Reducing the Many Impacts of Bird Strike

HCL Technologies uses Abaqus to simulate bird-plane collisions, design safer aerostructures, and reduce physical testing

Less than two years after his pioneering flight at Kitty Hawk in 1903, Orville Wright recorded the first collision of a flying machine with a bird. In the hundred-plus years since then, as aircraft and air travel have increased, so have midair meetings between birds and planes. When avian life and airplanes share airspace, accidents are inevitable.

In recent years, bird strikes—as they're now called—have become an increasingly regular and costly occurrence. While the birds never fare well, 85 percent of the time the plane escapes unscathed. In the other instances, there can be damage to the aircraft, sometimes extensive, and even human casualties. Annually, there are approximately 10,000 strikes with civilian planes recorded in the U.S. alone, with losses of more than $650 million for commercial and military aircraft. Since 1988, over 220 fatalities have been reported worldwide.

To address this growing problem, the Federal Aviation Administration (FAA) and national and international bird-strike committees document the effects of incidents and work closely with airports, airlines, and pilots on strike prevention.

Aviation engineers are focused on the problem, too, concentrating on how to strengthen aerostructure designs so that damage is minimized and flying safety is ensured, even when the inevitable happens.

Designing for bird impact

Bird-plane collisions most commonly occur on an aircraft's forward-facing structures, such as its nose cone, cockpit windshield, engine cowling or blades, or the leading edge of the wings and the empennage (tail assembly). The force of the blow depends on the bird's weight plus the speed and direction of impact, with the energy increasing as the square of the difference in speed between the two objects. When a 12-pound Canada goose strikes an aircraft going 150 miles-per-hour (a speed common for many planes during takeoff and landing), for example, it generates the kinetic energy of a 1000-pound weight dropped from a height of 10 feet—enough force to do significant, even catastrophic damage.

A recent project at engineering services firm HCL Technologies in Bangalore, India, involved design and development of a vertical stabilizer for a commercial passenger aircraft tail assembly. In this effort—and in the face of fuel-efficiency initiatives and the pressure to reduce structural weight—the engineering team was tasked with designing a lighter-weight alternative to a traditional metallic design. But replacing aluminum, a material that resists impact well, with composites introduces challenges, since the newer materials are more brittle than metal and more vulnerable to impact.

"We looked at a variety of material options for the vertical stabilizer, including all-composite and composite/metal hybrid versions," says Ganthimathinathan Perumal, senior project manager in the Engineering and R&D Services department at HCL. "Each design iteration required its own bird-strike analysis to see if it met the appropriate safety regulations."

In order to be flight certified, FAA and EASA (European Aviation Safety Agency) rules prescribe that all commercial aircraft must be designed to withstand a collision with a four-pound bird anywhere on its structure at cruise speeds and still be able to continue flight and land safely. In the U.S., FAA regulations also specify that the empennage structures are built to withstand the impact of an eight-pound bird at cruise speeds.

Simulating bird strike

To comply with bird-strike requirements, aircraft engineers have traditionally been required to physically test all structures—a costly and time-consuming process involving firing an object of known mass and density at the structure with a compressed-air cannon. For some time, they have also used computer modeling during design development to complement testing. As simulation has evolved from a simplified pressure pulse on a rigid surface to today's highly realistic analyses, the practice has come to be accepted as an increasingly reliable and cost-effective tool for predicting what happens during a collision.

For their simulation needs, the R&D team at HCL relies on Abaqus finite element analysis (FEA). "Bird strike is a highly dynamic, nonlinear event," says Anwar Ibrahim, project manager at HCL.

"It involves complex contact behavior, especially after impact when fragments of the damaged structure and the bird hit other parts of the aircraft. Abaqus handles this multiphysics problem well."

The tool also has a large library of material models that are highly useful for design exploration of new materials. "For composites, we use the built-in progressive damage and failure model," he says. "This includes fiber rupture in tension and fiber buckling, as well as matrix cracking, shearing, and crushing."

For the HCL engineers who utilize FEA at R&D locations throughout India, Ganthimathinathan notes additional benefits. "Our customers use a wide range of software during design development, and we have to be able to work with all of them. Abaqus is vendor-neutral and compatible with a wide variety of other tools. We've been using it successfully for more than ten years."

Evaluating models, methods, and materials

While the goal of the stabilizer analysis was to explore lightweight designs, the study started by verifying a model of a metallic stabilizer to establish a baseline. "Earlier analyses have focused on metal aerostructures, so we used aluminum to figure out the best way to approach the problem," says Ganthimathinathan.

Since bird-plane collisions create large material deformations, methodologies for modeling 'soft body' impact needed to be tested, as well, notes Ibrahim. "We wanted to validate whether the meshing strategy of the Lagrangian or the Coupled Eulerian-Lagrangian (CEL) approach would provide the most accurate results. Abaqus has the capability to do both."

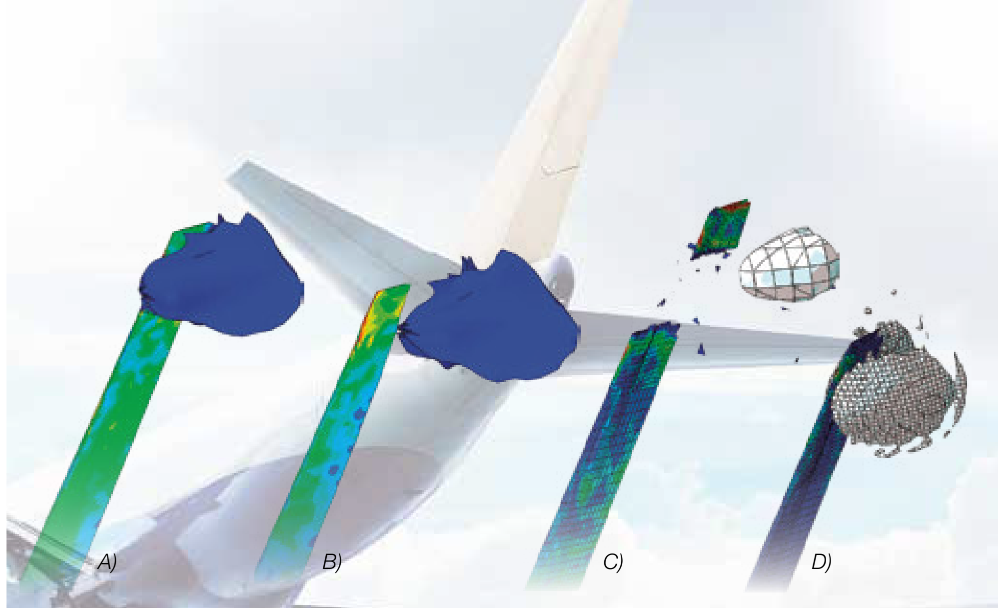

Figure 1. To benchmark their bird-strike methodologies, HCL engineers used Abaqus to analyze several all-aluminum vertical stabilizers for tail assemblies. Graphics (A) and (B) show unrealistic bird deformation using the Lagrangian method at different time steps during collision. In graphics (C) and (D), (C) illustrates failure behavior of the stabilizer with skin thickness of 1.5 mm while (D) shows more realistic soft-body material behavior during impact using CEL method.

For the benchmark, the R&D team modeled a four-pound bird traveling at a speed of 150 meters-per-second and impacting metal stabilizers with a skin thickness of 1.5 mm. They determined that the CEL method, with its simplified meshing, provided results that more closely represented reality, while also using less run time (see Figure 1).

With their models and methods verified, the engineering team then analyzed a series of composite and hybrid stabilizer designs. In every iteration, the number of plies and material composition of the layup were changed, and a bird-strike analysis was performed. For the structure to pass, the leading edge of the stabilizer needed to withstand 'virtual impact.'

While a 30-ply all-composite design (comprised of glass and Aramid fibers) survived the impact of the four-pound bird model, a similar 20-ply design failed. To increase the strength of the lighter 20-ply design, engineers replaced the outermost composite ply with a single aluminum layer (0.9 mm in thickness). This hybrid design, when impacted by the model bird, incurred damage on the outer metal layer but prevented the underlying composite layers from severe or catastrophic damage (see Figure 2). Physical testing of the successful hybrid design for flight certification is pending.

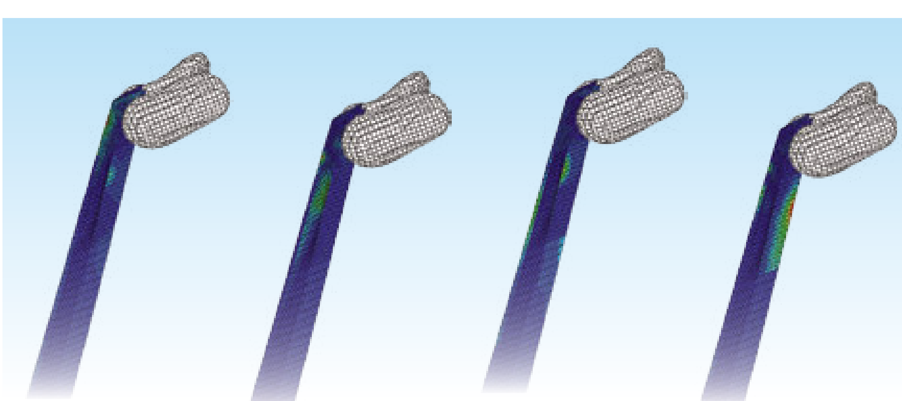

Figure 2. In this simulation of a bird strike with a lightweight vertical stabilizer, Abaqus was used to generate the following composite behavior results (left to right): fiber tension; fiber compression; matrix tension; and matrix compression. The stabilizer was a 20-ply hybrid design comprised of an outer aluminum layer and 19 underlying composite layers.

The changing roles of simulation and physical testing

More and more, aviation engineers are turning to composites and hybrid materials in order to design lightweight aerostructures. As they do, they must make sure that their designs meet the industry's stringent safety requirements for events such as bird strike. Both simulation and physical testing will continue to play a role in the validation and certification process. But the balance between the two is shifting.

FEA has long been embraced by engineers. "Using simulation, we can widen our design options and easily make changes until we find a version that satisfies the regulations," says Ibrahim. "The scope of the analysis process allows us to minimize physical tests and reduce development costs and time."

Regulatory agencies are endorsing the technology, as well. According to European Joint Aviation Requirements (JAR), compliance with bird-strike requirements can be proven by analyses which are based on tests carried out on representative structures of a similar design. This regulatory path will further streamline the development process and amplify savings for manufacturers.

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