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Bird strike on a flat plate: Experiments and numerical simulations

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ABSTRACT

In this study, experiments of bird impact with a flat plate are conducted at different striking velocities and simulated using an explicit finite element software PAM-CRASH with three bird material models. The predicted displacement and strain in the plate and impact reaction force on the clamping fixture are compared with experimental measurements. The results suggest that the elastic–plastic material model with a defined failure strain is best suited for bird strike simulation at low impact velocities, the isotropic elastic–plastic hydrodynamic solid model is best suited for bird strike simulation at intermediate impact velocities, and the SPH (smooth particle hydrodynamic) method with the Murnaghan EOS (equation of state) for solid element is best suited for bird strike simulation at high impact velocities. Using the appropriate bird material model, the simulation results agree very well with experimental data.

1. Introduction

Bird strike is a major threat to aircraft structures, as it can lead to serious structural damage and cause fatal accident. Therefore, the international certification regulations require all forward facing components to prove a certain level of bird strike resistance before they can be employed in an aircraft. Bird impact experiment provides a direct method to examine the bird strike resistance. However, design of the aircraft structures usually involves many iterations of design-manufacture-test and conducting bird impact experiments is not only time consuming but also costly. Furthermore, experimental data are often highly dispersed, which presents an obstacle for them to be directly used in structural design. Therefore, numerical methods were developed for bird strike simulation in order to reduce the number of intermediate tests and shorten the component design phase. Heimbs [1] provides an extensive review of the computational methods for bird strike simulations. Fig. 1 shows a flow chart of the process to design a bird-strike resistant component.

Many studies have been conducted in the past to develop constitutive models for bird to improve the numerical simulation results. Several authors tried to model the bird with a simple elastoplastic material law with a defined failure strain and some of them highlighted the limitations of this simplified approach [2–4]. Bai [5] discussed different elastic–plastic constitutive models and compared their numerical simulations with experiments. Wang et al. [6] developed an optimization/search method to identify the bird material constants for a given constitutive model. As an example, the parameters of the "plastic kinematic" model in LS-DYNA were determined using experimental data of a bird striking an aluminum panel. Zhang and Li [7] proposed a method to determine the material constants of a rate sensitive, strain hardening model based on a nonlinear least square and penalty function method. Their numerical simulation results using the calibrated model parameters show good agreement with experimental measurements.

Airoldi and Tagliapietra [8] presented a study of bird impact against a vertical stabilizer specimen made of carbon epoxy composite with a light alloy leading edge. In this study, the bird material is modeled with a nonlinear hydrostatic constitutive law governed by an equation of state (EOS) and coupled with an elastic–plastic deviatoric response. Johnson and Holzapfel [9] studied soft body impact on composite structures, where the Smooth Particle Hydrodynamic (SPH) method combined with a material law for hydrodynamic solid was used to model the flow and large deformations in the impactor. Since gelatine was used for the impactor material, the elastic–plastic contribution to the material behavior was neglected and the material model reduced to the EOS for pressure. Meguid et al. [10,11] showed the mechanical property of bird change from the low velocity to the high velocity regimes. At

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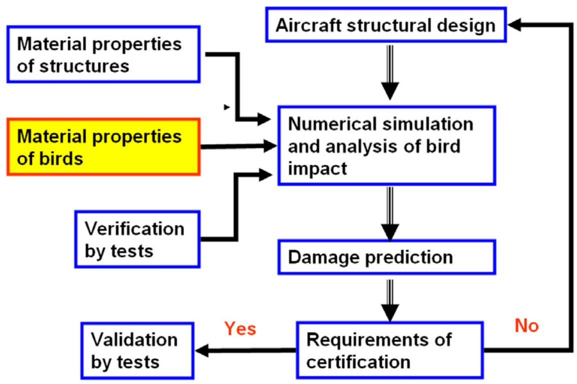


Fig. 1. Flow chart of the process to design a bird-strike resistant component.

low speeds it is neither uniform nor homogeneous but at progressively higher speeds the bird can be considered as a homogeneous jet of fluid impinging a structure. Jenq et al. [12] simulated a rigid plate hit by a hemi-spherical tip-ended cylindrical soft impactor, where the material properties of the soft impactor was modeled to be similar to the properties of a real bird and the shear strength of the bird was neglected based on the study by Wilbeck [13]. Three different formulation approaches, the Lagrangian (LAG), Eulerian (EUL) and the Arbitrary Lagrangian Eulerian (ALE) methods, were adopted in the numerical analyses and the coupled-field ALE method was found to result in better agreement with Wilbeck's test results. Hanssen et al. [14] conducted experimental and numerical studies on bird strike of aluminum foam-based sandwich panels. In their numerical model, a multi-material ALE element formulation was used to represent the motion of the bird and the bird was represented by an idealized geometry and the material model was defined by a linear equation-of-state. The bird material was identified for this model using the material properties specified by Langrand et al. [15]. Liu et al. [16] simulated bird strike of an arc windshield of an aircraft and found the bird behaved like a fluid and was torn to debris splashing to all directions when the impact velocity exceeds 250 km/h.

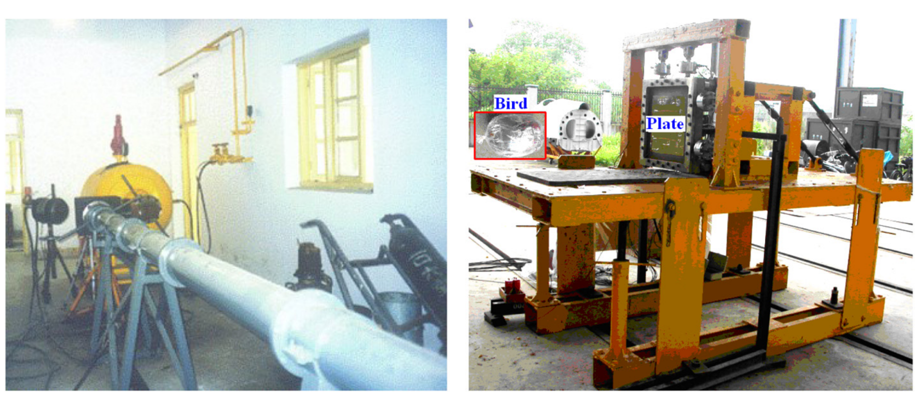
Although the certification of bird-strike resistant aircraft components still depends on real physical tests, proposals are increasingly put forward to use more simulation techniques instead of experiments in certain well-defined scenarios [1,17]. Goyal et al. [18] developed a model to simulate bird strike events under various conditions and to compare between the LS-DYNA simulations using the Lagrangian and the SPH methods. Georgiadis et al. [19] developed a simulation methodology to support the bird-strike certification of the carbon fiber epoxy composite, moveable trailing edge (MTE) of the Boeing 787 Dreamliner. In this work, the explicit finite element software PAM-CRASH was used to perform the simulations, where the SPH method was employed to model the bird and the EOS parameters were determined using the optimization tool PAM-OPT. The modeling procedures were validated firstly through comparison with existing test data and secondly through the testing and analysis of representative structures.

Although a large number of papers have been published on bird strike studies, there is a shortage of experimental data (especially data obtained using real bird) in open literature. The first part of this study is to conduct a series of bird strike experiments and to measure the dynamic responses of the plate and the clamping fixture. Because the actual bird material is composed of bone, blood, meat, etc. and thus is very complex, choosing a suitable constitutive model with properly identified model parameters is often the main problem in the numerical simulation of bird strike. The three commonly adopted bird constitutive models in numerical simulations are the elastic–plastic constitutive model with a defined failure strain, the isotropic elastic–plastic hydrodynamic solid model and the Murnaghan EOS for solid element. The objective of the second part study is, by comparing our numerical and experimental results, to provide a general guideline of what material model should be used under which impact scenario. In this study, experiments of bird impact with a flat plate are simulated using the three bird material models. The software package PAM-CRASH, which is widely used in research community as well as automotive, railway and aerospace industries for crash simulations, is employed in the numerical simulation. The material parameters are identified and the simulation results are compared with experimental data. The results show that the elastic–plastic material model with a defined failure strain is best suited for low impact velocity simulations, the isotropic elastic–plastic hydrodynamic solid model is best suited for intermediate impact velocity simulations, and the SPH method with Murnaghan EOS for solid element is best suited for high impact velocity simulations.

2. Bird strike experiments

2.1. Test method

Fig. 2 shows the experimental apparatus of bird impact with a flat plate. The plate is bolted to a clamping fixture, which is fixed by 8 force sensors to a heavy frame support attached to the ground. Regulatory authorities only define the mass of bird to be used,



(a) The gas gun (b) The target system

Fig. 2. Experimental rig of bird impact with a plate.