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A Brief Introduction to the Bird Strike Numerical Simulation

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Abstract: Bird impacts can be extremely critical events for the air transport safety. Since aircraft structures have become more and more complex components, the numerical prediction of the damage onset and evolution induced by a bird impact has become a very challenging task. The aim of this work is to provide a brief overview of the numerical techniques adopted for the prediction of the bird impact phenomenon on a leading edge of a regional aircraft wing. Smooth Particle Hydrodynamics (SPH), Rigid and Lagrangian models have been investigated and the results have been compared and critically assessed.

Keywords: Bird Strike, SPH, FEM Analysis

Introduction

Bird strikes on airplanes can be very dangerous events, which are becoming more and more common due to the increasing in air traffic (Georgiadis *et al*., 2008). According to certification requirements, aeronautical structures must be able to withstand bird strikes events, ensuring the global structural integrity and the passengers' safety. Due to the high relative velocity between the bird and the airplane, bird strike event can be surely classified as high velocity impact events, even if a true classification of the impact events on the base of their velocity and energy is a very challenging task (Riccio *et al*., 2016a; Caputo *et al*., 2013; Riccio *et al*., 2016b).

Several works can be found in literature dealing with bird strike events and showing the effects on the most critical structural components, which can experience this phenomenon: The windshield (Plassard *et al*., 2015; Lu *et al*., 2015; Ugrcic *et al*., 2015) and the leading edge (Sun *et al*., 2010; Guida *et al*., 2008; Smojver and Ivancevic, 2010; Wang and Yue, 2010; Hanssen *et al*., 2006; Airoldi and Cacchione, 2006; Johnson and Cook, 1983; 1985; Johnson and Cook, 1985; Liu *et al*., 2013a; Liu and Sun, 2014; Lavoie *et al*., 2007a; Liu *et al*., 2013b; Jain and Ramachandra, 2003; Guida *et al*., 2011).

In order to design structures able to tolerate bird strike, the knowledge about impact phenomena should be improved by means of experimental observations and numerical simulations. Since impact experimental tests, representative of bird strike events, can be very costly and time consuming, it becomes mandatory to develop numerical Finite Element Models able to predict the high velocity impact phenomena on the aircraft structure (Guida *et al*., 2008; Smojver and Ivančević, 2010; Wang and Yue, 2010). In the frame of the numerical simulations, several interacting aspects have to be considered, such as damage initiation and accumulation (Johnson and Cook, 1983; 1985; Xue and Wierzbicki, 2009; Liu *et al*., 2013a; Liu and Sun, 2014), contact behavior (Johnson and Cook, 1983; 1985) and bird modelling approaches (Lavoie *et al*., 2007a; Liu *et al*., 2013b; Jain and Ramachandra, 2003; Guida *et al*., 2011; Liu *et al*., 2008).

Bird strike on metallic leading edge is usually simulated by means of a progressive dynamic failure analysis adopting a Johnson-Cook (J-C) constitutive material model (Johnson and Cook, 1983; 1985). Alternative approaches taking into account the influence of both stress and strain rates on failure propagation are presented in (Sun *et al*., 2010; Xue and Wierzbicki, 2009; Liu *et al*., 2013a; Liu and Sun, 2014).

Indeed, bird material strength can be considered irrelevant if compared to the aircraft material one. Hence, bird can be considered as a soft body impacting, as a pressure flow, the impact area. The simulation with finite elements of the material deformation during soft body impacts can be characterized by excessive elements distortions when a Lagrangian (Guida *et al*., 2008; Smojver and Ivančević, 2010; Airoldi and Cacchione, 2006) formulation is adopted. These distortions induce excessive spurious deformation modes (hourglass) affecting the accuracy of results.

The aim of the present paper is to briefly introduce and compare the numerical approaches commonly adopted to simulate the high velocity impacts and to predict the bird impact effects on real aeronautical structure. Indeed, three different numerical approaches are investigated in the present paper: The first approach adopts rigid body elements (Hibbitt, 1984) to model the

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bird, the second approach adopts the Lagrangian theory (Lavoie-Perrier, 2008; Lavoie *et al*., 2007b) to take into account bird deformation during impact the last approach uses the Smooth Particle Hydrodynamic (SPH) formulation (Lavoie *et al*., 2007b; 2007c) to model the bird body. The SPH approach capability to bypass the Lagrangian approach limitations, in terms of elements distortions, has been assessed.

In section 2 the numerical model and the finite element implementation are briefly introduced while in section 3 the most relevant results are presented. Finally in section 4 the results are critically assessed.

Numerical Model and Finite Element Implementation

Wing FEM Model

The investigated aeronautical structure is an Aluminium 7075-T6 wing section of a regional aircraft. ABAQUS explicit Finite Element Code has been used for the numerical simulations. The FEM model of the wing section has been made of shell elements without considering material failure criteria. The wing section, whose dimensions are reported in Table 1, has been clamped on both external edges along y direction, according to Fig. 1.

The whole wing section model has been discretized using 51568 full integration point shell elements S4. The actual thickness of the wing section components has been taken into account by means of different offsets. Surface to surface tie constraints, available in ABAQUS, have been adopted to connect the differently meshed parts with a self-contact interactions law based on a penalty contact based algorithm; furthermore, an average 0.5 friction coefficient has been considered in sliding contact to account for the roughness of contacting surfaces. Figure 2 shows a fully description of the wing section components.

Bird Model

A 150 m/s velocity impact has been considered. It was found that the most appropriate substitute material for the bird during a high velocity impact event, is the gelatine with 10% porosity and 950 kg/m^3 density. While the better geometrical shape is a cylinder with hemispherical ends and a length to radius ratio equal to two, since this shape shows the real bird pressure time history during the impact tests as declared in (Ugrcic *et al*., 2015). The bird material density has been reduced to be 938 kg/m^3, as suggested in (Liu *et al*., 2008). Hence, the numerical model of the bird, characterised by the following dimensions, is shown in Fig. 3:

- Lb = 228 mm, bird structure length
- Φ = 114 mm, bird structure diameter

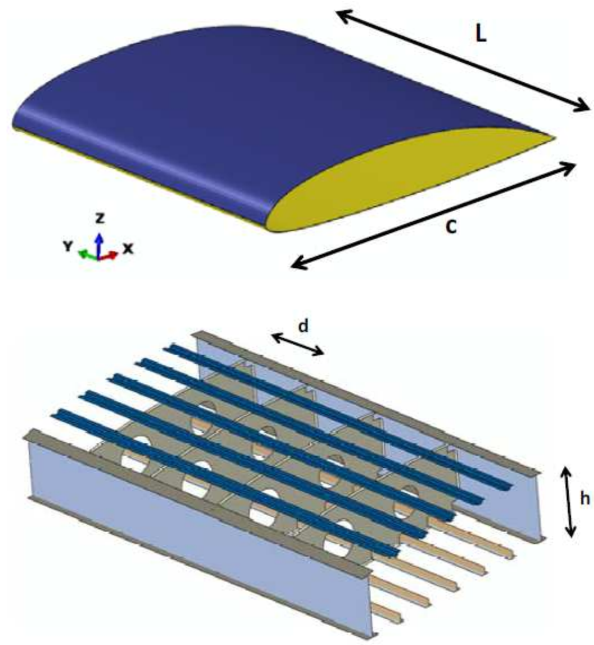

Fig. 1. Wing section structure

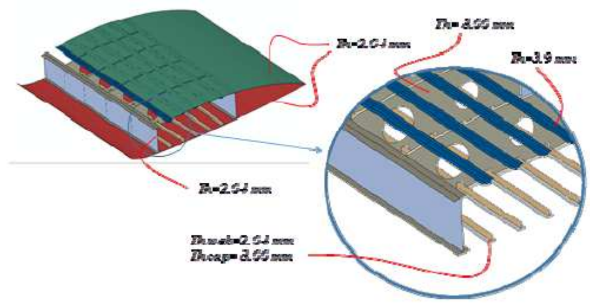

Fig. 2. Wing section thicknesses

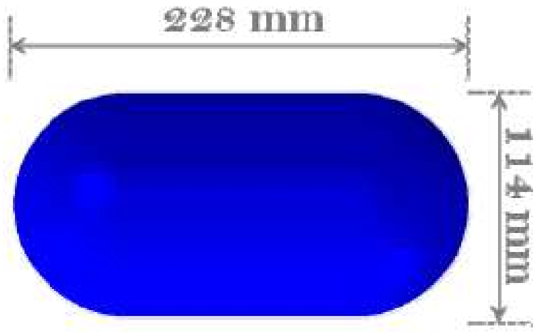

Fig. 3. Bird structure

Table 1. Section Wing dimensions

Section wing length (L)	2.71×10^3 mm
Airfoil profile chord (c)	3.10×10^3 mm
Wing ribs interaxle spacing (d)	5.92×10^2 mm
Wing rib height (h)	4.23×10^2 mm

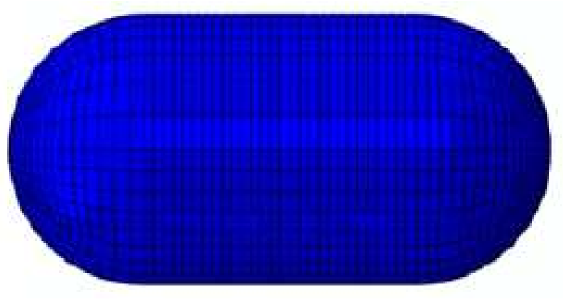

Fig. 4. Rigid and lagrangian model

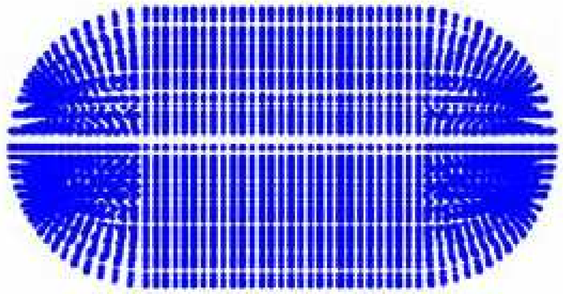

Fig. 5 SPH model

As already remarked, the bird has been modelled as an equivalent mass of water, since birds are made mostly of water and air in their bones and lungs (Georgiadis *et al*., 2008; Smojver and Ivančević, 2010; Lavoie *et al*., 2007b). The bird hydrodynamic response is studied using the Equation of State (EOS) materials which define the pressure to density ratio and the volumetric strength of the material. Relevant results for bird strike simulations can be found in (Johnson and Holzapfel, 2003) where the complex pressure field, arising in the impact region when a bird impacts a target, is introduced. The peak pressure value has the following theoretical value (Hugoniot pressure):

$$P_H = \rho_0 U_S \left(U_0\right) U_0 \tag{1}$$

where, ρ_0 is the initial material density, U_S and U_0 are, respectively, the shock and impact velocities (Johnson and Holzapfel, 2003). After the beginning of the impact event, the maximum pressure is followed by a pressure release phase and, finally, by the development of a stable and constant pressure flow given by the following relation:

$$P = \frac{1}{2}\rho_0 \left(U_0\right)^2 \tag{2}$$

The EOS material model validation relating the impact with a rigid plate showed a good agreement with the experimental Hugoniot, theoretical and stagnation pressure time history curves, as can be seen in (Smojver and Ivančević, 2010).

As anticipated in the introduction, the bird structure has been modelled according to three different approaches: Rigid body, Lagrangian and Smooth Particle Hydrodynamics (SPH). The rigid and the Lagrangian models (Fig. 4) are modelled using standard eight node solid brick elements (C3D8R) with reduced integration to reduce the computational costs. The Lagrangian bird model is defined by considering a distortion control and a viscous hourglass control in order to avoid excessive elements distortion. The model has been validated by comparing Hugoniot and stagnation pressures developing an impact on a rigid plate at a velocity of 116 m s^{-1}, normally to the target (Smojver and Ivančević, 2010).

According to the SPH method the bird is modelled as discrete elements considered as particles separated by a spatial distance called "smoothing length". The physical properties of the single particle are obtained by summing the all particles properties. The model is shown in Fig. 5.

Results

The results of the explicit analyses are reported in Fig. 6 where the magnitude of the impact induced displacements obtained with the different bird models introduced in the previous sections, are compared. The displacements of the leading edge obtained with rigid body bird model, the Lagrangian formulation bird model and the SPH based bird model are, respectively, reported in Fig. 6a-c. In the following section, these results are analyzed and discussed.

Discussion

According to the results shown in Fig. 6, the largest wing indentation (0.4233·103 mm) has been found considering the Rigid Body approach (Fig. 6a). On the other hand, as it can be observed in Fig. 6c, the SPH model provides the lowest wing indentation (0.1253·102 mm). According to Fig. 6-b, the Lagrangian approach, adopting a homogeneous material constitutive model, shows an intermediate wing indentation (0.3290·103 mm). Indeed, according to the SPH approach, the single particles can move without interactions leading to a larger impact surface if compared to the one evaluated with a Lagrangian or rigid model. This is the reason why the wing indentation predicted by the SPH approach is smaller. In terms of computational costs, the Lagrangian approach has been found to be the less effective one while the Rigid Bird Model has revealed to be the most effective one.

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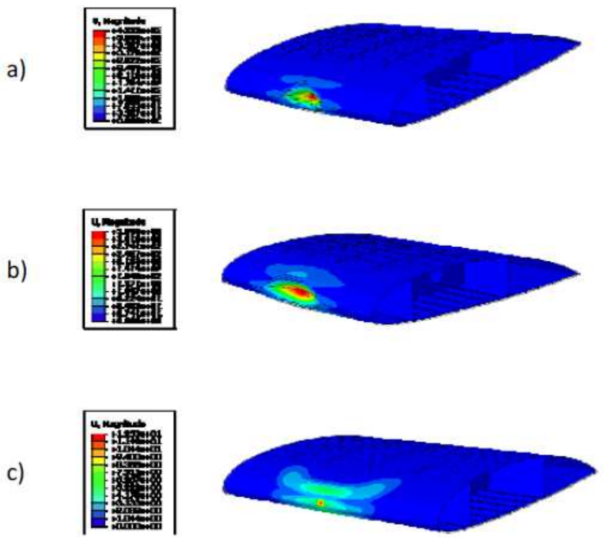

Fig. 3. (a) Rigid Body displacements; (b) Lagangian model displacements; (c) SPH model displacements

Conclusion

A numerical investigation on the bird impact phenomenon on a leading edge of a regional aircraft wing is presented in order to evaluate the bird impact effects on real aeronautical structures. Three different numerical approaches (Rigid Bird Model, Lagrangian Model and SPH Model) have been presented and compared. The results, as expected, showed a variable output in terms of wing indentation provided by the different approaches. The Lagrangian approach has been found to be the less computationally effective one, while the Rigid Bird Model has revealed to be the most computationally cheap one.

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Author's Contributions

All the authors contributed equally to prepare, develop and carry out this manuscript.

Ethics

This article is original. Authors declare that are not ethical issues that may arise after the publication of this manuscript.

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