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Bird Strike Simulation on a Wing Slat using Abaqus/Explicit

Acknowledgement

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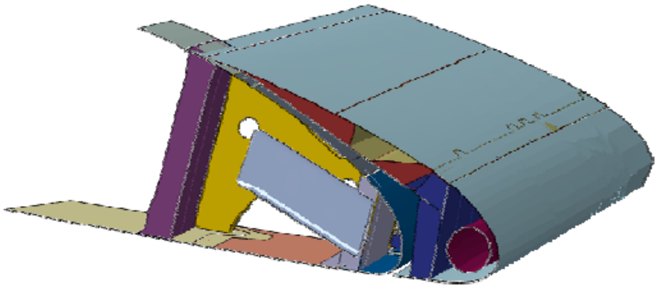

Summary

Bird strikes cost the United States aviation industry tens of millions of dollars annually in aircraft damage and schedule delays. Increasing the ability of the aircraft to resist bird strike induced damage is one part of an overall approach to mitigating this expense [1].

Experimental bird strike testing is part of the certification process for certain aircraft component designs. If a subset of the tests can be replaced with computational simulation, the cost of the prototype testing can be reduced. Further, bird strike resistance considerations can be included in the design process, thus increasing the probability that certification tests will be successful.

In this Technology Brief we describe how Abaqus/Explicit has been used to assess the bird impact performance of a wing slat.

Key Abaqus Features and Benefits

- Capability for modeling progressive damage and failure of ductile metals
- General contact capability greatly simplifies the definition of interactions in models that involve the highly nonlinear, evolving contact conditions associated with impact and fragmentation
- Mesh-independent fasteners with connector elements allow for the specification of sophisticated material properties, damage, and failure.

Background

A bird strike, or a collision between an airborne animal and a man-made vehicle, can have dramatic effects on an airplane. As reported in [1], the world aviation industry bears a substantial cost associated with bird strikes, in the form of aircraft damage and flight schedule disruption; in addition, more than 200 lives have been lost in civilian and military bird strike events prior to 1999.

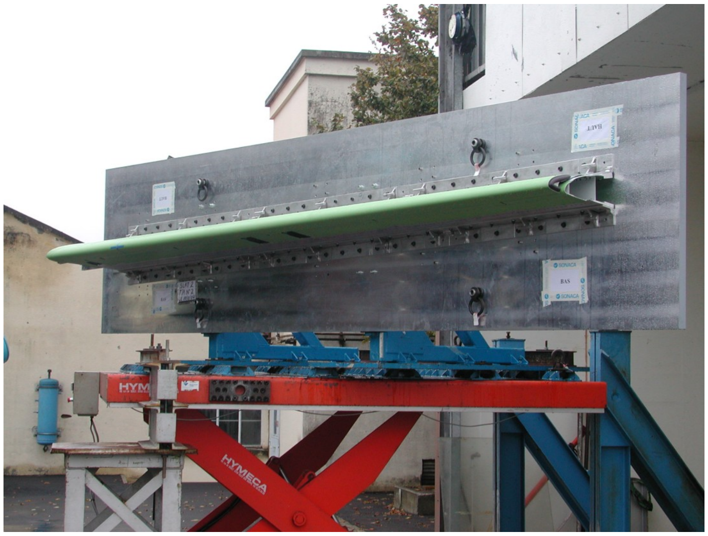

Figure 1: Bird strike test apparatus

To ensure safety, assessment of bird strike resistance is part of the aircraft certification process. Aircraft manufacturers commit significant resources to the development of structures that will pass the necessary certification tests. In Figure 1, some of the bird strike testing equipment employed by SONACA is shown.

Accurate simulation allows the design process to include bird strike as a loading scenario, reduces the number of prototype tests required, and ultimately increases confidence in successful certification testing.

In this Technology Brief we explain how Abaqus/Explicit can be utilized during the aircraft design phase to assess the effect of a bird strike on a wing slat and fixed leading edge. The simulated extent of bird penetration and component damage is compared to test results.

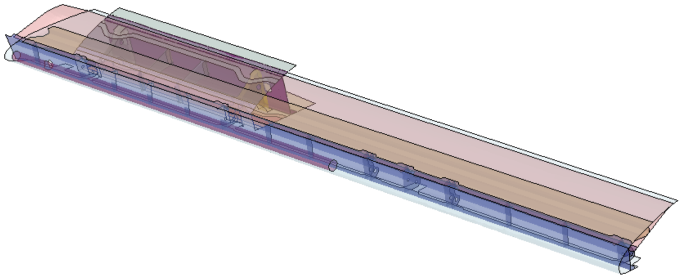

Figure 2: Front slat and leading edge geometry

Analysis Approach

The geometric model of the wing slat and fixed leading edge is created in CATIA. The fixed leading edge is included in the model to provide the supports for the track roller fittings and to check for secondary damage if the bird passes through the slat. The geometric model is transferred from CATIA to Abaqus/CAE via the Abaqus associative interface for CATIA. Figure 2 shows the geometry of the complete model. The present analysis focuses on a slat in its fully retracted position; however, this model can also be used to study scenarios in which the slat is in other positions.

The material damage initiation criterion is of ductile type. Damage evolution is based on effective plastic displacement, and elements in the model are deleted upon reaching maximum degradation.

The linear U_s-U_p Equation of State (EOS) material model is chosen for the bird, as its behavior can be idealized as hydrodynamic. The bulk modulus acts as a penalty parameter to enforce the incompressible constraint. Plasticity and ductile damage are also defined for the bird.

The wing structure contains 40,000 S4 shell elements. A standard 4 lb bird model is used, containing 3237 first-order reduced-integration brick elements. The orientation of the bird with respect to the slat is shown in Figure 3. Figure 4 shows the rear view of the wing fixed leading edge. Both figures have some parts removed for better visualization.

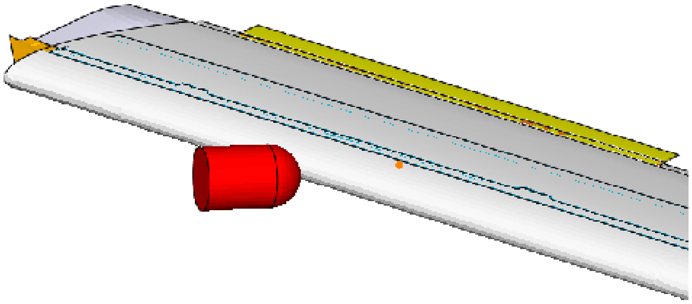

Figure 3: Initial orientation of bird

About 500 fasteners are modeled in the leading edge, each including plasticity and failure criteria. Separate studies have been performed to calibrate the fastener model to the real fastener behavior under various loading conditions.

The bird impacts the structure with an initial velocity of 184 m/sec. The point of impact is chosen to be at the center of the leading edge, on the nose skin. The velocity and incident angle are part of the specification for the certification test and can be adjusted. The duration of the event is 0.008 seconds.

The contact that occurs during the bird strike is very complex in that the interacting surfaces evolve during the solution. It is hard to predict in advance all the interactions that may occur between faces and edges of the wing structure during impact. It is even harder to predict where the fragments of the impacted bird may come into contact with the interior of the wing structure.

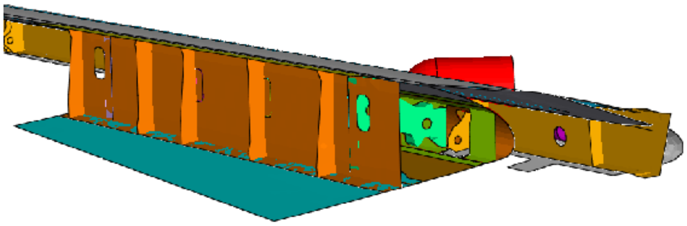

Figure 4: Rear view of leading edge

The general contact algorithm available in Abaqus/Explicit is very powerful and suits this situation well. With it, only a contact domain that contains all components where contact may potentially occur needs to be defined. During the simulation the algorithm automatically detects which surfaces and edges come into contact.

Results

The impact sequence is shown in Figure 5. The cross section of the fully retracted front slat and the fixed leading edge at the bird impact location are visible. The images progress from left to right and top to bottom, respectively.

At the beginning of the sequence the bird strikes the slat skin, then pushes it on to the piccolo tube and forces it to flatten against the slat spar. The slat skin then tears and the bird penetrates into the slat cavity. The slat spar then gets pushed onto the D-nose skin on the fixed leading edge, which in turn collapses onto the wing subspar. By this time some of the rivets on the slat have failed and the slat skin continues to deform significantly as the bird expands into the slat cavity. Peak deflection of the structure occurs at approximately 2.75 ms, when the rib plates experience the impact and bend slightly. From then on the structure rebounds, and failed components start to detach from the main structure.

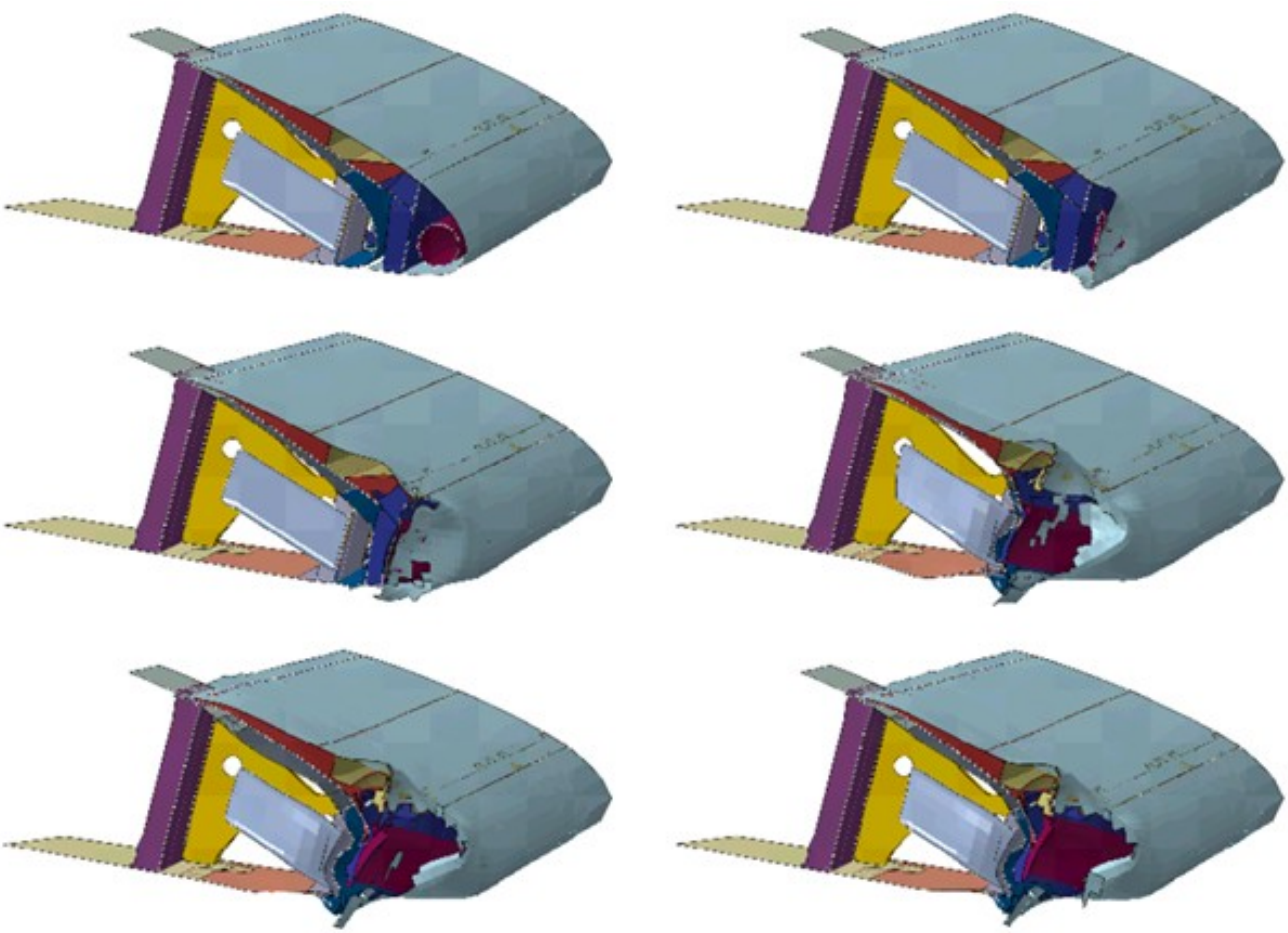

Figure 5: Impact sequence, from left to right and top to bottom

Although there is some plastic deformation, no failure is observed on any of the fixed leading edge components or on the track roller supports, and the bird does not penetrate the main fixed leading edge.

In this study the bird is modeled with Lagrangian elements, which perform well during simulation because of the deletion mechanism that prevents elements from becoming excessively distorted. Note that when the elements are deleted, the nodal masses continue to impact the structure. This treatment keeps the time increment size at a reasonable level and ensures that the total mass and momentum of the bird is conserved.

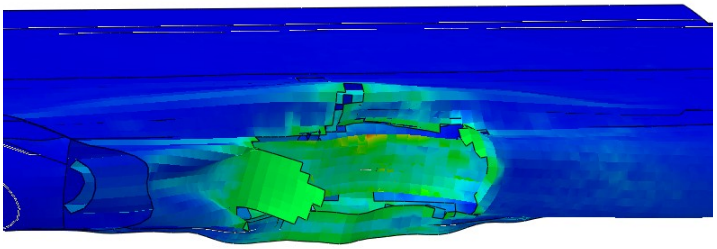

Figure 6: Equivalent plastic strain contour

A contour plot of equivalent plastic strain after impact is shown in Figure 6. The impacted structure from a prototype test is shown in Figure 7. Further analysis of the Abaqus results showed that no secondary damage in the front wing spar occurred.

The results on the fasteners can be analyzed by visualizing all failed fasteners in Abaqus/Viewer, or the failure mode of each fastener can be studied separately.

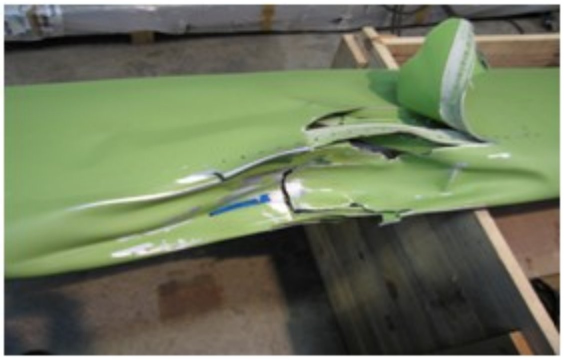

Figure 7: Prototype test result

Conclusions

A bird strike event on the slat of an aircraft wing structure is successfully simulated with Abaqus/Explicit. With its strong damage and failure modeling capabilities, fastener functionality and general contact algorithm, Abaqus/Explicit is an ideal tool for such highly dynamic, nonlinear applications. While the present application focuses on metallic materials, Abaqus/Explicit also allows for the simulation of composite aerospace structures. Finally, by providing an accurate simulation capability, Abaqus/Explicit allows bird strike loading to be included in the design process.

References

1. J. R. Allan, A. P. Orosz, “The costs of bird strikes to commercial aviation,” Bird Strike Committee Proceedings, 2001 Bird Strike Committee - USA/Canada, Third Joint Annual Meeting, Calgary, AB, Canada

Abaqus References

For additional information on the Abaqus capabilities referred to in this brief, please see the following Abaqus 6.11 Analysis User’s Manual references:

- ‘Damage and failure for ductile metals,’ Section 23.2
- ‘Defining general contact interactions in Abaqus/Explicit,’ Section 34.4.1
- ‘Mesh-independent fasteners,’ Section 33.3.4

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