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NUMERICAL ANALYSIS OF BIRD STRIKE EVENTS WITH THE HELICOPTER WINDSHIELD

Janusz Ćwiklak, Norbert Grzesik

Polish Air Force Academy, Aviation Faculty
Dywizjonu 303 Street 35, 08-521 Deblin, Poland
tel.: +48 815517423, fax: +48 815517417
e-mail: j.cwiklak@wsosp.pl, n.grzesik@wsosp.pl

Abstract

The aim of this article is to describe simulation results of a bird strike with a helicopter windshield. The simulation was performed based on LS-DYNA software by means of the SPH and Lagrangian methods. For the sake of the analysis, we selected a light helicopter, which is not covered by any certification requirements with regard to the windshield. The simulations were conducted for various bird shapes (sphere, cylinder, cylinder with hemispherical endings) for the cruising speed of V_c = 285 km/h. As a result of the simulations, we achieved comparative analyses of the methods at stake in the aspect of time curves of the kinetic energy, velocity and windshield deformation. The findings are depicted graphically and are presented in the form of charts. The deformations that were obtained as a result of the conducted tests may be referred to the data included in the AAIB report, which described the case of damaging the Agusta A-109C helicopter due to a collision with a seagull at the speed of approximately 278 km/h. The deformations obtained through numerical simulation do not make an accurate representation of this type of damage as in the case of a real one. Nevertheless, they reveal its character. While examining the test simulations from the quantity viewpoint, it is possible to observe slight discrepancies related to the applied approaches of bird modelling. In case of the kinetic energy, the slight discrepancies in the initial moment stem from rounding the mass of a single particle of the model, by means of the SPH method. The velocity curves of the accepted centre of the bird model vary considerably, depending upon its shape, which is linked with the deformation manner of the particular models.

Keywords: *air transport, bird strikes, numerical analyses*

1. Introduction

As proved by the test findings, one of the factors, which significantly exerts a negative influence on flight safety, is a potential risk of birds affecting an aircraft, particularly at the airport and in its vicinity [4, 10]. Various components of the aircraft are exposed to damage. It becomes apparent that the engine damage and piercing of the windshield are extremely hazardous events. The consequence of birds' sucking may be engine shutdown [4, 14]. Besides, breaking the cockpit glass is likely to cause serious injuries of the pilot, which will prevent him from continuing the flight. One should note that apart from the obligatory, experimental strength tests, which are conducted in laboratory conditions in order to satisfy certification requirements, there are a number of theoretical methods performed based on proper numerical modelling of the event [1, 5, 15-17]. As it was already mentioned, both the experimental tests as well as numerical simulations do not refer to the category of light helicopters. In addition, study of the literature often points to windscreen damage including piercing of the helicopter glass and falling of the bird into the cockpit. Therefore, it seems justified to conduct numerical simulations of bird strike events and assess their consequences for this category of helicopters. Similarly, to other research of this kind, for the sake of the analysis we adopted classic Lagrangian-based modelling and the SPH approach [5]. Judging by the available literature of the object of study, there exist several modelling methods of the bird shape. They include various geometries, the most established ones being a sphere, a cylinder and a cylinder with hemispherical ends [5, 13].

2. Research Methodology

Bird strike, i.e. a collision of a flying object, such as a plane or a helicopter, or its components with a bird may be numerically modelled by means of the following methods:
- classic approach, where the bird is modelled according to the Lagrangian method,
- ALE coupling (Arbitrary Lagrangian Eulerian),
- SPH method (Smoothed Particle Hydrodynamics).

In the literature, it is possible to find a number of studies whose authors compare the results obtained through computational methods, including [3-6]. Due to the fact that we deal with severe impactor deformations (bird deformations) after the impact, the most optimal approach seems to be the one, which exploits the SPH method. For comparison, we also conduct simulations by means of the traditional Lagrangian method, which uses 8-node solid elements to model the bird. On the basis of the tests whose results are documented e.g. in [6], it is possible to state that the most useful artificial material for the bird's body is gelatine with density equalling 950 kg/m^3 and 10% porosity. Other considered materials include beef, RTV rubber (*Room Temperature Vulcanized Rubber*) and neoprene (synthetic rubber) [6]. The densities of the bird material declared by the authors of other studies [8, 9, 11, 15] also oscillate around the value of 950 kg/m^3.

Literature study offers various material bird models, used in FEM numerical analyses, starting with the simplest elasto-plastic model with kinematic strengthening [15] to more complex methods, which include equations of state (EOS), for instance in a tabulated form (*EOS_ TABULATED) [8], in a polynomial form (EOS_LINEAR_POLYNOMIAL) [10] and other. The most frequently used equation of state for this type of models is Grüneisen equation.

2.1. Bird model

Within this paper, we modelled a bird, 1.8 kg in mass (4 lbs) in three shapes (Fig. 1):
- spherical (D = 153.53 mm),
- cylindrical (D = 106.45 mm; L = 2D = 212.90 mm; maintaining the cylinder's length to its diameter ratio as 2:1 [1, 5, 7, 10]),
- cylindrical with hemispherical ends (D = 113.12 mm; L = 2D = 226.24 mm; aspect ratio as above).

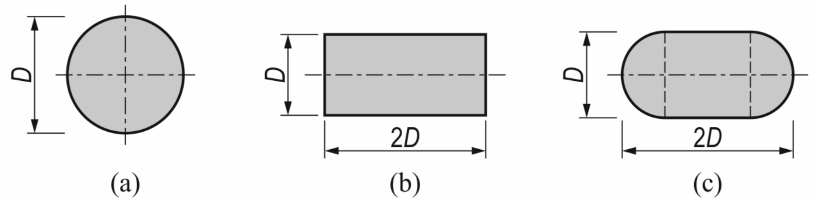

Fig. 1. Shapes and sizes of dummy bird: spherical (a), cylindrical (b) and cylindrical with hemispherical ends (c)

The measurements of the above objects have been determined based on the adopted bird mass and material density. We constructed two numerical models for each shape – one for the SPH method and the other for the Lagrange-based method.

The solid element models were built in the LS-PrePost pre-processor, by means of mesh generators for simple solids such as the sphere or the cylinder. The dummy bird models had their initial velocity set in the option *INITIAL_VELOCITY. The velocity vectors were applied to all model particles (SPH) as well as all the nodes of the model elements (Lagrange), collecting the above-mentioned components into the so-called sets (*SET). The analyses adopted the pattern of units which corresponds to the International System of Units, i.e. length – [m], force – [N], time – [s], tension/pressure – [Pa].

The model exploited the so-called "null" material model (*MAT_NULL), where we declared

Grüneisen equation of state (*EOS_GRUNEISEN). This equation defines pressure for compressed material in the form [6]:

$$p = \rho_0 C^2 \mu \left\{ \frac{\left[1 + \left(1 - \frac{\gamma_0}{2}\right)\mu - \frac{a}{2}\mu^2\right]}{\left[1 - (S_1 - 1)\mu - S_2 \frac{\mu^2}{\mu + 1} - S_3 \frac{\mu^3}{(\mu + 1)^2}\right]^2} \right\} + (\gamma_0 + a\mu)E\,, \tag{1}$$

whereas for the expanded material as:

$$p = \rho_0 C^2 \mu + (\gamma_0 + a\mu)E, \tag{2}$$

where:
C – bulk speed of sound,
γ_0 – Grüneisen gamma,
S_1 – linear coefficient,
S_2 – quadratic coefficient,
S_3 – cubic coefficient,
a – first order volume correction to γ_0,
μ – volume parameter, expressed as $\mu = (\rho/\rho_0) - 1$,
ρ – density,
ρ_0 – initial density,
E – internal energy per unit of mass.

The material data for the dummy bird model have been listed in Tab. 1.

Tab. 1. Material data used for bird model [18]

*MAT_NULL			*EOS_GRUNEISEN	
density	cut-off pressure	viscosity coefficient	bulk speed of sound	linear coefficient
RO [kg/m^3]	PC [Pa]	MU [Pa·s]	C [m/s]	S1 [–]
950	-10^6	0.001	1.647	2.48

In the model for the SPH analysis, we declared default properties attributed to the particles (*SECTION_SPH). The constant (CSLH) is equal to (1.3), while the scale coefficient for the smoothing length equals HMIN = 0.5 and HMAX = 2 [15].

2.2. Windshield model

Within the conducted analyses, the impact loaded object was a helicopter windshield. We selected the windshield of Agusta A-109, manufactured by the concern of Agusta Westland. The main criterion adopted at its selection was availability of the geometrical model CAD, downloaded from GrabCAD free cross-platform source [13] as well as the accessibility of the strength parameters of the material, from which the windshield was produced.

We selected two elements, type 2 (default) – shell elements Belytschko-Tsay with five degrees of freedom in each node. The shell elements had the Agusta A-109 glass thickness declared, i.e. 3.81 mm [12]. We used a solid element generator LS-PrePost, which formed a solid element mesh by adding thickness to the existing shell elements.

The Agusta A-109 windshield is manufactured from acrylic glass [14]. The material parameters of this type of glass, mentioned in paper [15], have been listed in Tab. 2. We used the elasto-perfectly-plastic model (*MAT_PLASTIC_KINEMATIC), with the modulus of reinforcement equalling 0.

Tab. 2. Material data used for bird model [15]

*MAT_PLASTIC_KINEMTIC				
density	Young's modulus	Poisson's ratio	yield stress	failure strain
RO [kg/m^3]	E [Pa]	PR [–]	SIGY [Pa]	FS [–]
1,190	$3.13 \cdot 10^9$	0.426	$6.8 \cdot 10^7$	0.067

2.3. Parameters of the numerical analysis

The conducted numerical analysis exploited the computational code LS-DYNA v.970, in particular the contact model *CONSTACT_AUTOMATIC_NODES_TO_SURFACE [7]. The function of the master segment was taken by the windshield, whereas the slave segment was the dummy bird. The analyses took into consideration friction coefficient between the contact objects, which equalled 0.1 [2]. We adopted the default or recommended values for the majority of the required parameters [3].

The velocity of the object affecting the windshield was determined based on the helicopter cruise speed, which was equal to 285 km/h (79.167 m/s) [20]. This is the speed of the dummy bird striking a fixed windshield. The analysis time was adopted as 10 ms.

In the course of the analysis, we registered the bird's kinetic energy, the resultant of velocity of the point which overlapped the centre of the bird's mass (for the SPH method – the value averaged from eight values in the vicinity of the mass centre; in the Langrange-based method – the value of the central node of the dummy bird) as well as total displacement of the theoretical piercing point on the windshield.

3. Results and discussion

The findings cover deformation of the pattern in selected time steps and total displacement contours of the windshield model as well as reduced stress contours according to Huber–Mises–Hencky hypothesis. Due to the limited size of this article, the graphically represented results are shown only in the final time step, i.e. 10 ms, which indicates the final result of the deformation.

While observing windshield deformations, it is possible to notice that practically in every variant of the bird modelling, the windshield becomes damaged in a similar manner (Fig. 2). The deformations obtained for the windshield made up of shell elements are similar and do not depend upon the shape and the bird modelling method. The same situation occurs in the case of the windshield modelled by means of solid elements. For each of the six variants, we obtained similar deformations. The differences appear when we begin to examine the findings for various methods of windshield modelling, i.e. 2D and 3D. It is particularly striking in case of reduced stress contours, which are very chaotic in the shell elements windshield, and their distribution and differentiation in values do not allow making a definite interpretation. The windshield, which is constructed with shell elements, allows obtaining satisfying results only in case of deformations and displacements. The stress contours for the 3D windshield model point to more harmonious distribution. This is connected with the type of used finite elements and their characteristics. Moreover, the erosion of elements in both variants of the windshield model is of different character. In the solid model, the windshield elements in the place of joining to the helicopter frame are not subjected to erosion, which takes place in the shell element model.

Figures 3-5 show time curves for the selected values, i.e. kinetic energy of the dummy bird model, velocity of its assumed mass centre and total displacement of the "theoretical" piercing point on the windshield. For comparison, the results have been listed in the following configurations: SPH/classic Lagrangian approach, different bird model variants and the shell/solid numerical model of the windshield.

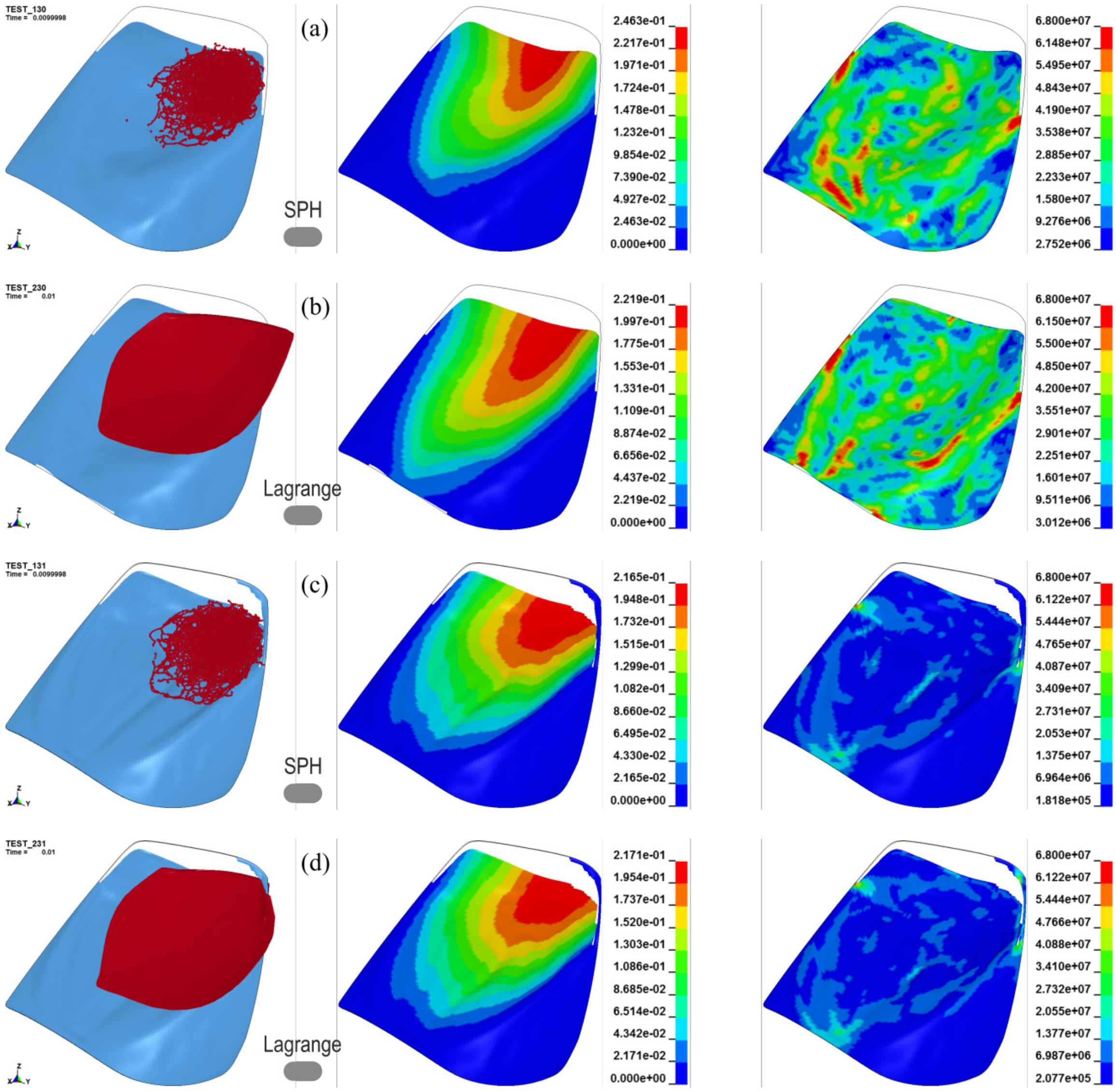

Fig. 2. Deformations of 2D and 3D solid elements of the windshield caused by a bird model strike for the last time step. In the middle column, there are total displacement contours [m]; in the right column, there are reduced stress contours [Pa]

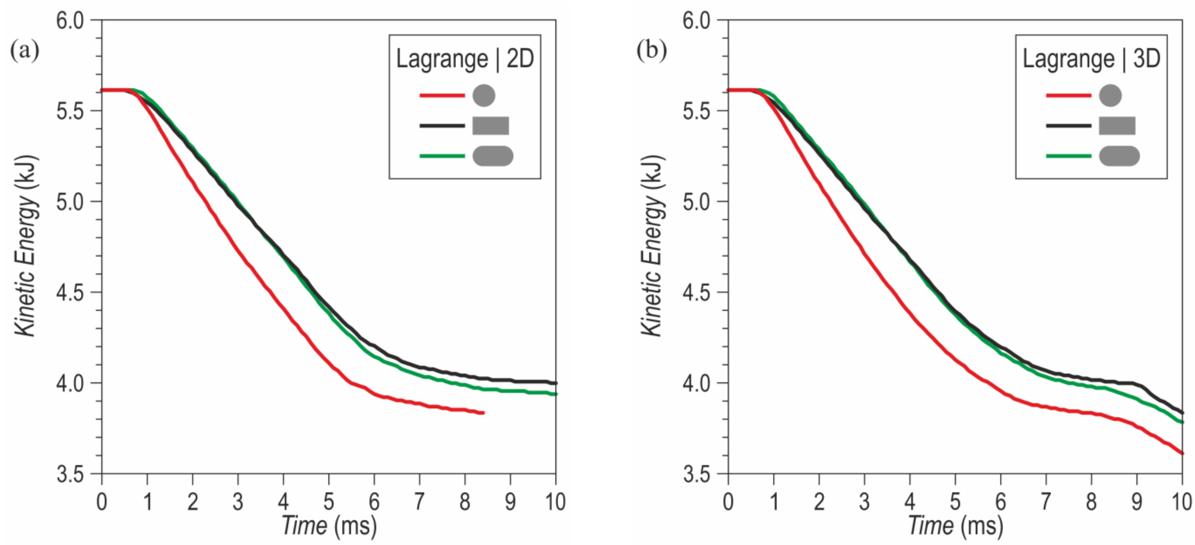

Fig. 3. Listing of time curves of the kinetic energy of the dummy bird, in relation to its shape and modelling manner

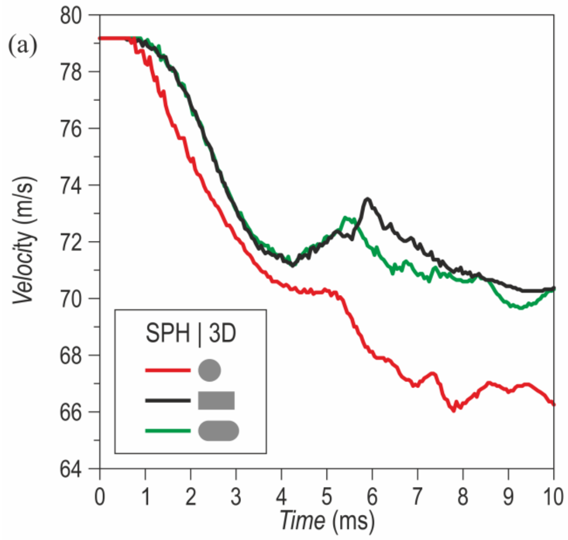

Fig. 4. Listing of time curves of the accepted velocity of the dummy bird centre, in relation to its shape and modelling manner (SPH / Lagrange approach)

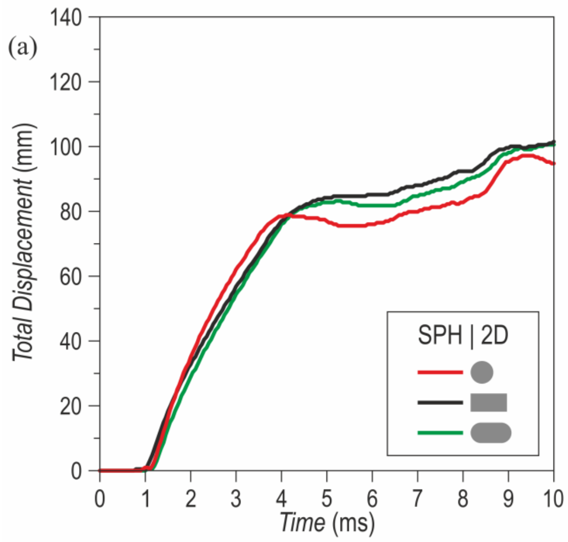

Fig. 5. Listing of time curves of the total displacement of the "theoretical" piercing point on the windshield, in relation to its shape and modelling method (SPH / Lagrange approach)

While examining the test simulations from the quantity viewpoint, it is possible to observe slight discrepancies related to the applied approaches of bird modelling. In case of the kinetic energy, the slight discrepancies in the initial moment stem from rounding the mass of a single particle of the model, by means of the SPH method. In the classic approach which uses the solid bird model, its mass results from material density and solid volume, which in its shape corresponds, more precisely, to the assumed shape of the dummy bird models. Thus, the initial kinetic energy is the same for all three-bird models. The type of finite elements, which were used in the windshield modelling, practically exerts no influence upon the value of the kinetic energy, although in the last two 2 ms of the analysis there appear certain discrepancies in the obtained curves.

The velocity curves of the accepted centre of the bird model vary considerably, depending upon its shape, which is linked with the deformation manner of the particular models. In case of the spherical model, its total velocity is practically on the decrease all the time, while in the rest of the variants it falls up to a certain moment and then remains on a stable level or slightly grows.

In the case of total displacement of the "theoretical" piercing point on the windshield, it is possible to draw a general conclusion that it achieves a mean value of approximately 80 mm. This value sustains throughout the remaining part of the analysis, which may indicate permanent damage of the windshield. The results obtained for the solid windshield model are demonstrated with lower divergence.

In all the conducted simulations, the windshield was damaged - it became cracked in its top part, where it was fixed to the helicopter frame. Besides, in one of the analyses it was possible to observe the element erosion in the bottom part of the windshield. It is highly probable that "the bird" after striking and windshield damage will fall inside the aircraft.

The deformations which were obtained as a result of the conducted tests may be referred to the data included in the AAIB report (Air Accidents Investigation Branch), which described the case of damaging the Agusta A-109C helicopter due to a collision with a seagull (Herring Gull) at the speed of 150 knots (approximately 278 km/h) [12]. The deformations obtained through numerical simulation do not make an accurate representation of this type of damage as in the case of a real one. Nevertheless, they reveal its character.

In the FEM analysis, the windshield damage was initiated where the glass was fixed with the windshield frame, in its upper part, likewise the case mentioned in the report [12]. More careful examination of the flight trajectory of particular particles in the numerical bird model allows to draw a conclusion that after the bird's collision with the windshield and initiating its damage, the bird model continued to move alongside the windshield and fell inside the helicopter, as it was confirmed by the AAIM report, where the bird model was found inside the helicopter.

4. Conclusion

The test analyses were aimed at determining a model for further simulations, therefore they should be considered from the standpoint of quality agreement of the results. While observing windshield deformations of the selected time steps, it can be seen that practically in each variant of the bird modelling and the windshield model, the resultant damage is of similar character. In the solid windshield model, its elements do not undergo erosion in the fitting places with the helicopter frame, as it is the case of the shell model. For the sake of visual representation, the 3D windshield simulation variant is recommended, Moreover, stress contours in the 3D windshield model demonstrate more "stable" distribution, in contrast to the rather chaotic layout of fields in the shell model. It is connected with the type of used finite elements and their characteristics. It seems justified to use the windshield, which is modelled by means of solid elements.

As for the methodology of modelling, the SPH approach leads to a more congruent model of the deforming bird. In reality, the bird, which strikes a much more rigid object, is a rather monolithic/congruent structure for a certain period, and does not become flat. The advantage of using the SPH method is the fact that all the conducted simulations ended appropriately. However, in the case of modelling the dummy bird in the classic approach, one of the analyses was terminated prematurely due to lack of congruence. As far as the very bird model is concerned, further simulations are conducted for the cylindrical model with spherical ends, as it reflects the real bird torso to the largest extent.

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