impact resistance of the structure and numerical models. The experiments aimed to verify both numerical models of the ownership structure and the numerical model of the bird projectile. The flat and curved panels were defined in dependency on the preliminary design of the final part, bird mass and impact speed range. The flat test specimens represented monolithic and sandwich structure design. The simple curved test specimens represented sandwich structure design. The VZLU test rigs designed from point of view of numerical boundary conditions were used for attachment and instrumentation of the tests (Fig. 7).

For the flat test specimen, it was realised 6 perpendicular impacts and 6 declined impact 45° with a range of impact speed from 375 to 586 km/h. For curved test specimens, it was realised 3 bird strike tests with a range of impact speed from 326 to 450 km/h.

Fig. 7: VZLU test rigs to attached of flat and curved test specimen for bird strike tests.

The test results are compared to numerical simulations and the correlation of the models is performed. Altered parameters for material properties calibration on the base of test results were porosity of the projectile, fracture energy of composite material and hardness parameters of crushable foam material model of the sandwich core. The input parameters for calibration from the test results were maximal displacement during impact, reaction forces and results from non-destructive inspections (NDI). The results of the tests and numerical simulations were also qualitatively assessed on the basis of the high-speed camera pictures in terms of projectile behaviour and failure of the test specimens (Fig. 8).

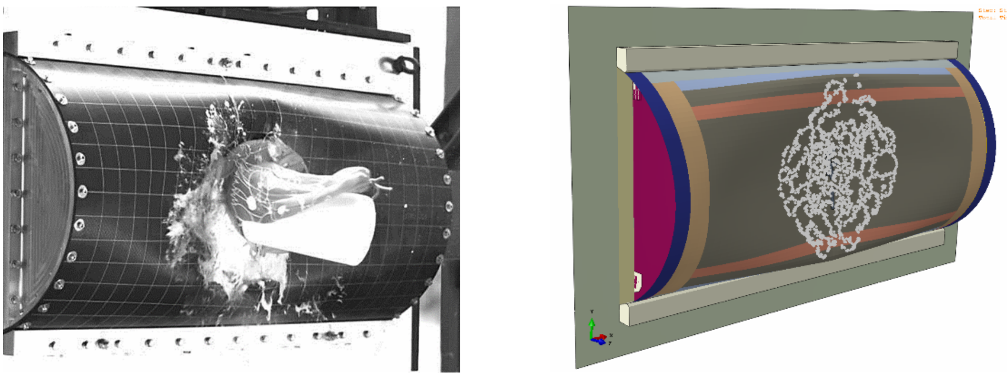

Fig. 8: Example of comparison high-speed camera measurement with numerical simulation during impact test on curved test panel.

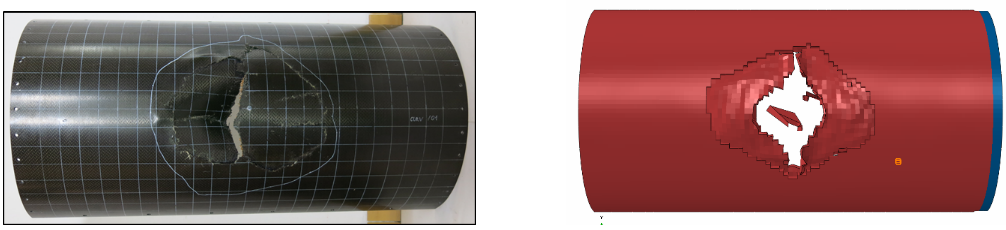

Fig. 9: Example of post-test damage and failure analysis of curved test panel and comparison with result of numerical simulation (failure of sandwich core).

2.1.2 Full scale structure

The analyses of full-scale composite cowlings were performed according to CS29.631 airworthiness requirements [5] for cruise speed and bird mass 1 kg. The design of composite cowlings and integrated parts of a structure such as frames, antennas, fasteners were analyzed for 11 bird trajectories and two lengths of the bird projectiles (Fig. 10).

The global FE model (Fig. 10) used the same parameters as used for verification and calibration of FE models of flat and curved panels such as size and quality of element, properties etc.

Parameters for evaluation of resistance of the structure to the bird impact from numerical models were:

- Maximal displacement – contact with inner structure or rotating parts (Fig. 11);
- Composite damage criterion – Hashin tensile fire criterion [6];
- Sandwich core damage;
- Loading of mechanical joints during the impact – analyzing of combined loading of mechanical fasteners by Bruhn methodology [7] (Fig. 12).

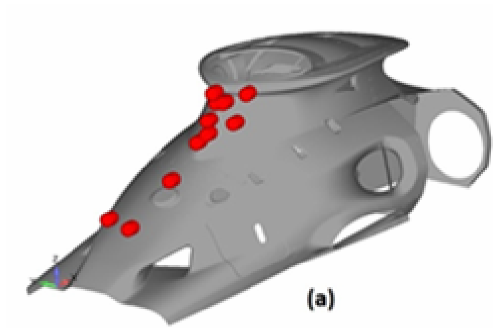

Fig. 10: Global FE model of cowlings with trajectory of bird projectile.

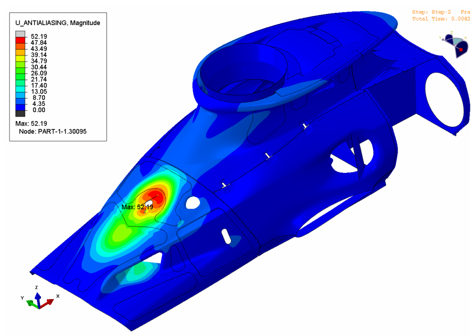

Fig. 11: Example of contour map of displacement.

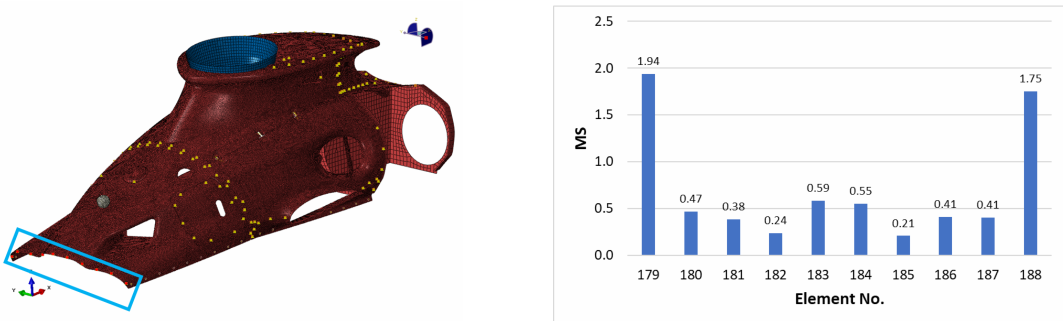

Fig. 12: Example of analysis of margin safety (MS) of the mechanical fasteners on the global FE model during the impact.

3 Conclusion

The proposed technique validation of FE models on the specimen and element levels enabled improvements and optimization in the design phase. The experiences obtained in the field of calibration of numerical models for high-speed impacts confirm different behaviour of isotropic and orthotropic material models. The application of verified numerical models in the field of emergency load cases using simple test specimens allows not only the optimization of the design in terms of compliance with airworthiness regulations, but also increasing the durability and safety of newly designed composite structures.

Acknowledgement

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