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Foreign Object Damage Analysis of Aircraft Structural Materials

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ABSTRACT

Present day aircraft industry is focusing on weight reduction and fuel usage optimization which would ultimately lead to greener aero structures. The major challenge is the material selection by considering the design, operation and accidental scenarios. Composites have been considered along with advanced aluminum alloys for aero structures. One of the extreme operational scenarios is foreign object damage onto aircraft outer surfaces. The papers focus on the impact capability analysis of composites and aluminum alloys. Overall methodology of meeting the certification requirement is discussed using numerical tools. Finite Element of an aircraft windshield & surround structure for the bird-strike requirement according to the Federal Aviation Administration (FAA) Certification Specifications is discussed. Various methods of bird modeling and impact analysis is presented. Analysis is made based on the obtained numerical results. The Analysis Software used for the impact analysis were LS-Dyna and Ansys along with Hyper-mesh was used for pre-processing (Mesh). The geometry is developed using Catia. The objective of the paper is to bring out the simulated impact strength of the aircraft panels get an insight into the impact strength while meeting other criteria. Analysis high lights the need for considering extreme operation scenario like bird strike (Impact) while aiming for better material options for aircraft structures.

Introduction

New Materials for aircraft structures have been developed to meet the growing demands of the weight reduction and better fuel usage optimization. While the research has been focusing on the strength and density aspect of material options like aluminum and composites extreme operational scenario like Foreign Objects Damage will induce high impact loads onto to structures. The criteria are addressed in FAA regulations. As the problems impact highly non linear in nature certification based on numerical results has been a challenge. Future materials development model should be directed to address the impact loads that areexpected during operation [1]. Focus of static strength and density criteria should also include the dynamic failure mechanisms like bird strike. In current work existing models of bird in numerical tools like LSDYNA is used. Meeting the Certification requirement can be better understood by using numerical tools. This is help us in final applicability og material while choosing design direction. Due to increased air traffic in recent decade’s bird strike is seen as major threat to air safety. In addition higher flight speed (high Mach) is leading to higher kinetic energy and huge impulsive force generation during the impact conditions. The probability of bird hit on outer surfaces of the aircraft is high based on earlier experience. The date available in the open literature shows the projected parts of fight need attention. The loss of life due to bird strike has been recorded to be significantly high number. Among the all components of aircraft front facing components of an aircraft which include the nacelles, windshield, wind leading edge, compressor blade, et care often most susceptible to such strikes. It is therefore critical to ensure that the different structural parts are able to withstand such high velocity impact for safe landing of the aircraft after the strike This essentially requires maintaining integrity while undergoing plastic deformation.

Table 1. Aircraft components and FAR Sections

<table>
<thead>
<tr>
<th>Aircraft Component</th>
<th>Bird Weight</th>
<th>FAR Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windsheer and Frame</td>
<td>4 lb</td>
<td>25.7.75(b)</td>
</tr>
<tr>
<td>Wing Leading Edges</td>
<td>4 lb</td>
<td>25.7.57(e)(1)</td>
</tr>
<tr>
<td>Engine Leading Edges</td>
<td>8 lb</td>
<td>25.731, 25.75(e)(1)</td>
</tr>
<tr>
<td>Engine – Inter Up</td>
<td>4 lb</td>
<td>25.7.57(e)(1)</td>
</tr>
<tr>
<td>Engine – Face Integrity</td>
<td>4 lb</td>
<td>33.7.7, 25.75(e)(1)</td>
</tr>
<tr>
<td>Engine – Continued Operation</td>
<td>Upto 8 of 1.5 lb birds</td>
<td>33.7.7, 25.75(e)(1)</td>
</tr>
</tbody>
</table>
Certification Standards like established by Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) list regulations spell out the requirement for the bird strike.

Computer codes supplemented by few experimental test cases. Hence the numerical models for both bird and the part being impacted needs to be established. From the literature typical bird models are studied these reported as following. A 4 lbs (1.82 kg), homogenous bird model with a simplified geometrical shape was modeled popularly.

**Table 1. Bird Properties as per Federal Regulations**

<table>
<thead>
<tr>
<th>Aircraft Component</th>
<th>Bird Weight</th>
<th>FAR Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windscreens and Frames</td>
<td>4 lb</td>
<td>25.775 (b), 25.775 (c)</td>
</tr>
<tr>
<td>Wing Leading Edges</td>
<td>4 lb</td>
<td>25.571 (a)</td>
</tr>
<tr>
<td>Empennage Leading Edges</td>
<td>8 lb</td>
<td>25.631, 25.571 (e1)</td>
</tr>
<tr>
<td>Engine - Lint Lip</td>
<td>4 lb</td>
<td>25.571 (e2)</td>
</tr>
<tr>
<td>Engine - Fan Integrity</td>
<td>4 lb</td>
<td>33.77, 33.571 (f1)</td>
</tr>
<tr>
<td>Engine - Continuation Operation</td>
<td>Up to 1.6 of 3 in birds</td>
<td>33.77, 33.571 (f1)</td>
</tr>
<tr>
<td>Up to 8 of 1.5 lb birds</td>
<td>33.77, 33.571 (f1)</td>
<td></td>
</tr>
</tbody>
</table>

Explicit Finite Element analysis is a numerical technique used in case of highly nonlinear behavior of materials with inelastic strains, high strain rates and large deformations, such as it occur during a bird strike. For a bird strike phenomenon, to obtain a good prediction of the impact loads and damage of an aircraft structure under impact loading, it is essential to adopt a realistic material model for a bird and its associated material and geometrical parameters. Following few methods are popularly used in the literature.

**Lagrangian approach.**

**Arbitrary Lagrangian Eulerian (ALE) approach.**

**Smoothed Particle Hydrodynamics (SPH) approach.**

A typical case of impact of simulate collision of the Lagrangian bird model at 900 degrees to a flat rigid panel (glass and aluminium) at an impact velocity of 116 m/s.

**Modelling**

**Geometry Modeling**

The model was designed in CATIA and subsequent FEM model in ANSYS is developed for a square plate and bird as in shape of hemispherical head and cylindrical aft.

Hexagonal mesh is done on the plate whereas solid mesh on the bird model. After improvised FEM, properties were assigned after importing the pre-processed geometry from hyper-mesh where all the nodes were assigned for analysis.

A) Composite Windshield 1. MAT_NULL (Bird) Combination of a)MAT_VISCOELASTIC(Acrylic Layer) b)MAT_KINEMATIC_PLASTIC(PVB Layer)

B) Aluminium panel MAT_ELASTIC card defines the properties of deformable aluminium.
After the assignment of properties like material properties and constraints, in LS-Dyna the time control cards are assigned in *Control card. Time period for execution was assigned 0.005 sec. The input deck is created in .d3plot format whereas the output from the LS-prepost is in .k.

**Simulation**

As all the control cards are well in place, it is the time to run the model which provides the analysis report in .d3plot file which are imported in LS-prepost software to simulate.

**Simulation**

It is the final step of the software where the results and the performance of the material are animated and calculations are done consecutively. The bird completely sabotaged after the impact of 116 m/sec onto the windshield which results into the bending of the plate within certain limits and avoiding cracks and its propagation to failure. The regions denoted by Red color are the maximum value attained areas. Maximum Plastic Strain is 19.7%.
Von Mises stress is used to predict yielding of materials under any loading condition from results of simple uni-axial tensile tests. The von Mises stress satisfies the property that two stress states with equal distortion energy have equal von Mises stress. During Impact the maximum stress was generated at the point of impact. If Von Mises stress increases the ultimate tensile strength then it would result in failure of the component. After the impact, maximum stress exponentially increases on the fixed ends providing rigid support to the component. As per FAA regulations the fixture connection should be certified for impact loads. Maximum Von Mises Stress induced is $8.16 \times 10^7$ N/m$^2$.

Fig. 7. Deformation Pattern

Fig. 8. Stress Patterns

Fig. 9(a): Displacement Maximum Displacement is $9.526 \times 10^{-2}$ m

Energy Plot

This graph represents the energies of both the components as well as in-combination. The ASCII control card is selected in which glstat* option creates a glstat*(1) file. When glstat*(1) is loaded, the different parameters to be represented in the graph are selected thus creating a plot.
The time-history of the internal energy for each layer of the laminated glass is reported. The outer glass, on which the bird impacts directly, is the ply that absorbs the bigger amount of the bird impact energy, but contrarily to what you might think, after that the two PVB layers turn out to be very efficient about the energy absorbing because of their plastic behavior. This graph represents the energies of both the components as well as in-combination. The ASCII control card is selected in which matsum* option creates a matsum*(1) file. When matsum*(1) is loaded, the different parameters to be represented in the graph are selected thus creating a plot.

- Displacement

Fig. 10. Total displacement in the modal during impact.

Aluminium Panel

Different graphs and Ultra-Edit file of extension .k is being recorded after the scheduled simulation by the software. Von Mises Stress Maximum Von Mises Stress induced is 9.04e8 N/m²
The von Mises stress is used to predict yielding of materials under any loading condition from results of simple uni-axial tensile tests. The von Mises stress satisfies the property that two stress states with equal distortion energy have equal von Mises stress. Maximum Von Mises Stress induced is 4.36e8 N/m² Total Deformation The total permanent set in plate after the impact is called as total deformation which is lower than the ultimate deflection before breaking. Maximum Deformation in aluminium plate is 1.08e-2m Total Deformation Plot

**Conclusion**

Aim of this paper is to show by preliminary analysis that impact characteristic are significant for deciding the future materials for aircraft. Among the three approaches namely Lagrangian, SPH and ALE, Lagrangian was the most appropriate approach as it provides wide choices of contact algorithms and low CPU time. Numerical simulation was performed by using LSTC/LS-Dyna and Ansys explicit solver. A preliminary validation of the bird strike methodology was achieved through a simulation on a simplified, but representative, windshield structure and Aircraft panel.

**Recommendation**

**Composite Windshield:**

The windshield of aircraft comprising of four layers of different laminates which can absorb more impact energy induced during bird-strike than the conventional glass shield. To decrease the displacement observed in the analysis, thickness of the composite windshield should be increased.

**Aluminium Panel:**

As per the strike analysis, the margin of safety came out to be safer than the induced stress. Hence, the aluminium panel thickness can be reduced which can increase the cost-effectiveness by saving material.

**REFERENCES**