



A Numerical Investigation of a Bird Strike on the Structure of an Aircraft Wing Leading Edge

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Abstract

The bird strike incidents have been a problem since the start of modern aviation. It remains one of the most dangerous threat to the flight safety. Although catastrophic failure is uncommon, flight safety authorities require aircrafts to be designed to complete the flight without any harm. A finite element model based on smooth particle hydrodynamics (SPH) is developed to analyze the bird strike effect on a leading edge of an aircraft wing. Since birds strike at the leading edge of the wings from different orientation, bird strike simulations are performed from various orientations. results illustrated that the advancing angle of birds toward the leading edge has a significant effect on the deformation of the leading edge of an aircraft wing. In addition, kinetic energy and von Mises stress at the leading edge of the wings are discussed. Simulations illustrated that the advancing angle of a real bird causes substantial structural deformations on wing profiles.

Keywords: Bird Strike, Smooth Particle Hydrodynamics, Finite Element Analysis, Impact

1. INTRODUCTION

Aviation industry suffers from bird strikes issues since the early times of aviation. One of the first deadly accidents happened during an exhibition flight of Calbraith Perry Rodgers as a flock of birds strike on the aircraft causing the plane crash into the ocean in 1912. Although it has been a long time since the first incident of bird strike, it has been a serious problem for the flight safety. Numerous bird strike association are established to improve commercial, military, and private aviation flight safety, by sharing knowledge and understanding concerning the reduction of the frequency and risk of collisions between aircraft, birds and other wildlife. According to international bird strike committee, 42 fatal accidents killing 231 people and a total of 80 aircraft destroyed, which costs around \$1.2 billion to the commercial aircrafts worldwide during the period of 1912 and 1995 [1]. Although millions of dollars are spent every year to counter the bird strikes, the bird strike incidents are still an issue for the flight safety even today. Therefore, national and international flight safety authorities require valid bird strike evaluation tests before an operational use of an aircraft [2].

The tests required to investigate bird strike effect on the aircraft components are cumbersome for preparing the experimental set up and test components. After each test a new component is designed and tested again to observe the cause of each parameter which could be numerous. This

procedure is highly cost intensive, time consuming and hard to control all other parameters for a controlled test. Hence finite element modeling is an important tool to run multiple simulations within a short period of time without substantial costs in bird strike cases.

Guo et. al. [3] simulated the bird strike on a composite tail by utilizing finite element method which illustrated the current design was not compatible with the anti-bird strike regulations. Later the Smojver et. al. [4] developed a finite element model and validated it with an experimental work to study bird strike on wing leading of large aircrafts. The smooth particle hydrodynamics is employed for the bird strike on wing leading edge as a meshless method by Guida et. al [5]. Coupled Eulerian-Lagrangian (CEL) finite element model was adopted by Heimbs [6] for the bird and wing leading edge high-velocity impact. Jenq et. al. [7] exploited arbitrary Lagrangian Eulerian (ALE) method and modeled bird as a cylindrical body with semi spherical heads which is crashed into a flat rigid body. Goyal [8] et al. developed two different finite element models based on Lagrangian and Smooth Particle Hydrodynamics to compare capabilities of both models simulating the bird strike.

Liu et. al. [9] established a finite element model coupled with the SPH in addition to experimental work to design a tail leading edge structure to simulate the bird strike. According

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to their work [9], SPH is capable of modeling the bird strike on tail leading edge. Hence there are various approaches for modeling the bird strike on wing leading edges.

2. FINITE ELEMENT MODEL

A finite element model is an effective tool for high-velocity impact problems. In the previous section, various models which can be used to model the impact analysis of bird into a wing is discussed. The Lagrangian modeling method is a widely used approach for structural finite element problems. In this approach, the mesh is associated with the material and follows the motion and deformation during the analyses. Therefore, the Lagrangian formulation causes severe problems in analyses with high material deformation because of the large distortions of elements, hourglassing, reduced time steps and even termination of the analyses. Hence Lagrangian formulation stays ineffective for fluid splashing problems such as bird strikes. In the presented study SPH model is employed for the high-velocity bird strike simulations. One other widely used approach is Eulerian formulation where the mesh remains attached to space and the material flows through the mesh. The mesh in space is set up to cover the entire domain where material might exist later of interest increasing the size of the solution domain. Therefore, the increase in the model size increases the computational cost of the problem requiring advanced computational tools and more time.

Smoothed particle hydrodynamics (SPH) is a numerical method that is part of the larger family of meshless (or mesh-free) methods. The body material is defined by so-called particles or pseudo-particles which are assigned properties such as mass, pressure, density, temperature, and velocity. SPH is widely used to model bird strikes on wing leading edges due to their capability of addressing the splashing effect of fluids. Georgiadis et. al [10] moveable trailing edge (MTE) developed a methodology to support the bird-strike certification of the carbon fiber epoxy composite, moveable trailing edge (MTE) of the Boeing 787 Dreamliner employing SPH model. SPH models are highly effective in modeling bird strike incidents because of its capability of modeling the high distortion and deformation with a smaller computation cost. Hence, in this study, an SPH model is employed to model a simplified wing model to investigate the effect of the bird approaching angles on the wing deformation of an aircraft during the takeoff or landing conditions.

2.1 Bird Modelling

Aircrafts are required to attain high speed during the flight although the take of speed is lower than the operation speed of aircraft. However even take of speeds are fast enough for an impact of soft material such as birds. Even soft materials cause a significant damage on aircraft structures. At high speeds birds or any other soft objects undergo high distortion and acts like fluidic materials. Hence the smooth particle hydrodynamics (SPH) method which handles distortion problems is employed for the bird model. SPH model is Lagrangian meshless method which is first used by Lucy [11]

for solving hydrodynamics problems such as accretion disc, galaxy dynamics and star collisions. This method has been included in many commercial software to address problems with high distortion rates as well as to the bulk models with no cohesion such as sand, liquid, gas and even for grains [12].

In this work bird shape is assumed be hemispherical ended cylinder. Barber et. al. [13] investigated numerous bird species to come up with a bird density to be utilized in numerical studies and demonstrated a density of 950 kg/m³.

At high speed the bird body acts as a fluidic body crashing into the structures. Although there are many approaches to solve the bird strike problems, SPH stands out as a capable modelling approach for high speed cases. In the presented study Mie-Grüneisen equations of state providing the linear Hugoniot form.

2.2 Constitutive Model for The Structural Material

One of the most common materials is aluminum alloys in aircraft wing structures due to their light weight and durability. The impact speed of bird into the wing leading edge is 180 m/s which causes elevated strain for the material model hence strain rate effect should be accounted for. In this study an elastic-plastic material model with isotropic damaging model is employed. Copwer-Symonds strain rate dependent material algorithm has been implemented for the hardening. The parameters required from the finite element solver are obtained from the literature where detailed description about the model is explained [9]. The mathematical expression of the Copwer-Symonds law is given in the following equation where $a + b(\epsilon)^n$ is the static yield stress with strain hardening in which a is the yield stress is the effective plastic strain and b and n are material constants. The second term $1 + (\dot{\epsilon}/D)^{1/p}$ in the Eq.1 is the strain rate effect induced due to plastic deformation in which $\dot{\epsilon}$ is the strain rate.

$$\sigma(\epsilon, \dot{\epsilon}) = [a + b(\epsilon)^n] [1 + (\dot{\epsilon}/D)^{1/p}] \quad (1)$$

1Deformation after bird strike with 15° approaching angles for 0.15-0.60 ms respectively

In this study Al6061-T4 aluminum alloy is adopted for the wing leading edge. The material constants for Al6061-T4 aluminum alloy implemented in the finite element solver are $E=68$ GPa, $\nu=0.3$, $a=280$ MPa, $b=200$ MPa, $D=6500$ s⁻¹, $p=1$, $\epsilon_f=0.12$, and $\rho=2713$ kg/m³. These parameters were obtained by Liu et. al. [14] by conducting uniaxial compression and dynamic Hopkinson bar tests by employing curve fitting of results under room temperature conditions.

3. RESULTS AND DISCUSSIONS

The wing structure used in numerical analysis is a NACA9417 airfoil structure. In the presented study NACA9417 profile extruded 1000 mm to represent the wing leading edge. This

is an acceptable assumption because bird size is remarkably smaller than the complete wing structure for large passenger aircraft. The wing structure in the study is modelled with shell elements with integration points due to the thin aluminum sheets utilized in wings. The shell thickness is taken

as 2.5 mm. Al6061-T4 aluminum alloy whose properties are provided in previous section is implemented in the finite element model. the bird structure is constructed as a cylindrical body with a length of 300 mm and diameter 100 mm with a semi spherical tip.

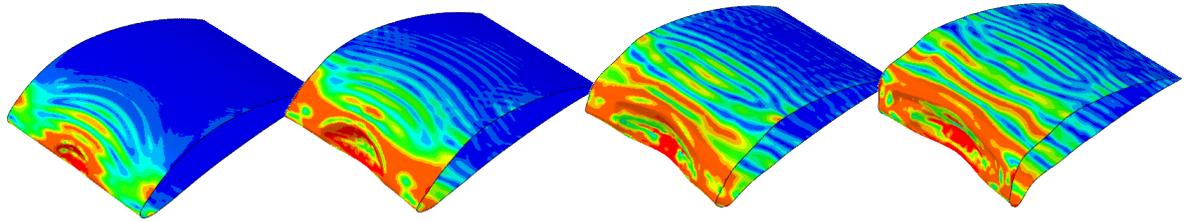


Figure 2. Deformation after bird strike with 0° approaching angle for 0.15-0.60 ms respectively

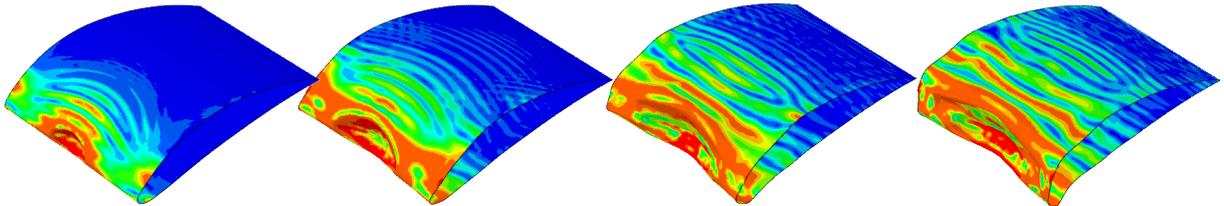


Figure 3. Deformation after bird strike with 15° approaching angles for 0.15-0.60 ms respectively

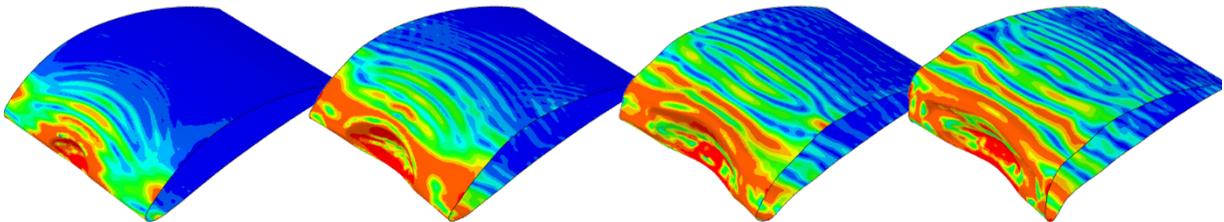


Figure 4. Deformation after bird strike with 30° approaching angles for 0.15-0.60 ms respectively

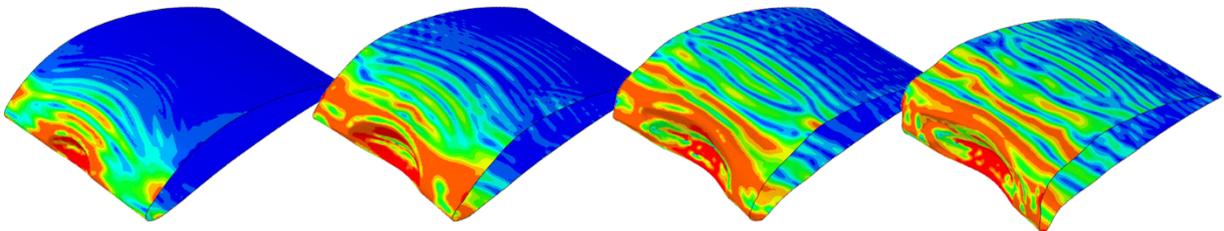


Figure 5. Deformation after bird strike with 45° approaching angles for 0.15-0.60 ms respectively

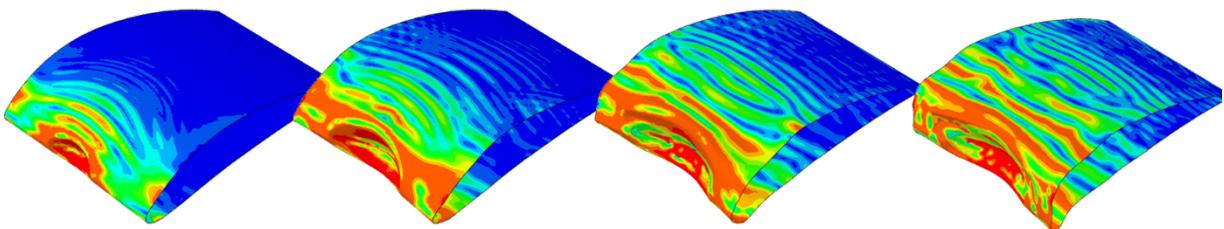


Figure 6. Deformation after bird strike with 60° approaching angles for 0.15-0.60 ms respectively

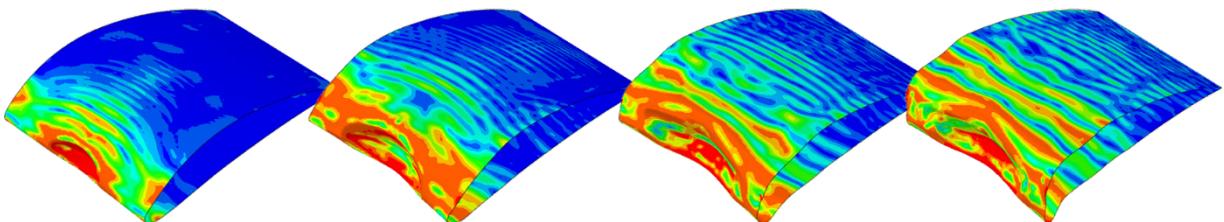


Figure 7. Deformation after bird strike with 90° approaching angles for 0.15-0.60 ms respectively

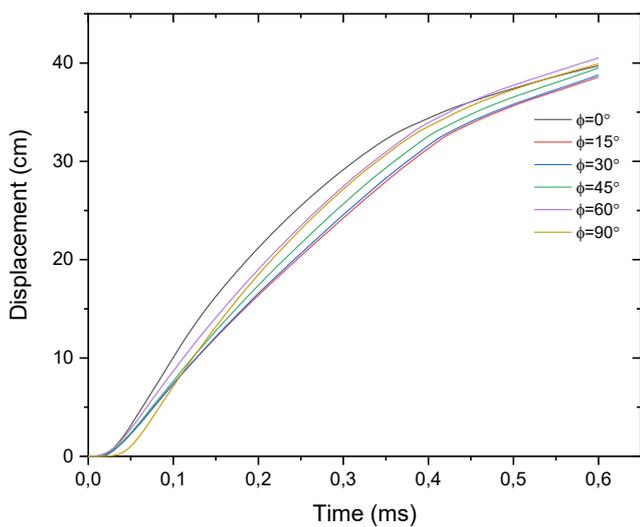


Figure 8. Deformation on the wing leading edge during the bird strike

4. CONCLUSION

In this study the effect of the bird approaching angle on the deformation of simplified wing leading edge of a commercial aircraft is investigated by means of finite element analyses. There are various approaches to model the bird strike at wing leading edge. In this study smooth particle method is employed for bird and wing interaction among various models. Al6061-T4 aluminum alloy is employed as the material of the wing leading edge in the presented study. Plastic deformation scheme of Johnson-Cook [15] material model is adopted to address the plastic deformation effectively. The bird material is selected to be water since the bird body composition is mostly water and the impact velocity is adopted to be 180 m/s. the wing leading edge experiences great deal of plastic deformation under high speed impact according to the figures. In Fig. 1 the bird approaching angles is illustrated for angles of 0°, 15°, 30°, 45°, 60° and 90° consecutively. There are slight differences in the deformation taking place after the impact. The elements are detected at the bird strike zone and their displacements are presented in Fig. 8 for the specified bird approaching angles. Surprisingly, no significant differences in the deformation of wing leading edge are returned by the simulations performed in this study. To author's best knowledge a substantial investigation of bird approach angle on the deformation of wing leading edge yet to be explored experimentally. Nonetheless further work is required to establish the viability of effect of bird approaching angle on wing leading edge deformation by means of experiments.

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