

A Brief Introduction to the Bird Strike Numerical Simulation

Aniello Riccio, Roberta Cristiano and Salvatore Saputo

Department of Industrial and Informatics Engineering, Second University of Naples, Aversa (CE), Italy

Article history

Received: 17-10-2016

Revised: 29-10-2016

Accepted: 03-11-2016

Corresponding Author:

Aniello Riccio

Department of Industrial and

Informatics Engineering,

Second University of Naples,

Aversa (CE), Italy

Email: aniello.riccio@unina2.it

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; Ugric *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; Airoidi 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; Airoidi 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

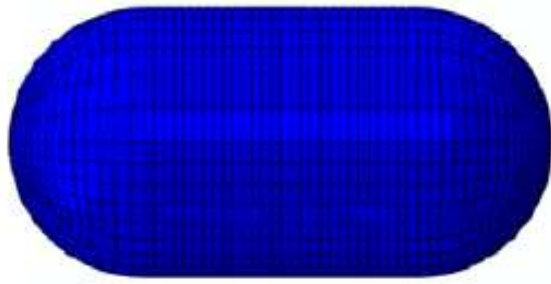


Fig. 4. Rigid and Lagrangian model

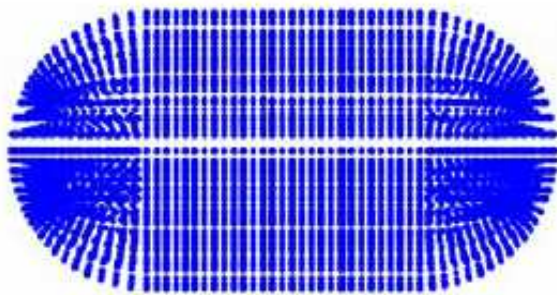


Fig. 5 SPH model

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):

$$P_H = \rho_0 U_s (U_0) U_0 \quad (1)$$

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:

$$P = \frac{1}{2} \rho_0 (U_0)^2 \quad (2)$$

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 ($0.4233 \cdot 103 \text{ mm}$) 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 ($0.1253 \cdot 102 \text{ mm}$). According to Fig. 6-b, the Lagrangian approach, adopting a homogeneous material constitutive model, shows an intermediate wing indentation ($0.3290 \cdot 103 \text{ mm}$). 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.

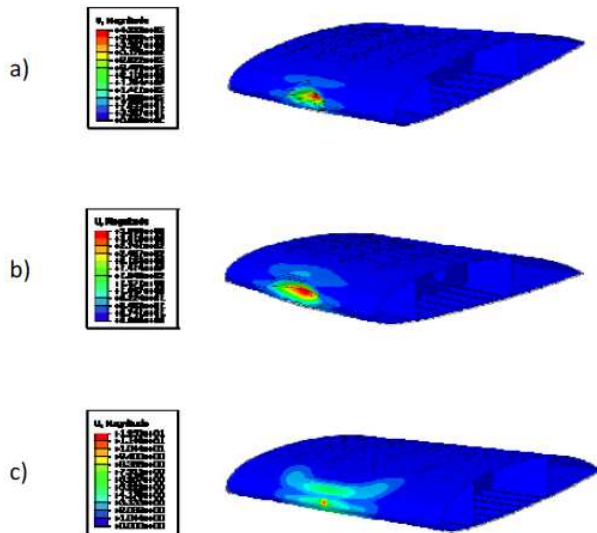


Fig. 3. (a) Rigid Body displacements; (b) Lagrangian model displacements; (c) SPH model displacements

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.

Funding Information

The authors have no support or funding to report.

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.

References

Airoidi, A. and B. Cacchione, 2006. Modelling of impact forces and pressures in Lagrangian bird strike analyses. *Int. J. Impact Eng.*, 32: 1651-1677. DOI: 10.1016/j.ijimpeng.2005.04.011

Caputo, F., G. Lamanna, A. De Luca, R. Borrelli and S. Franchitti, 2013. Global-local FE Simulation of a plate LVI test. *Struct. Durabil. Health Monitor.*, 9: 253-267.

Georgiadis, S., A.J. Gunnion, R.S. Thomson and B.K. Cartwright, 2008. Bird-strike simulation for certification of the Boeing 787 composite moveable trailing edge. *Compos. Struct.*, 86: 258-268. DOI: 10.1016/j.compstruct.2008.03.025

Guida, M., F. Marulo, M. Meo and M. Riccio, 2008. Analysis of bird impact on a composite tailplane leading edge. *Applied Compos. Mater.*, 15: 241-257. DOI: 10.1007/s10443-008-9070-6

Guida, M., F. Marulo, M. Meo, A. Grimaldi and G. Olivares, 2011. SPH – Lagrangian study of bird impact on leading edge wing. *Compos. Struct.*, 93: 1060-1071. DOI: 10.1016/j.compstruct.2010.10.001

Hanssen, A.G., Y. Girard, L. Olovsson, T. Berstad and M. Langseth, 2006. A numerical model for bird strike of aluminium foam-based sandwich panels. *Int. J. Impact Eng.*, 32: 1127-1144. DOI: 10.1016/j.ijimpeng.2004.09.004

Hibbitt, 1984. *Abaqus theory manual*. Hibbitt, Karsson and Sorensen.

Jain, R. and K. Ramachandra, 2003. Bird impact analysis of prestressed fan blades using explicit finite element code. *Proceedings of the International Gas Turbine Congress Tokyo, (TCT' 03)*.

Johnson, A.F. and M. Holzapfel, 2003. Modelling soft body impact on composite structures. *Compos. Struct.*, 61: 103-113. DOI: 10.1016/S0263-8223(03)00033-3

Johnson, G.R. and W.H. Cook, 1983. A constitutive model and data for metals subjected to large strains, high strain rates and high temperatures. *Proceedings of the 7th International Symposium on Ballistics, (ISB' 83)*, pp: 541-547.

Johnson, G.R. and W.H. Cook, 1985. Fracture characteristics of three metals subjected to various strains, strain rates, temperatures and pressures. *Eng. Fracture Mechan.*, 21: 31-48. DOI: 10.1016/0013-7944(85)90052-9

Lavoie, M.A., A. Gakwaya, M.N. Ensan and D.G. Zimcik, 2007a. Review of existing numerical methods and validation procedure available for bird strike modeling. *Proceedings of the International Conference on Computational and Experimental Engineering and Sciences, (EES' 07)*, pp: 111-118.

Lavoie, M.A., A. Gakwaya, M.N. Ensan and D.G. Zimcik, 2007b. Review of existing numerical methods and validation procedure available for bird strike modeling. *Proceedings of the International Conference on Computational and Experimental Engineering and Sciences, (EES' 07)*, pp: 111-118.

Lavoie, M.A., A. Gakwaya, M.N. Ensan and D.G. Zimcik, 2007c. Validation of available approaches for numerical bird strike modeling tools. *Int. Rev. Mech. Eng.*

- Lavoie-Perrier, M.A., 2008. Soft body impact modelling and development of a suitable meshless approach. Université Laval.
- Liu, J., Y.L. Li and F. Xu, 2008. The numerical simulation of a bird-impact on an aircraft windshield by using the SPH method. *Adv. Mater. Res.*, 33: 851-856. DOI: 10.4028/www.scientific.net/AMR.33-37.851
- Liu, Y., Z. Li, Q. Sun, X. Fan and W. Wang, 2013b. Separation dynamics of large-scale fairing section: A fluid–structure interaction study. *Proc. Institut. Mechan. Eng., Part G: J. Aerospace Eng.*, 227: 1767-1779. DOI: 10.1177/0954410012462317
- Liu, Y.J. and Q. Sun, 2014. A dynamic ductile fracture model on the effects of pressure, Lode angle and strain rate. *Mater. Sci. Eng. A*, 589: 262-270. DOI: 10.1016/j.msea.2013.09.082
- Liu, Y.J., Q. Sun, X.L. Fan and T. Suo, 2013a. A stress-invariant based multi-parameters ductile progressive fracture model. *Mater. Sci. Eng. A*, 576: 337-345. DOI: 10.1016/j.msea.2013.04.013
- Lu, Z., M. Seifert and C.H. Tho, 2015. Bird impact simulation of polycarbonate windshield subject to brittle failures. *Ann. Forum Proc. AHS Int.*, 2: 969-975.
- Plassard, F., P.L. Hereil, P. Joseph and J. Mespoulet, 2015. Experimental and numerical study of a bird strike against a windshield. *Proceedings of the 11th International Conference on the Mechanical and Physical Behaviour of Materials under Dynamic Loading, (MDL' 15)*, EDP Sciences, pp: 1-6. DOI: 10.1051/epjconf/20159401051
- Riccio, A., S. Saputo and A. Sellitto, 2016. A user defined material model for the simulation of impact induced damage in composite. *Key Eng. Mater.*, 713: 14-17. DOI: 10.4028/www.scientific.net/KEM.713.14
- Riccio, A., S. Saputo, A. Sellitto, A. Raimondo and R. Ricchiuto, 2016. Numerical investigation of a stiffened panel subjected to low velocity impacts. *Key Eng. Mater.*, 665: 277-280. DOI: 10.4028/www.scientific.net/KEM.665.277
- Smojver, I. and D. Ivančević, 2010. Numerical simulation of bird strike damage prediction in airplane flap structure. *Compos. Struct.*, 92: 2016-2026. DOI: 10.1016/j.compstruct.2009.12.006
- Sun, Q., Y.J. Liu and R.H. Jin, 2010. Numerical simulation of bird strike in aircraft leading edge structure using a new dynamic failure model. *Proceedings of the 29th Congress of International Council of the Aeronautical Sciences, (CAS' 14)*, pp: 1-19.
- Ugric, M., S.M. Maksimović, D.P. Stamenković, K.S. Maksimović and K. Nabil, 2015. Finite element modeling of wing bird strike. *FME Trans.*, 43: 76-81. DOI: 10.5937/fmet1501076u
- Wang, F.S. and Z.F. Yue, 2010. Numerical simulation of damage and failure in aircraft windshield structure against bird strike. *Mater. Design*, 31: 687-695. DOI: 10.1016/j.matdes.2009.08.029
- Xue, L. and T. Wierzbicki, 2009. Numerical simulation of fracture mode transition in ductile plates. *Int. J. Solids Struct.*, 46: 1423-1435. DOI: 10.1016/j.ijsolstr.2008.11.009