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BIRD MODELLING FOR SIMULATION OF BIRD STRIKES

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Abstract

As proved in the conducted analyses, one of the factors, which, to a large degree, exerts a negative influence on flight safety, is a potential possibility of a collision of an aircraft with birds, in particular at an airfield or in its vicinity [12, 16]. Various parts of an aircraft are subjected to damage. It appears that damage to the engine as well as penetration of the windshield is extremely dangerous. The consequence of a bird falling into the engine can be engine shutting down [6, 21], whereas penetrating the canopy can cause a serious injury to the pilot, making him unable to continue piloting an aircraft. The analysis of the literature of the object of study [7] shows that the most damage of the windshield occurs in the category of aircraft and small helicopters, whose certification requirements were not specified in this case [1, 19]. It should be remembered that apart from the compulsory experimental strength tests, conducted in laboratory conditions in order to meet certification requirements, there exist various theoretical methods, which are realized based on proper mathematical modelling of the strike event [5, 10]. Therefore, due to lack of certification requirements for the category of normal aeroplanes and small helicopters and a high degree of damage, especially to the cockpit canopy, it seems justified to conduct simulation of the strike impact by means of proper software. In order to perform the modelling in question, it is necessary to select a proper bird model and a suitable simulation method, including appropriate software. Based on the available literature devoted to the subject, there are several methods of modelling a bird shape. Investigations exploit various geometrical figures in order to model the bird shape, the most common one being a cylinder, an ellipsoid and a cylinder with hexagonal endings [10]. The aim of this article is to analyse the selected methods in order to choose one of them for further research connected with the simulation of bird-strike events into a cockpit windshield of selected aircraft.

Keywords: *bird-strike, simulation, numerical modelling*

1. Introduction

It appears that apart from practical tests and simulations, which have been conducted for many years and based on numerical methods, scientists have not managed to make a standardized bird model, which exactly reflects real-life bird features. The models used both for real tests and simulations predominantly refer to the mass and approximate density, leaving out geometry (shape) in the domain of the capabilities of simulation programmes, simulation method so that the shape reflects the real one, as closely as possible [7].

On the basis of the conducted analyses of the object of study, it was determined that the most frequent basic geometrical shapes are a cylinder, a cylinder with hexagonal endings, an ellipsoid and a sphere. Exploitation of such primitive geometry results from simplicity to manufacture the model. The cylinder was particularly favoured in the early phase of experimental research, conducted by Barber and Welbeck [4, 22], while a cylinder with hexagonal endings is currently a dominant approach in geometry, which includes, to some extent, the bird mass as mass with gelatine properties.

Moreover, research was done with more complicated models of bird geometry. One of them is the model of a Canadian goose, prepared on the basis of biometric data of the bird [17]. The neck, torso and wings were modelled from various density materials, by means of the SPH method in LS-DYNA software.

2. Numerical methods used in simulating bird strike events

Designing a computer model of an impact between an aerial vehicle and a bird is an extremely complicated task, embracing a number of numerical hindrances. The main problems in the creation of this type of model are as follows:
- determining the characteristics of the bird's body material,
- numerical instability caused by a high degree of deformation and the bird's body disintegration during a strike,
- including non-linear dynamics of both the material and the geometry of the impact loaded surface [5, 10].

The analyses and numerical simulations of the phenomenon at stake, currently conducted, bring very close findings to the ones obtained in real attempts. Numerous publications present computation models of a bird strike at the surfaces of an airframe, as well as sucking in birds into turbine engines. Modelling the tests enables to detect and improve construction imperfections at a relatively early stage. This type of activities leads to reductions in expenditure and time saving in case of diagnosing the above-mentioned imperfections in the phase of research.

There are several methods of modelling the bird shape for such analyses.

The FE model has been commonly known for over 20 years, ensuring accurate data from the moment the bird becomes subjected to huge deformations. The advantage of this method is a short time of making the computations and relatively low equipment requirements. This model, however, is not precise enough for an analysis of strikes during which there is excessive deformation of the bird's body, since quite often it is not possible to obtain proper completion of the simulation.

Eulerian and Arbitrary Lagrangian Eulerian (ALE) model, which in comparison with **the FE model** allows obtaining proper completion of the simulation, however, excessive stretching of the mesh causes doubts as for its correct solution. The disadvantages of this method are lack of clear boundaries, diffusion, very high demands of the computational equipment.

Nodal masses model (Nm) also called Discrete element Method (DeM) is a model composed of nodes corresponding to mass. The findings of applying this model are very near to data obtained in realistic tests. The main drawback of this model is lack of internal interaction among mass nodes of the mesh, which leads to the lack of dispersion mechanisms that in turn cause unrealistic behaviour of the bird's body during a simulation.

Smoothed Particle Hydrodynamics (SPH) is a method based on the Fe code, mainly used in analysing problems, which are characterised by huge deformations. The SPH is resistant to mesh deformations problems. The data obtained by means of this method, likewise the NM method, are very near to real results. The SPH method is to obtain proper behaviour of the bird's body during a simulation, which is comparable with the behaviour recorded by a fast camera during real tests [5, 10].

3. Characteristics of research findings of various geometrical bird shapes

The conducted research proves that among all the above-mentioned shapes, a cylinder with hexagonal endings best reflects the experimental test findings [16], taking into account the influence of the model on the impact wave, the flow and the distribution of pressures. Moreover, a mere cylinder with bevelled endings was compared in simulation tests of bird strikes at a windshield [25, 26]. Similar to other cases, better results were obtained in case of a cylinder with hexagonal endings [20].

In previous research [9, 13], while comparing an ellipsoid with a cylinder without bevelled endings, it appeared that the profile of pressure distribution in the event of impact loading and immediately afterwards, was shown in an unrealistic way. Besides, on the basis of simulation tests findings, which compared a cylinder, a cylinder with hexagonal endings and an ellipsoid (Fig. 1), it was observed that the highest impact wave pressure is in the regular cylinder due to the largest contact surface. It was 43% higher than in the case of a cylinder with hexagonal endings, which in turn is 30% higher than in the case of an ellipsoid [13, 15].

Fig. 1. Geometrical shapes of bird models

It also appeared that a different ratio of length to diameter of the bird model (1.5:1, 2:1, 2.5) exerts a minimal influence on the research findings. An increase in the bird mass from 4 to 6 and 8 lbs merely caused a rise in the maximum pressure value.

In the direct comparison with a hexagonally-ended cylinder, also modelled in SPH, significant differences in the curve were observed. A neck strike, in the first phase, caused material damage, before the major strike was exerted with the torso. Therefore, the authors concluded that this might exert a significant influence on the heightened level of damage of the tested material.

4. Features of materials applied in bird modelling

A significant problem in a simulation is to determine the properties of the material used for bird modelling. In this respect, similarly to a diversity of bird shape models, we adopted various approaches to material modelling. In general, real birds are predominantly composed of water. Therefore, a hydrodynamic approach may be treated as a proper one in approximating the bird model for the analyses in question [10]. In addition, except for water the anatomical structure of birds contains air bubbles present in bones and lungs, which diminishes mean bird density. In order to account for their impact upon the right model, the bird as a whole is homogenized; the mean density is on average accepted as between 900 and 950 kg/m^3 [10, 15]. This corresponds to the amount of porosity of 10-15% gelatine in an artificial bird, which is usually used for bird strike tests [16]. However, in simulation tests, it was proved that accepting porosity at the level of 30-40 % brings better results rather than the 10-15 % as in Welbeck's experimental research. The results were obtained on the basis of simulating a bird strike by means of the SPH method into an ideally rigid plate, where the porous material was changed within the range of 0% to 40%.

Some authors tried to model the bird from elastoplastic materials [27], while others stressed limitations of the simplified approach [23]. It is observed that no fluid-like flow response can be achieved with such an elastoplastic material law, only if the shear modulus G is set very low. Another material used, similar to rubber, is hyper-elastic Mooney-Rivlin. It appeared that determining the type of material has become key for the needs of simulation [9].

It is much more common to use the equation of state (EOS) to model bird strikes, defining by pressure the relation of the values of water parameters in room temperature. The majority of EOS employs the polynomial form [13]:

$$p = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3, \tag{1}$$

where: C_0, C_1, C_2 and C_3 are constants connected with the material, and μ is a dimensionless coefficient, based on the ratio of present density ρ towards the initial density ρ_0, $\mu = \rho/\rho_0$.

On the other hand, in other studies [18] EOS was expressed with the formula:

$$p = p_0 + B\left[\left(\frac{\rho}{\rho_0}\right) - 1\right], \tag{2}$$

where p_0 is reference pressure and B is material constant,

$$p = \frac{\rho_0 C^2 \mu \left[1 + \left(1 - \frac{\gamma_0}{2}\right)\mu - \frac{\alpha}{2}\mu^2\right]}{\left[1 - (s_1 - 1)\mu - s_2 \frac{\mu^2}{\mu + 1} - s_3 \frac{\mu^3}{(\mu + 1)^2}\right]^2} + (\gamma_0 + \alpha\mu)E, \quad (3)$$

where E denotes internal energy, γ_0 is Grüneisen parametre, C is bulk speed of sound, α is the first order volume correction to γ_0, and s_1, s_2, s_3 are constants.

It should be noted that the above equation is appropriate for materials in a solid state, which remain in this state also after a strike; therefore, it must be remembered in simulating bird strikes at aircraft constructions. Applying suitable EOS largely depends upon the used software, which usually does not leave too much choice as regards EOS.

All EOS have certain constants, which are constant and which may be pre-defined, however they cannot be measured directly.

A standard technique is using analytically simplified approximations or exploiting parameters, obtained experimentally. In order to obtain data for simulation, i.e. identify the necessary parameters, we conducted investigation, described in the works. [2, 18].

5. Bird model

In the light of the above, we conducted research by means of even more complex and realistic model of bird geometry by means of the SPH method, in LS-DYNA, where the bird's head, neck, torso, bones, lungs and wings possessed different densities and different equations of state [16]. For the sake of the research, we used a standard model whose shape was a cylinder with hexagonal endings with the following parameters:

- standard volume $-3.958 \cdot 10^6$ mm^3,
- length -334 mm,
- aspect ratio -1.6,
- ALE 3144 cells.

In both cases, the „null material model" was used, combined with the Grüneisen equation of state. Cylinder data: $\rho = 9.2 \cdot 10^2$ kg/m^3, $\mu = 4 \cdot 10^{-4}$. Data of the bird model:

- total: $\rho = 9.2 \cdot 10^2$ kg/m^3,
- neck: $\rho = 1.5 \cdot 10^3$ kg/m^3,
- torso $\rho = 1.15 \cdot 10^3$ kg/m^3,
- wings $\rho = 8.45 \cdot 10^2$ kg/m^3.

We used biometric data of a Canadian goose (Fig. 2) for the building of the model [10, 17], where it was evident that the torso constitutes 70% of the total bird mass. For the sake of the equation of state, we adopted $C = 1.4829 \cdot 10^3$ m/s, $s_1 = 2.0367$.

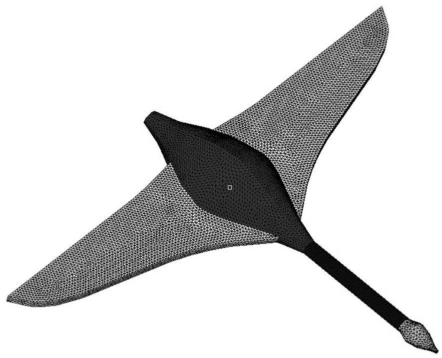

Fig. 2. Model of a Canadian goose, adopted for simulation purposes [17]

The conducted simulations, which used the ordinary model and the bird-shaped model (torso and neck plus head); indicate that the changes in total energy of the impact event are similar in both cases. The total energy remains constant, whereas the potential energy is on the increase, and the kinetic energy is on the decrease. The fundamental difference in the results of both simulations is the time needed to change the kinetic energy into the potential one. The bird-shaped model does not exert significant changes in energy transformation to the time equalling 1.75 ms, followed by the main strike by the bird torso into the examined object. This happens due to a low mass of the head and the neck of the bird, which impact loaded in the time under 1.75 ms.

As regards the value of stagnation pressure in the event of an impact, it is possible to observe its growth at the time of head impact loading up to 150 MPa, and it remains unaltered by the moment of torso striking. The torso strike occurs after a time of 1.75 ms, leading to an increase of pressure up to the value of 250 MPa, and then it disappears, pointing to the end of the strike (Fig. 3).

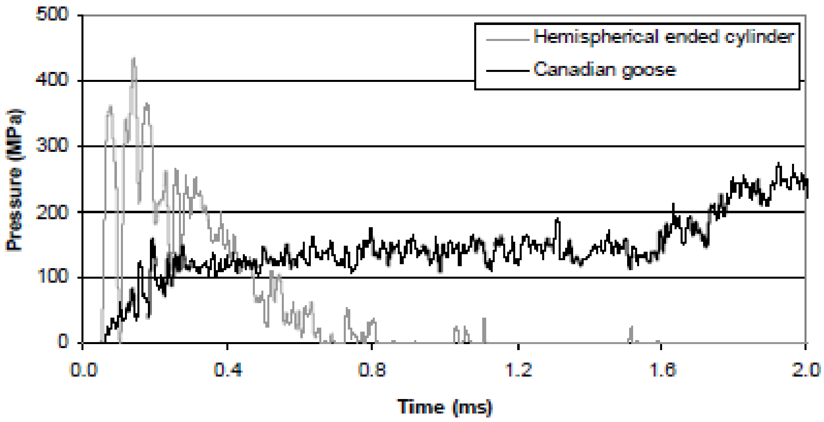

Fig. 3. Stagnation pressure (centre of panel target) predicted for the impact of a multi-material bird model, compared to a hemi-spherical ended cylinder [17]

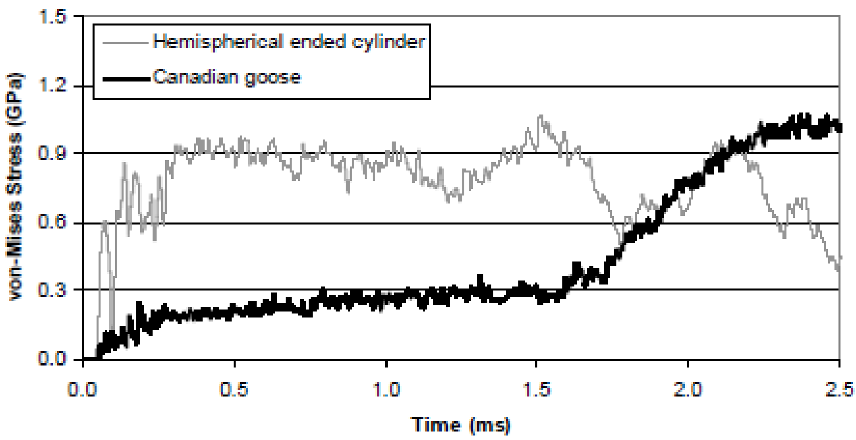

Fig. 4. Equivalent von-Mises stress (centre of panel target) predicted for the impact of a multi-material model, compared to the hemi-spherical ended cylinder [17]

In comparison with the simulation based on the bird model, cylinder-shaped, the stagnation pressure reaches a lower value, yet in a longer time. The strike, first with the head and neck and then with the torso, has got an influence on a diminished pressure value, which later grows up to 1 GPa, and then after reaching this value, disappears. Moreover, in Fig. 4, it is possible to trace particular values of maximum pressure, corresponding to the head strike, torso strike, and the like, which significantly differs from the diagram where the bird model of one density has been adopted.

As it is seen in Fig. 5 in case of a strike by a bird-shaped model, initially there is a smaller material deformation, compared to the strike of a cylinder with hexagonal endings, however, after the torso strike the deformation is considerably growing.

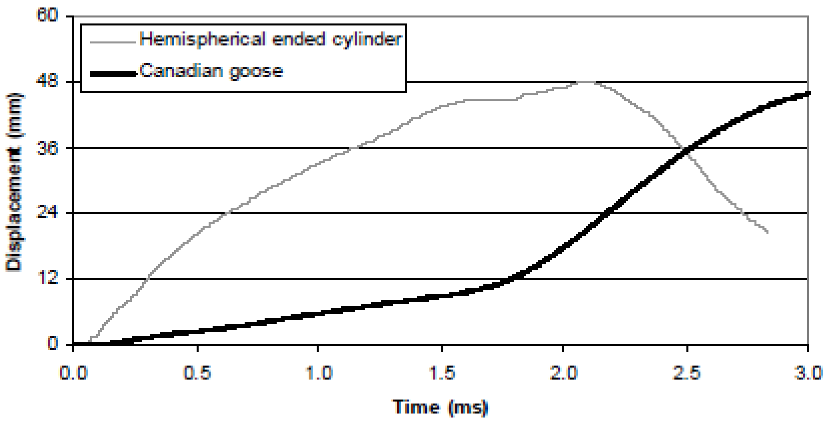

Fig. 5. Resultant displacement (centre of panel target) predicted for the impact of a multi-material model, compared to the hemi-spherical ended cylinder [17]

Moreover, the deformation reaches the value of 45 mm in the time of 3 ms, while in the case of a cylinder, this time is shorter and equals 2 ms. It is worthwhile observing that the deformation after the impact involves only the head plus neck and equals 10 mm. This fact means that total deformation in the event of a real bird strike event where an aircraft is involved, will be higher. Thus, the test, which relies on a cylinder model, hexagonally ended, may lower the simulation findings, compared to a real impact. It must be emphasized that there is a shortage of other similar investigations, whose findings might serve as comparison with the presented ones. Therefore, it is necessary to continue this type of simulations. The question remains whether chickens used in certification tests are sufficiently representative for the bulk of real strike events, where the impact on the aerial vehicle construction first involves the head, and subsequently the torso and the wings [24].

6. Discussion and further research

In conclusion to the conducted analysis of bird modelling in the simulation of impact events with aircraft, it is necessary to stress that the problem at stake is still open and in need of continued research. According to the available material by S. Himbs [10], the applied simulation methods as well as the adopted bird model have their limitations, which are caused by the imperfections of both the adopted method and the bird model itself. Despite this fact, scientific investigations are extremely costly, not devoid of faults; however, they are still obligatory in order to obtain certification of an aerial vehicle. Therefore, conducting research, improving methods which simulate impact events and bird modelling seem to be justified and useful, taking into consideration development of science itself and practical exploitation of scientific advances, in this case in order to improve flight safety.

As seen in the literature survey of the object of study, the best results, which come very close to the experimental ones, are obtained by means of the SPH or ALE method. It appears that a weaker link in this research is a bird model, both as for its shape, size and properties of the used material, which could reflect the reality. Moreover, it must be mentioned that strikes involve an arrange of various bird species, living in our country.

Undoubtedly, in the environmental conditions in Poland, a white stork possesses similar physical properties to a Canadian goose, discussed in this paper. Taking into account a white stork habitat and the activity area particularly of military aviation, we can trace certain parallels [6].

There is also an increased impact probability, involving damage to an aircraft. Because no simulation research involving a stork model has ever been conducted, the author intends to conduct this type of research.

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