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Bird Strike Certification by Analysis of ARJ21 Multi-Functional Vertical Stabilizer

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ABSTRACT

In this paper a building block certification strategy is implemented on Regional Jet Aircraft vertical stabilizer (VS) structure under Bird-Strike impact, and design was aimed for subsequent safe load landing in case of Bird Strike Impact. Certification by Analysis is centered around FAA requirements of novel multi functional VS structural design. Verification, Validation, and Accreditation (VVA) process using numerical multi-scale modeling approach on large scale structural models were performed to predict large deflections and damage and fracture evolution subject to soft bird strike impact scenario, and subsequent limit load landing. The Progressive failure analysis code GENOA integrated with Explicit Finite Element (FE) coupled with micromechanics damage-analysis formulation capability is implemented to predict failure progression in a VS multi-material design including range of isotropic, orthotropic, and anisotropic materials, and Multi Media material energy absorption. Deflections at the impact location were compared against experimental data; from these results, the Lagrangian bird model was chosen for incorporation into a bird-impact progressive failure dynamic analysis methodology. Impact at velocities below and above that which induced failure were simulated and compared with test results. The completed methodology is able to accurately match the elasto-plastic deflection response and predict damage initiation and progression at higher velocities. Additionally, the progressive failure dynamic analysis methodology clearly identifies failure locations, mechanisms and their percent contribution to multisite failure and can help guide the design process for parts that must withstand soft impacts.

KEYWORD: 1) Regional Jet Bird Strike Design and Analysis; 2) Soft impact damage; 3) Safe limit load landing; 4) Certification assisted by Analysis; 5) Building block validation strategy, 6) Multi-functional material, 7) Scaling law; 8) Energy dissipation/absorption.

INTRODUCTION

Soft impact events, such as collisions with birds and hailstones, continue to pose great challenges to the design of safe aircraft components and systems. In this application, a Multi-functional material was selected to produce a new design for the leading Vertical Stablizer (VS) of the ARJ21 in which the foam could act as filler, thus improving the mechanical (stiffness, flexibility) and impact behavior meeting Manufacturer’s objectives in order to: **1**) Maintain the external shape; **2**) Reduce the total weight of the structure; **3**) Select a section in which the damage caused by an impact could be higher; **4**) Reduce the size to the laboratory scale. A scaled structure was used for this purpose; and **5**) Adapt the design in such a way that allows performing the Virtual impact tests.

This effort utilized a Multi-Scale Progressive Failure Dynamic Analysis (MS-PFDA) using Virtual Testing numerical Finite Element based stress analysis tools to accurately predict how the structure would fail due to impact: **a**) Ability to predict the 5 stages of load -displacement curves; **b**) Ability to produce the damage foot print as combination of energy, stress, and strain and not just the stress per current industry practice; and **c**) Ability to identify materials exhibiting Strain rate or limited strain rate effect.

Therefore, extensive testing of components and full parts is often needed to ensure aircraft design conformance with certification standards. In addition to the high cost and long development cycle associated with such destructive impact tests, difficulties arise in collecting data due to the short duration of the impact window, high impact forces, and potential for damage to structures and measuring equipment. Testing is further complicated usage of multi-material, and design multi-functionality common in modern aircraft design by the need to address laminated and fiber reinforced composite structures, and joining of metallic and composite sub elements and mitigate to full VS design.

RESULTS

Experiment and Analysis Validation: Design of the COMAC’s ARJ21 VS was first conducted on the middle section, which is corresponding to the sub-structure used in experiments. The original composite ribs in the VS were shortened and the space in-between the ribs and leading edge skin was filled with a candidate foam (Rohacell 51WF foam). E-glass composite laminate acting as a mini spar was formed to support the foam. The shield panel in front of the spar was thickened. Ribs and the laminate were adhesively bonded together.

Validation of Bird Strike Analysis with sub-model Experiment: The PFDA simulation of test was conducted on the sub FE model (**Figure 1**) for bird strike location approximately in the middle section of the VS, which was selected according to the experimental setup. The displacement at the upper end of the sub-model was simulated as a function of the impact time and compared with the experiments meeting tremendous accuracy as compared with test. Successful Experimental Tests were conducted at COMAC’s Testing site in Xian City, China directed by Chief Designer of ARJ21, Mr. Yong Chen.

The simulation predicted displacement that matched the provided Experimental tests with less than 10% error at the peak of the displacement allowing for confidence to perform additional tests for alternate locations of Bird Strike using Virtual Analysis and justifying the Virtual testing method as a means of meeting CAAC requirements. The correlation validated the developed bird strike analysis approach, including the VS FE model, materials properties, and boundary conditions, as well as the bird model. The bird geometry was modeled as a cylinder with two hemispherical ends using Volume Element. The equivalent radius of the bird was set to 73.5 mm and the length of the bird was 283.5 mm. Bird mass was set as 3.63 kg, which resulted in a bird density of 0.911743E-9 ton/mm^3. The bird was modeled with 9,246 solid finite elements and 1,380 wedge finite elements.

Results from PFDA simulation of the sub and full scale VS model redesigns during bird penetration into VS, illustrates the deformed shape and damage state when damaged elements are taken out. Since the deformation and damage of the bird also adsorbs the bird kinetic energy. The damage of VS structure absorbs the bird kinetic energy and lessens bird kinetic energy when it reaches the front spar. In both design, the primary requirement for non-damage on the front spar is satisfied. Insertion of the low density, soft foam and support structures increases the bird strike resistant of the VS structure before the front spar. Similar results depict state of the VS during and after bird penetration for the full FE model. The re-design shows better characteristics by keeping the bird on the surface while absorbing energy and distributing damage to a large area. This resulted in additional weight saving, and absorption of energy within the local multi-function material and control of damage initiation in the metal cover, foam parts, and metallic shield during the impact process. The change of birds internal and kinetic energies during impact were obtained using Progressive Failure Dynamic Analysis (PFDA). The earlier reduction in bird kinetic energy quantitatively demonstrated the advantage of the re-design.

Certification: Results obtained from bird strike analysis with impact location were very similar to tests performed on the sub structure and full VS structure. A comparison of the prediction versus full impact test shows that foam slows down the bird and Shield protects the spar for safe landing.

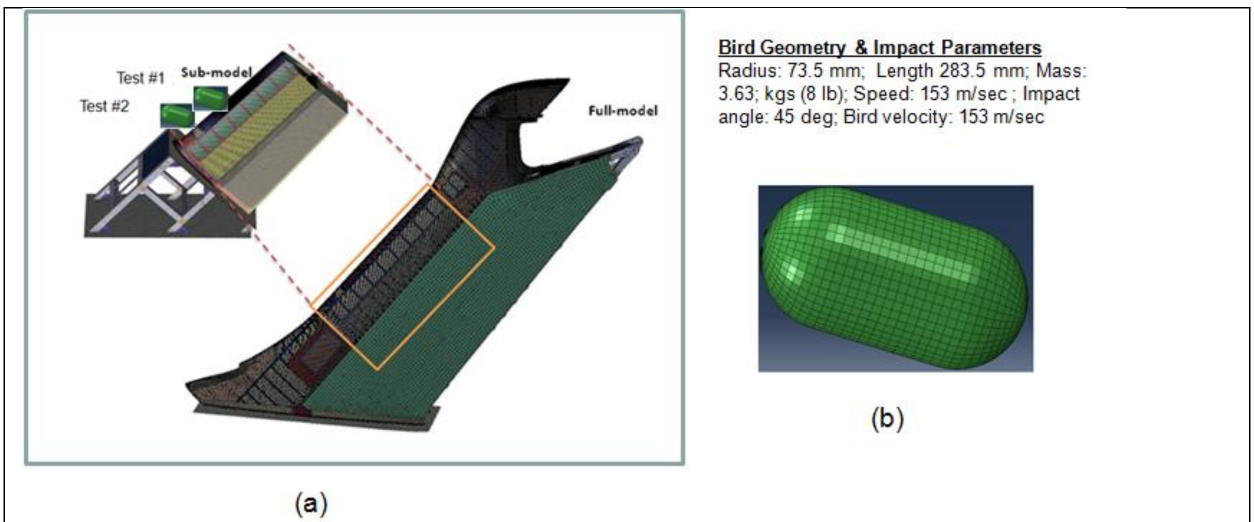

Figure 1. FE mesh of sub-model and full-model of ARJ21 vertical stabilizer: a) Full-scale, subscale, b) Bird Model