A Review on BirdStrike Analysis on Leading Edge of an Aircraft Wing Structure using a SPH Formulation

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Abstract - *Bird strikes are a major threat to aircraft structures, as a collision with a bird during flight can lead to serious structural damage. Computational methods have been used for more than 30 years for the bird-proof design of such structures, being an efficient tool compared to the expensive physical certification tests with real birds. At the velocities of interest, the bird behaves as a soft body and flows in a fluid like manner over the target structure, with the high deformations of the spreading material being a major challenge for finite element simulations. This paper gives an overview on the development, characteristics and applications of different soft body impactor modeling methods by an extensive literature survey. Advantages and disadvantages of the most established techniques, which are the Lagrangian, Eulerian or meshless particle modeling methods, are highlighted and further topics like the appropriate choice of impactor geometry or material model are discussed.*

Key Words: **Bird-Strike, Survey, FEM Analysis, Aircraft, Leading Edge Wing Structure.**

1. INTRODUCTION

Bird strikes on aircraft are a potentially dangerous events which is faced by military and civilians nowadays, the impacts are inevitable and is catastrophic in damage. Although exterior aircraft structures can be exposed to various scenarios of foreign object damage (FOD) like hail, runway debris or tire rubber impact, about 90% of all incidences today are reported to be caused by bird strike.

Numerous statistics are published each year, illustrating recent numbers on monetary, material and human losses due to bird strike in commercial and military aviation and leading to immense monetary losses due to repair, delay and cancellations. The reports & statics indicated that 72% of all collisions occur near the ground below 500 ft. and 92% under 3000 ft., making the take-off and landing phases especially critical.

All forward facing components are concerned, i.e. the engine fan blades and inlet, the windshield, window frame, radome and forward fuselage skin as well as the leading edges of the wings and empennage.

Consequently, the aviation authorities require that all forward facing components need to prove a certain level of birdstrike resistance in certification tests before they are allowed for operational use. These requirements are compiled in the Federal Aviation Regulations (FAR), European Joint Aviation Regulations (JAR) and lately in the Certification Specifications (CS) of the European Aviation Safety Agency (EASA):

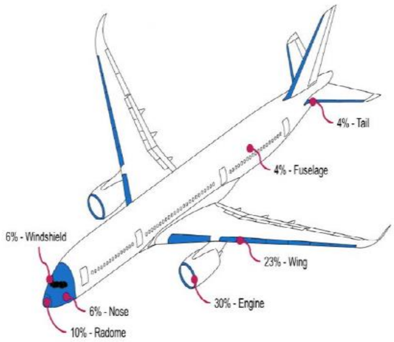
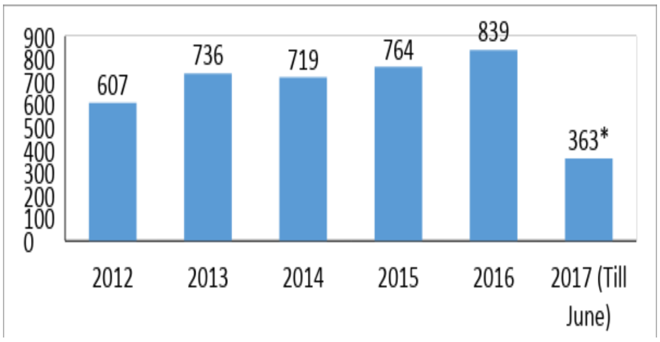


Figure 1 : The wings and engine of an aircraft bear maximum damage.

For wing leading edges the certification criteria require that even in case of penetration of the leading edge skin no critical damage may be introduced to the front spar elements or the wing box, assuring a continued safe flight and landing after impact. This has to be proven for 4 lb (1.8 kg) birds impacting the wing and 8 lb (3.6 kg) birds impacting the empennage leading edge at operational speed (FAR/JAR/CS 25.571, 25.631). Bird strike reports can involve single or multiple strikes.

At least two aircraft are struck every day in India by birds or animals during taking off and landing According to data obtained from the Directorate General of Civil Aviation (DGCA), more than 4,000 aircraft suffered wildlife strikes in about 80 airports over the past five years. These events increased from 607 in 2012 to 839 in 2016.

The busiest airports in the country New Delhi and Mumbai, reported 135 and 72 cases in 2016 respectively. According to the civil aviation regulator, the growing incidence of bird strikes is the result of lack of sanitation, abundant availability of food in and around airports, such as Small insects, food particles, water bodies that attract birds are found in abundance during the rainy season leading to increase in cases in monsoon. Domestic airlines lost more than Rs 25 crore in 2014 to bird hits.



Graph 1: Reported Wildlife Strikes

Data accessed under RTI from DGCA shows hits by animals and birds on planes have been rising. One of the examples of catastrophic damage by bird impact is on 8th June 2018 airplane's engine of GoAir flight G8-101 flight flying to Port Blair from Kolkata as shown in figure had to return to the airport after a bird strike left the damaged and expected cost to be around Rs 5 crore.

2. COMPUTATIONAL METHODS

Numerical methods were developed and applied since the late 1970s for the purpose of rapid and improved design optimization, ensuring that the very first full-scale bird strike certification test is successful. The definition of a suitable bird model is often the main problem in the numerical simulation of bird strike. Starting with relatively simple nonlinear calculations and a pressure load applied to the target structure in the 1970s, complex fluid–structure interactions are treated today with explicit simulation codes and high performance computing (HPC). the major load cases for the aircraft industry treated with explicit finite element (FE) analysis codes. Therefore, many studies and investigations on bird strike modeling have been conducted in the past and a lot of papers on different modeling methods have been published in the technical literature. There are still at least three techniques today, Lagrangian, Eulerian & SPH Formulation which are widely used, each having its own advantages and disadvantages

3. LITERATURE SURVEY

The bird strike is a well-know phenomenon, some impacts were recorded since the first decades of the 1900's. In the past various scientists studied the bird strike with several empirical design methods, in order to define the characteristics (thickness, material, etc...) of the aircraft components able to resist at bird strike events. In the 1970's, the validation of the bird-proof components was solely dependent on experiments, because of the absence of numerical tools. Furthermore, a tabular overview of all bird strike analysis publications with detailed information on the software, modeling method, impactor geometry, mass and velocity as well as the target application of each paper is given in the appendix.

Table 1 : Detailed Survey of Bird-Strikes

Year	Author	Remarks
1968	Allock & Collin[1]	Were the first to determine prime constituents of substitute bird model by studying wax, foam, emulsions, and gelatin as substitute materials for birds.
1975	Barber et al.[2]	First to perform an experimental campaign of bird impacts against a rigid circular plate. They found that a pressure time history is composed by four different phases: a) an initial shock (Hugoniot pressure), b) an impact shock decay, c) a steady state phase and d) a final decay of the pressure,
1976	Peterson et al.[3]	They performed a series of bird strike tests on rigid plate and turbo-machinery too. They concluded that the behaviour of the bird can be assimilated to a fluid one, and so showed that bird loading model treats the bird model as a fluid dynamic process.
1977	Wilbeck[4]	Showed that, in case of high velocity impact, the response of the bird is similar to that of the water for which the strength of the material is extremely small compared with the impact loads.
1979	Cassenti[5]	Studied analytically the experiment carried out by Barber et al. (1977), Developed the governing equations for a soft body impact on a rigid plate.
1981	Wilbeck & Rand [6]	Found that the gelatin, with the specific gravity of water, produces a loading profile similar to real birds and the response depends on material density and not on material strength. By using Explicit nonlinear finite element (FE) codes & crash analysis software, good results were obtained.
1990	Niering[7]	Studied the bird strike problem numerically and modeled the bird using a Lagrangian approach. His research provided different methods of computer simulation

		for the bird strike event
1992	Benson[8]	Published a detailed review of the general methods for Lagrangian and Eulerian hydro codes, that are currently used to solve transient large deformation problems in solid mechanics. He provided the first public light on the basis for the methods used in commercial codes for impact analyses.
1997	Birnbaum et al.[9]	Analysed bird impact simulation problem by using all modeling techniques (Lagrangian, Eulerian, ALE and SPH) to simulate the fluid-structure interaction.
2000	Lacome[10]	-Gave an important contribution for the description of the conventions used for the selection of the smoothing length and provided important informations regarding the SPH process of the neighbour search in the interpolation and for the SPH approximations for the equations of energy and mass conservation.
2002	Langrand et al.[11]	Modeled the bird impact against rigid targets using both the Lagrangian and ALE formulations in Radioss
2003	Yang et al.[12]	Elaborated an experimental and FEM of windshield subjected to high speed bird impact.
2004	Lars et al.[13]	Studied the problem of the bird strike by LS-Dyna using a multi-material ALE formulation. They obtained an acceptable bird deformation and small energy loss.
2006	Hanssen et al.[14]	Investigated bird impact against aluminium foam-based sandwich panel using the ALE approach.
2008	Liu et al.[15]	Focused on the analysis of an effective numerical method to simulate bird impact aircraft windshield events, using the SPH approach and the explicit finite element program PAM-CRASH.
2008	Guida et al[16]	Developed a finite element model for simulating the birdstrike test on the tail plane leading edge structure. They studied the impact
		on a composite component made of aluminium skin and flexcore as interior sandwich structure, and found good correlation between the numerical and experimental results.
2009	Xue et al.[17]	Investigated the several interacting aspects such as Damage initiation and accumulation in the numerical simulation. Alternative approaches taking into the account the influence of both stress and strain rates on failure propagation were also presented.
2010	Salehi et al.[18]	Investigated the effect of the birdstrike on different aircraft windows both numerically and experimentally. They studied structures made up of different geometries and materials by using various modeling approach (ALE and SPH).
2011	Guida et al.[19]	Found that the Lagrangian-SPH combination provided the best results in terms of impact visualization and a good prediction of the deceleration of the projectile, compared to the test results.
2012	Reza Hedayati et al.[20]	They explained three different orientations (Impact from its Head, tail, bottom or wings) and its effect on the response of an airplane part. It was concluded that the Impact from Bird Bottom side is the most damaging scenario, while the tail side impact is the less dangerous one.
2013	Francesco et al.[21]	They studied the birdstrike phenomenon against several windshield geometries. They focused about the development of a numerical simulation on a complete aircraft windshield-surround model with an innovative configuration.
2014	Q.Sun et al[22]	They performed numerical predictions of structural behavior and damage caused by bird strikes in a large airplane leading edge

		structure at different locations. They showed that the failure of leading edge structure under bird strike can be effectively simulated.
2015	Bogdan-Alexandru[23]	They approached to simulate a model bird-strike using Lagtange mesh free method in Autodyn. SPH model has been used to simulate a 3D impact of the bird with the aircraft wing, at different angles, at a velocity of 262,22 m/s. Found the safe impact velocities for which the wing is not damaged.
2016	Aniello Riccio et al.[24]	They provided a brief overview of the numerical tecchniques adopted for the prediction of the bird impact phenomenon on a leading edge of a regional aircraft wing. SPH, Rigid & Langrangian models have been investigated and the results have been compared and critically assessed.
2017	Zdobyslaw et al.[25]	Reviewed the current research trends in bird strike and hail impact simulations on wing leading edge.They focused on wing LE, although all forward-facing aircraft components are exposed to the impact of foreign object during the Flight.
2018	S Orlando et al.[26]	They presented the design, analysis and the test of the CRFP flap to demonstrate its compliance with the regulation and safety standards toward the bird strike requirement. They defined a methodology based on the finite element analysis to predict the damage for high-velocity impact of a full-scale aircraft component using the SPH bird impact model, 4lb, at a velocity of 194 kts (100 m/s).

4. CONCLUSIONS

Nowadays, it is more and more possible to substitute the aircraft structure's certification tests by validated simulations of bird strike. The acceptance of certification just by simulation requires the demonstration of complete model validation with test data on similar structures.This evolution from simple to complex and accurate methods did not lead to the establishment of one generally accepted bird impactor modeling approach. Therefore, it can be difficult for the analyst to have an overview and to decide for an appropriate modeling method. The intention of the current paper is to give this overview on computational methods for bird strike simulation by an extensive and so far unique literature review on the topic of soft body bird impactor modeling.

Although a lot of in-house bird strike research work is conducted in aerospace companies and documented in internal reports, the focus of this literature review was on generally accessible papers and publications. More than 190 papers have been evaluated in a meticulous study, giving a considerable impression of the progress in bird strike modeling over the last 30 years. Though, a guarantee on completeness is by no means given. The focus is on the successive development of different numerical methods for the bird modeling.

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