Fan Blade Bird-Strike Analysis and Design

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ABSTRACT

Bird ingestion is a costly and difficult engine test to perform. It is also one of the most challenging and complex analytical investigations in engine design. The capability to model bird ingestion effects is, therefore, critical to the success of any competitive jet engine program. LS-DYNA has been used in the design and analysis of fan blades for bird-strikes. Descriptions of the bird and blade models used in the analyses along with the contact algorithms used to describe their interaction will be presented. In addition, comparisons of analysis and test results from bird-strikes on fan blades will also be presented.

INTRODUCTION

Certification of jet engines requires the demonstration of the ability to ingest birds into an engine and meet Federal Aviation Administration regulations for airworthiness. Specifically, the medium or flocking bird requirement is to ingest several 1.5-lb or 2.5-lb birds into an engine and maintain specific thrust levels for various time durations. The large bird requirement is to ingest a 6-lb or 8-lb bird and demonstrate safe shutdown. The capability to predict the damage to fan blades from bird ingestion is, therefore, a critical component in the structural design of fan blades for jet engines.

To predict component damage from birds requires both a structural model of the fan blade and a method to generate the distribution of impact loads onto the structure. The finite element method is a desirable approach because of its ability to handle complex geometries, material nonlinearities, and the component-projectile dynamic interaction. This approach has been used with LS-DYNA to design fan blades to meet the bird ingestion requirements.

APPROACH

Analysis

Using LS-DYNA, the bird and blade are modeled independently and their interaction is defined with an analytical contact algorithm. The bird is modeled as an ellipsoid of solid elements with material properties similar to water. The hydrodynamic or fluid-like behavior for the bird is required because the impact stresses imposed on the bird are far in excess of its material strength and because it undergoes large deflections and segmentation during its interaction with the blade. The blade is modeled with plate elements with a thickness defined at each nodal point. An elastic-plastic-strain-rate dependent material model is also defined for the blade. Figure 1 shows a typical bird and fan blade finite element model.

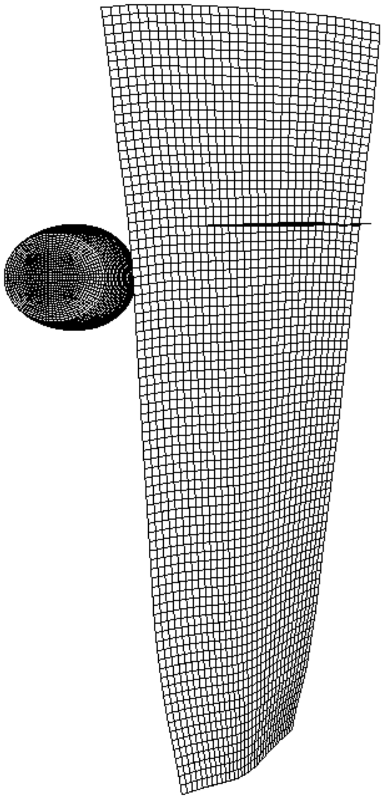

Figure 1. Blade and Bird Finite Element Mesh

The analysis is completed in two phases. The first phase is an implicit solution of the blade where the blade root nodes are fixed and a body force load representing a prescribed angular velocity is applied to the blade. This results in the proper blade deformation and stress for the start of the transient analysis. In the second or transient phase of the analysis, the blade root nodes are prescribed to rotate with the angular velocity from the first phase and the entire blade is given the same initial angular velocity. For shrouded blades like that shown in Figure 1, the shroud nodes are constrained to move only radially during the implicit solution and they are prescribed to rotate with the blade angular velocity during the transient analysis. These boundary conditions simulate the constraints imposed by the neighboring blade shrouds. At the start of the transient analysis, the bird model is given an initial velocity based on the aircraft speed. During the transient analysis, the bird and blade interaction is achieved via the defined contact algorithm. The blade nodes are defined in a slave set to contact the master surface blade elements. The transient analysis is then performed in LS-DYNA explicit.

Design

In order to use the analysis in the design of new blades, analytical thresholds for failure were determined. This was achieved by comparing analytical results of tests where failure or cracking of the blade occurred with results from tests where no cracks or failures occurred. For all these analyses, a consistent modeling approach was used, i.e., identical bird material models, blade material models, mesh densities, and contact algorithms. Analysis maximum strains were documented at the blade lead edge and at the shroud hard point (the location on the blade airfoil in front of the shroud) for comparison with test results to determine the blade analytical failure threshold. New blade designs are then analyzed with the same consistent modeling approach to assure this maximum strain threshold is not exceeded.

DISCUSSION OF RESULTS

Analysis and Test Comparisons

Using the above procedures, an analysis of a bird-strike on a fan blade was completed for comparison with test results. In the test, a 2.5-lb bird with a velocity of 180 knots was shot at a fan blade in-board of the shroud. The fan diameter was 94 inches and the blades had a speed of 3862 rpm. The test resulted in a cracked blade at the shroud hard point that is visible in Figure 2. The LS-DYNA analysis of the blade resulted in the deformed shape shown in Figure 3. The shroud hard point strain in the analysis exceeded the material analytical failure threshold, which is indicative of some type of failure. In addition, the lead edge line strains correlated well with the strains calculated from a grid placed on the blade prior to test.

The LS-DYNA analysis is readily extended beyond a single fan blade to include an entire set or multiple fan blades. Figure 4 shows a deformed blade set from a 2.5-lb birdshot. Figure 5 shows the LS-DYNA deformed shape plots from an analysis of that test event. The total extent of damage including the number of blades damaged in the test correlates well with the analysis results.

CONCLUSIONS

These design and analysis procedures using LS-DYNA for bird-strikes on fan blades have been documented as part of standard work procedures and they are being used in the design of new fan blades. In addition, efforts are underway to incorporate the threshold strain into the LS-DYNA material model to evaluate crack propagation. It should also be mentioned that a similar analytical approach has been used in the design of spinners and nosecones for bird-strike events.

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Figure 2. Deformed Blade with Crack

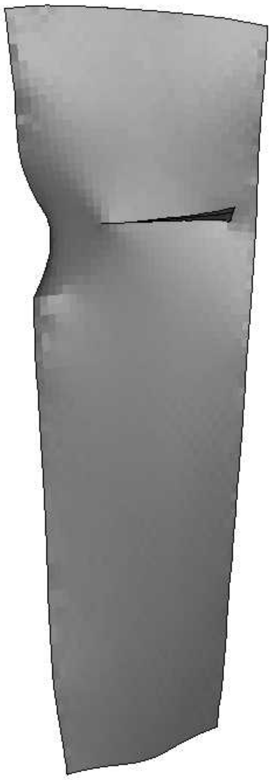

Figure 3. Analysis Deformed Blade

Figure 4. Deformed Blade Set from Test

Figure 5. Deformed Blade Set from Analysis