Bird Strike Tests Verification of Simulation for Development of Composite Inlet for Tilt-rotor Aircraft

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Abstract: Bird strikes are an important phenomena that must be considered when designing aircraft. Most major bird strike incidents result in engine damage. Because an engine is the sole thrust-providing system of an aircraft, the effect of bird strikes on engine inlets and systems must be investigated and mitigated to the maximum extent. Especially in the case of convertible aircraft, such as an aircraft with tilting rotors, this effect is critical from the point of view of the operation, from the point of view of flight mechanics, and the overall control of the aircraft. International certification regulations require that all forward-facing aircraft components be proven to withstand bird strikes to a certain level before they can be used in an aircraft. A bird impact test provides a direct method for determining bird strike resistance; however, the design of aircraft structures typically involves numerous iterations, from design to manufacturing to testing and back, requiring that many bird impact tests be conducted. This is not only time-consuming but also costly. Furthermore, the experimental data from these tests are frequently narrowly focused, acting as a barrier to their direct use in refining structural designs. Owing to these shortcomings, several numerical methods have been developed to simulate bird or hailstone strikes to reduce the number of intermediate tests required and subsequently shorten the duration of the component design phase. The paper aims to experimentally validate numerical models for verifying composite air duct design for new tilt-rotor aircraft using flat and simple curved test panels.

Keywords: Bird strike; Impact; Composite

1 Introduction

Foreign object impacts, such as birds, 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, engine cowlings, and inlets [1].

International certification regulations require that all forward-facing aircraft components should be proven to withstand bird strikes to a certain level before they can be employed in an aircraft [2]. A bird impact test provides a direct method for determining bird strike resistance; however, the design of aircraft structures typically involves many iterations from design to manufacturing to testing and back, requiring that many bird impact tests be conducted. These empirical verifications, which cause damage to expensive prototypes or part of structure [3-5], and the biological hazard of using real birds, can be costly and time-consuming. Furthermore, experimental data from these tests are often narrowly focused, constituting a barrier to their direct use in refining structural design. Owing to these shortcomings, several numerical methods based on CEL (Coupled Eulerian-Lagrangian) [6] or SPH (Smoothed Particle Hydrodynamics) [7-9, 15] have been developed to simulate bird strikes to reduce the number of intermediate tests required and subsequently shorten the duration of the component design phase. More bird models are verified only on isotropic material or impact on the rigid wall [10,11].

The principal objective of the present work is to provide a more universal experimental procedure, applicable e.g., for a different type of material or technology production, for verification of a numerical model for bird strike analysis on the real composite structure. The verified numerical simulation will allow the design to be optimized for the next to satisfy certification on final design respectively expensive prototypes.

The testing program was established to assist in the selection of composite material and optimised lay-up from the point of view of energy absorption from bird impacts on the composite inlet for a new generation of tilt-rotor aircraft. 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 [13]. Fig. 1 shows the building block diagram for the proposed approach.

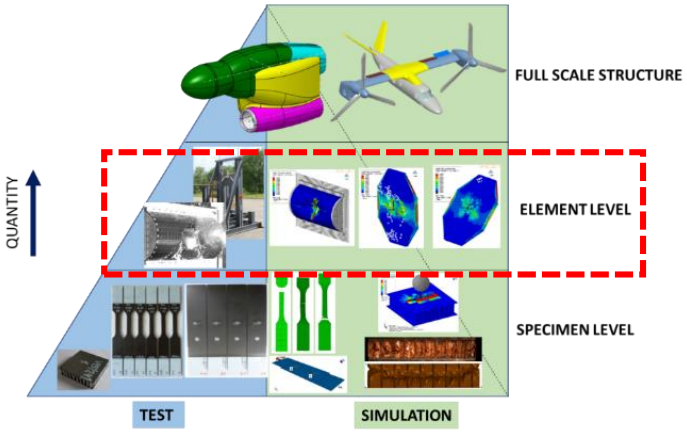

Fig. 1 Building block diagram (BBD) for bird strike resistance analysis of composite inlet.

2 Materials and methods

The physical bird impact tests were performed at the Czech Aerospace Research Centre (VZLÚ) according to airworthiness requirements [1]. The real bird projectiles (chicken) were used during the experimental verification according to airworthiness requirements [14]. The weight of the bird projectile was 1 kg [2]. The projectiles were accelerated by compressed air through the smooth borehole of a gun barrel up to the required velocity according to specifications. Fig. 2 shows the air gun test facilities.

Fig. 2 VZLU air gun for bird strike tests.

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 designs (see Fig. 3). The simple curved test specimens represented monolithic structure design (see Fig. 3). The partner of TRIcEPS project Composite Impulse GmbH & Co manufactured the flat and curved test specimens.

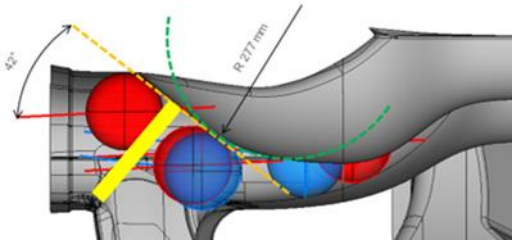

Fig. 3 Analysis of bird strike on the critical parts of the inlet for design of replacement test panels.

The VZLU test rigs designed from the point of view of numerical boundary conditions were used for the attachment and instrumentation of the tests (Fig. 4) [13].

Fig. 4 VZLU test rigs to attached of curved (left) and flat (right) test specimen for bird strike tests.

For the flat test specimen, it was realised three 42° and three 52° declined impacts with a range of impact speed from 307 to 428 km/h. For simple curved test specimens, it was realised 3 bird strike tests with a range of impact speeds from 100 to 204 km/h. The speed of impact was defined on the result of the previous test from the point of view of panel damage or failure. The main criterion was barely visible damage.

Standard qualitative techniques for high-speed impact analysis, such as high-speed cameras and post-test non-destructive techniques (NDT), were used for the analysis of the test results and verification of the numerical model. A technique of dynamic displacement measurement by using a laser triangulation sensor during the impact process was used for quantitative analysis and a more precise verification of the data obtained from the numerical model (Fig. 5) [13]. The measurement range of the laser sensors was 300 mm (centre of test specimen) and 40 mm (test rig frame). The actual bird impact point was then determined via the high-speed camera record and visual inspection. The measurement data acquisition rate is adjustable over a range from 1.5 to 49.1 kHz and was set at 20 kHz during testing. The resolution of the sensor was 0.3 μm.

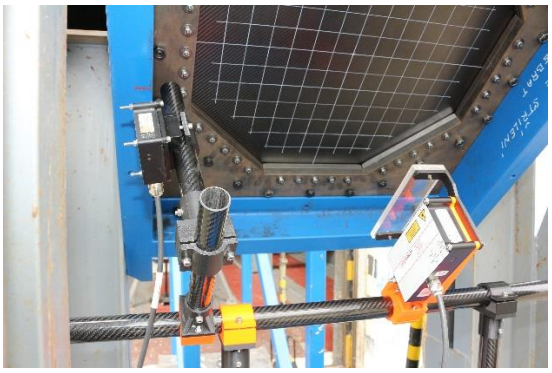

Fig. 5 Displacement measurement during the bird strike test.

The video images were recorded by three high-speed cameras; the two cameras, recorded the course of the impact from the front side and backside, and one camera was used to measure the projectile speed.

The reaction force during the bird strike of curved panels was measured by load cells (see Fig. 6). Three load cells of KISTLER 9105A type were used in the test rig. The signal from load cells was stored using BMC Messsysteme GmbH data acquisition system completed with Vishay 2230 type amplifier. The measurement frequency was 10 kHz with 50,000 sample/s for load cells.

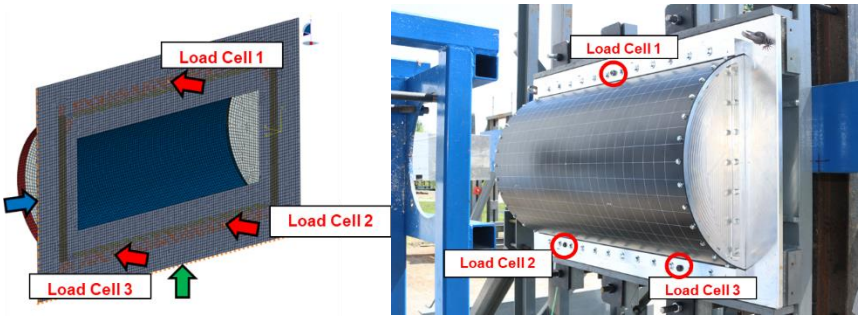

Fig. 6 Measurement of reaction force during bird strike on curved panels by load cells.

NDT of bird-strike test panels was performed before and after bird-strike tests. Monolithic test panels were inspected by visual and ultrasonic methods by immersion C-scan (UT-PE method) (see Fig. 7). Visual and mechanical impedance inspection were used for the NDT of the sandwich test sample.

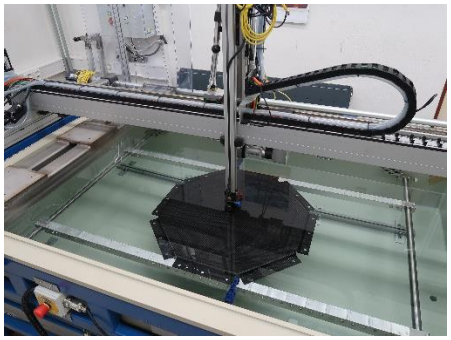

Fig. 7 Example of C-scan inspection of flat test panel in VZLU immersion tank.

3 Test result analysis

For the verification of numerical analyses, the experimental results were evaluated in terms of qualitative and quantitative parameters:

- images from high-speed cameras,
- visual and NDT inspection before and after the tests,
- displacement measurements using the laser triangulation sensor (flat panels),
- reaction force measurement (curved panels).

3.1 Flat test specimen

The flat test panels represented the real structure in the area of oblique impact on the part of the air duct and the filter door. The experiments confirmed the higher impact resistance of the monolithic construction compared to the sandwich construction of the filter door.

Fig. 8 - Fig. 10 show examples of high-speed camera picture analysis from the point of view of test specimen displacement and failure initialization.

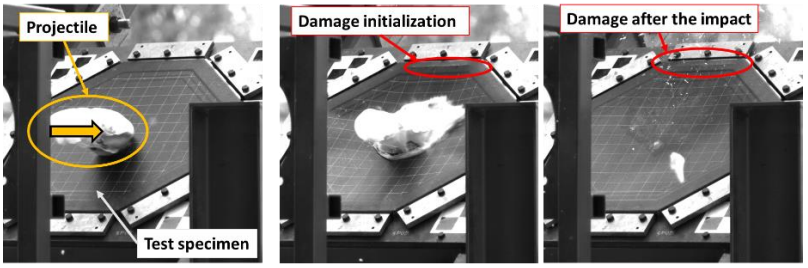

Fig. 8 Example of high-speed camera pictures during the bird-strike test on the monolithic composite test panel for impact speed 403 km/h.

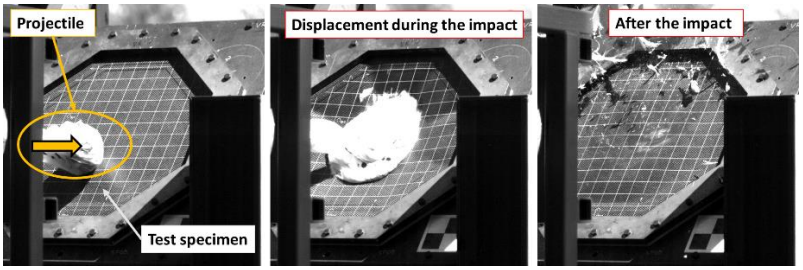

Fig. 9 Example of high-speed camera pictures during the bird-strike test on the sandwich composite test panel for impact speed 332 km/h.

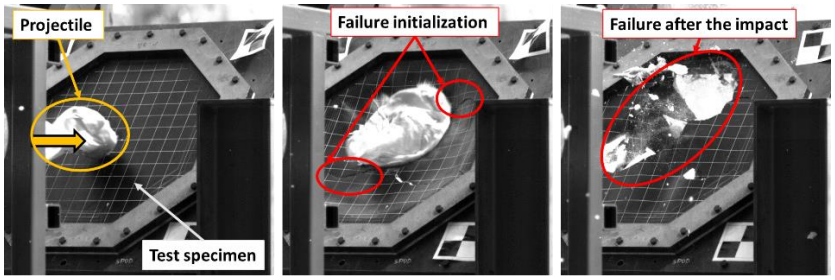

Fig. 10 Example of high-speed camera pictures during the bird-strike test on the sandwich composite test panel for impact speed 392 km/h.

Fig. 11 shows the result of the experimental verification of bird impact on monolithic (42°, 403 km/h) and sandwich (52°, 392 km/h) composite panels at the same impact speed.

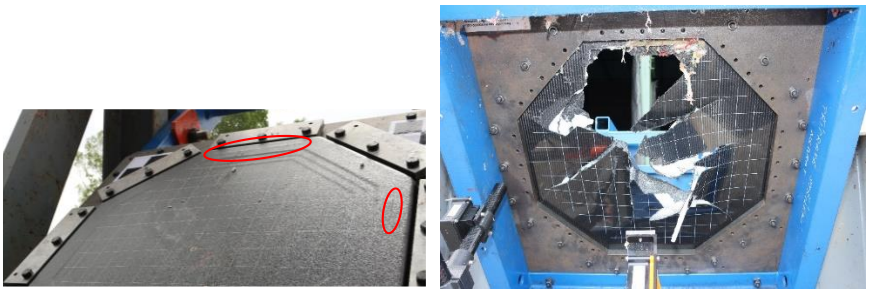

Fig. 11 Visible damage and failure after the test on the monolithic (left) and sandwich (right) composite test panel.

The visual results were simultaneously compared with the NDT inspection to obtain information on the size and character of damage and compare them with numerical models (see Fig. 12).

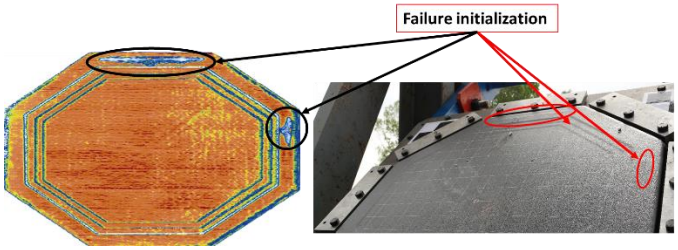

Fig. 12 Comparison of NDT and visual inspection of flat monolithic composite panel after the test.

Fig. 13 shows the results of measuring the deformation in the centre of the panel using laser triangulation sensors. These results confirm the greater effectiveness of the sandwich composite structure in terms of damping but less strength and stiffness in terms of impact energy absorption.

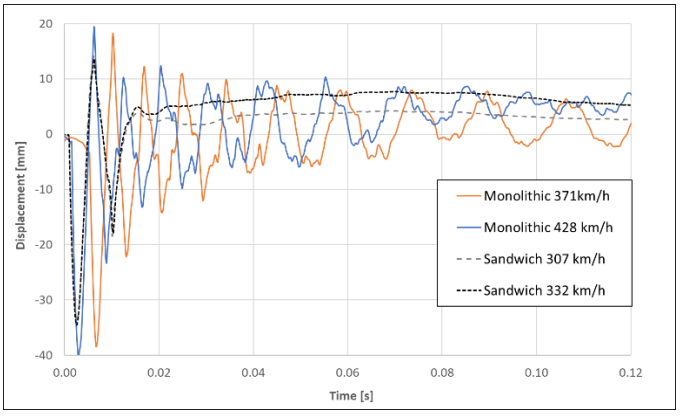

Fig. 13 Results of measuring the displacement in the centre of the flat test panels during impact.

3.2 Curved test specimen

The curved test panels represented the real structure in the area for the gear box. The experiment made it possible to assess the effect of curvature on the stiffness and strength of a thin-walled composite structure close to the real shape of a real air duct.

Fig. 14 shows an example of high-speed camera picture analysis from the point of view of test specimen displacement and failure initialization.

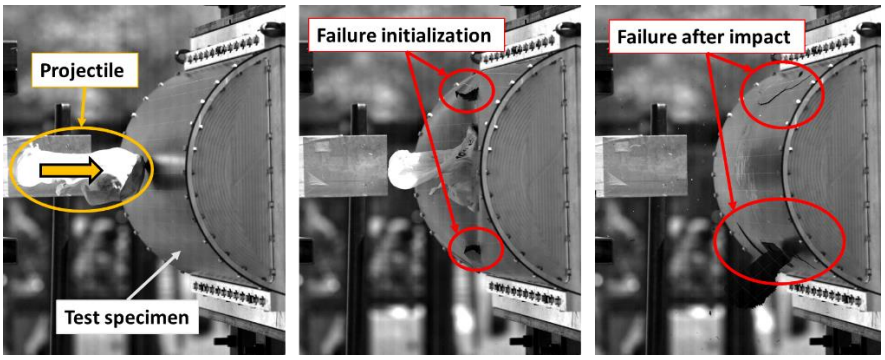

Fig. 14 Example of high-speed camera pictures during the bird-strike test on the curved test panel for impact speed 185 km/h.

An important result from the point of view of numerical model verification is the size and extent of damage to the composite structure after a defined projectile impact. Fig. 15 shows the influences of speed impact on the size of damage on a simple curved composite panel.

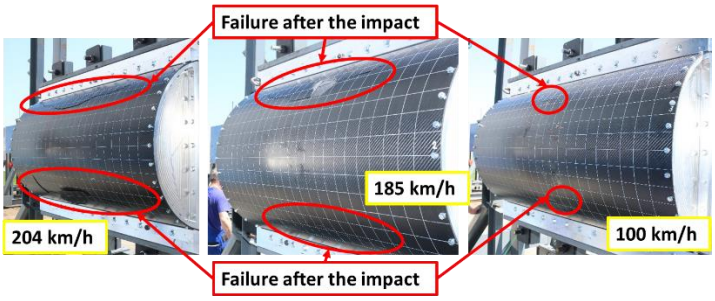

Fig. 15 The influences of speed impact on the size of damage on simple curved composite panel.

Fig. 16 shows the results of measuring reaction forces during the impact. These results confirm the influences of impact speed on the size and course of the reaction force.

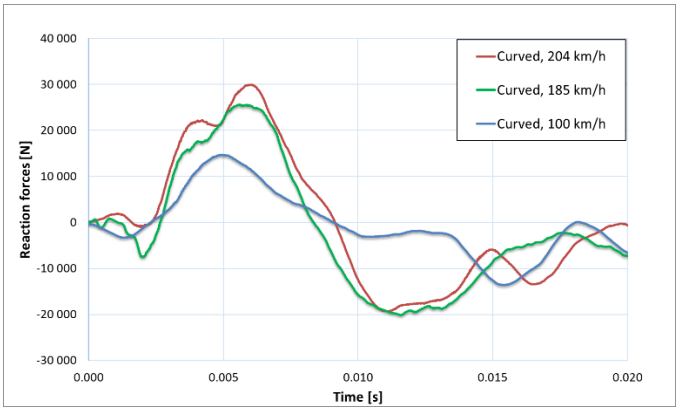

Fig. 16 Reaction forces analysis from bird-strike test on curved composite panels.

Conclusion

The obtained results from the experiments confirmed, in most cases, the expected resistance values of the test specimens determined based on preliminary numerical simulations.

The application of measuring systems for high-speed loading, such as laser distance meters or force meters for measuring reaction forces, will enable quantitative assessment and verification of numerical models.

The obtained results from the experimental measurement and the subsequent NDT analysis will enable the refinement of the material model for simulations on a real structure.

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