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INFLUENCE OF THE BIRD MODEL SHAPE ON THE RESULTS OF NUMERICAL ANALYSES OF BIRD MODELS IMPACT AGAINST A RIGID PLATE
Wpływ kształtu modelu ptaka na wyniki analiz numerycznych zderzenia ze sztywną płytą

Abstract: *This paper presents results of numerical analyses of different bird models impacting a rigid plate. The results of the study were compared with findings derived from experimental research. The experimental studies were conducted using a dedicated gas gun kit. A gelatine projectile was used as a bird model, giving it a speed of 116 m/s. For the purpose of the numerical investigations, the authors used the LS-DYNA software package. It is a computational code for the analysis of fast-variable phenomena using different methods, such as Lagrange, Arbitrary Lagrange-Euler (ALE), Smoothed Particle Hydrodynamics (SPH). Three cylindrical bird models with different endings were developed using the SPH method. The shape of the end of the bird model was found to exert a significant effect on the Hugoniot pressure values. However, it does not affect the maximum value of the impact force. The differences only occurred at the initial moment of impact, which was related with the area of contact between the model end and the target.*
Keywords: experimental research, numerical analyses, bird modelling, bird-aircraft collisions

Streszczenie: *Zaprezentowano wyniki analiz numerycznych zderzenia różnych modeli ptaka ze sztywną płytą. Porównano je z wynikami badań eksperymentalnych, które* wykonano za *pomocą dedykowanego zestawu działa gazowego. Jako model ptaka wykorzystano żelatynowy pocisk, nadając mu prędkość 116 m/s. W badaniach numerycznych wykorzystano pakiet oprogramowania LS-DYNA. Jest to kod obliczeniowy do analizy zjawisk szybkozmiennych metodami Lagrange, sprzężenia Lagrange-Euler (ALE), Smoothed Particle Hydrodynamics (SPH). Metodą SPH opracowano trzy modele w kształcie walca z różnymi zakończeniami. Kształt zakończenia modelu ma istotny wpływ na wartości ciśnienia Hugoniota*, natomiast nie *wpływa na wartość maksymalną siły uderzenia. Różnice występowały jedynie w początkowej chwili uderzenia, co miało związek z polem powierzchni styku zakończenia modelu z celem.*
Słowa kluczowe: badania eksperymentalne, analizy numeryczne, modelowanie ptaków, zderzenia ptaków ze statkami powietrznymi

1. Introduction

Bird collisions pose a serious threat to aircraft structures, since a bird strike event during a flight can lead to serious structural damage to the aircraft [6]. For helicopters, the windshield, the front part of the fuselage, and the rotor blades are particularly vulnerable to bird strike [1, 7, 9]. As a result, aviation authorities require all front components to be certified for the event of bird collisions before they are admitted into service.

Computational numerical methods have been widely used for over 30 years in the preliminary design of aircraft components which are resistant to bird strikes and which constitute an effective tool unlike costly physical certification tests with real birds [8-11].

A collision of a flying object, i.e. an aircraft with a bird, can be modelled numerically using the classical Lagrange method, the ALE (Arbitrary Lagrangian Eulerian) and the SPH (Smoothed Particle Hydrodynamics) method [10, 14]. In the available literature, it is possible to find a number of articles in which authors compare the obtained results using the above-mentioned methods [5, 12, 13]. Due to the fact that after the impact there occur severe impactor deformations, the most optimal approach seems to be the one which exploits the SPH method [13].

In the process of modelling a collision of an aircraft and a bird, it is important to develop a model of the bird whose behaviour will be close to a real one, during the impact. Apart from selecting an appropriate model shape and parameters such as dimensions, mass, density, porosity [3, 15], it is crucial to choose an appropriate equation of state for the material adopted for bird modelling [3, 16].

The paper presents numerical investigations of different shapes of bird models when colliding a rigid plate. In order to meet the certification requirements for the bird impact resistance of various aircraft parts, it is essential to conduct the required experimental research [19]. The experimental research is often trade secrets of bureaus of construction. Consequently, the number of available articles on this type of research is very limited. It is, therefore, common to carry out numerical studies and compare the obtained results with experimental findings [17-19]. The experimental tests, which the numerical studies are reference to, were performed in the Institute of Aviation in Warsaw.

2. Research methodology

The main objective of the experimental study was to validate the numerical models of the bird in terms of its shape for the sake of further research with different aircraft components. The experimental testing was carried out using a gas cannon. The bird model was a projectile made of ballistic gelatine, weighing 1.8 kg (fig. 1). The velocity of the projectile, the impact force and pressure in the process of collision with the steel plate were recorded during the test (fig. 2) [2].

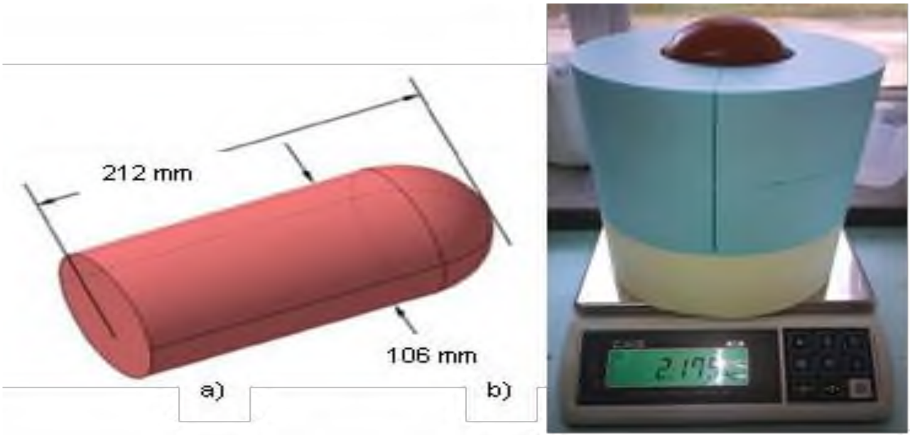


Fig. 1. Gelatin projectile: a) the geometry of the impactor model no 1; b) weighing of the impactor

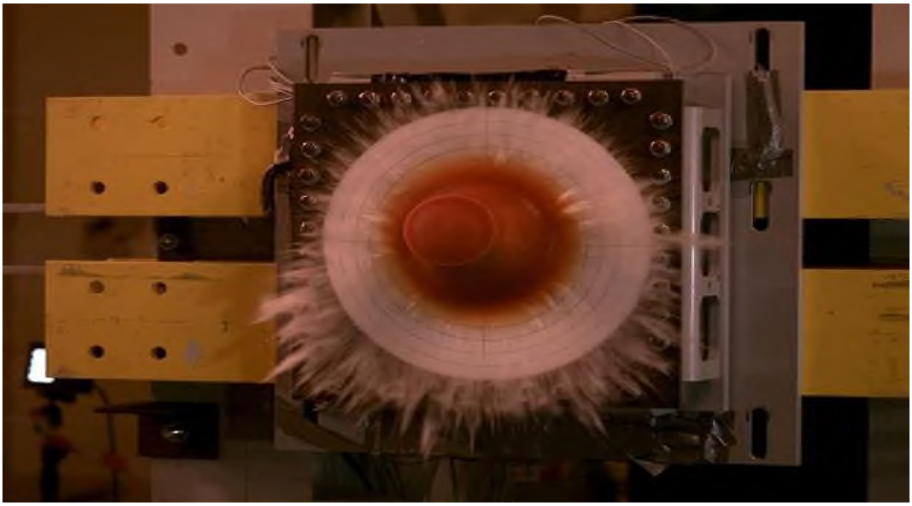
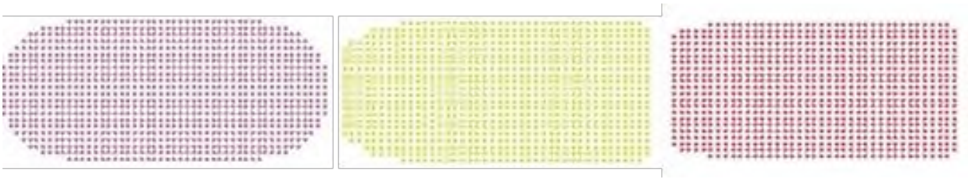


Fig. 2. Impact of the projectile on the target

The numerical simulations were conducted on the basis of LS-PrePost software [14]. Similarly to many experts, the authors examined a cylindrical bird model with different endings (fig. 3) [8, 10]. The bird modelling was performed using the SPH method [3, 8]. For a cylinder with spherical endings, the authors assumed a model ratio of length to diameter equal to 2:1, (D = 112 mm and L = 224 mm) with the SPH particle count equaling 79784. The test results were compared, including impact force, pressure and deformation of the bird model.



Model 1 Model 2 Model 3

Fig. 3. Numerical models of the bird in relation to the shape of the ending

The equation of state (EOS) is a relationship between density (volume), internal energy, temperature and pressure. For solids and liquids there are no analytically derived equations of state. Consequently, they are generated as empirical formulations based on experimental results. The use of the correct equation of state in a bird model is important in the process of numerical analyses of bird strikes [3]. A common equation of state for solids is the Mie–Grüneisen equation of state.
The Mie–Grüneisen equation defines the pressure for shock-compressed material, as [8]:

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

whereas for the expanded material, as:

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

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

3. Research results

In order to compare the experimental results, a number of numerical analyses were performed using the previously mentioned LS-PrePost software. The calculations were performed in LS-Dyna 970 [14]. One of the parameters recorded during the experimental study was the impact force. The impact force diagrams measured during the experimental tests were then compared with the force obtained from the simulation (fig. 4). When analysing the course of the curves, it can be stated that their shape is similar. Also the maximum values are well correlated with each other. In contrast, differences occur between 0.1 and 0.35 ms, from the beginning of an impact. In the experimental study, the impact force values during this time are equal to 100 kN, while in the simulation they decrease by approximately 50%. However, it should be noted that the first peak of force both during the experiment and simulation have similar values, which is important when comparing the Hugoniot pressure in the experiment and the simulation. When looking for an answer why there are such striking differences in the values of the forces at times ranging from 0.1 to 0.35 ms, the flight of the projectile up to the moment of impact was carefully analysed on the basis of a recorded video material. It was found that its semi-circular front ending was pulsing during a flight and became flattened under the influence of air resistance.

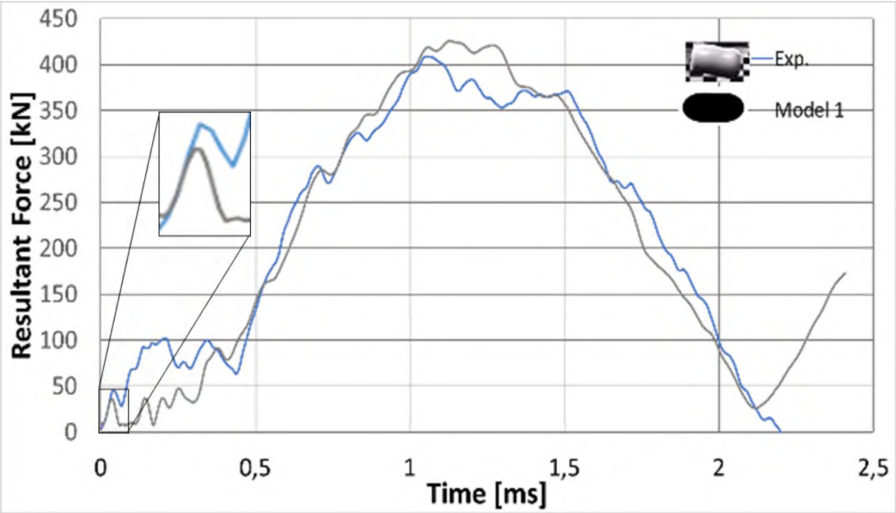


Fig. 4. Impact forces (test and model 1)

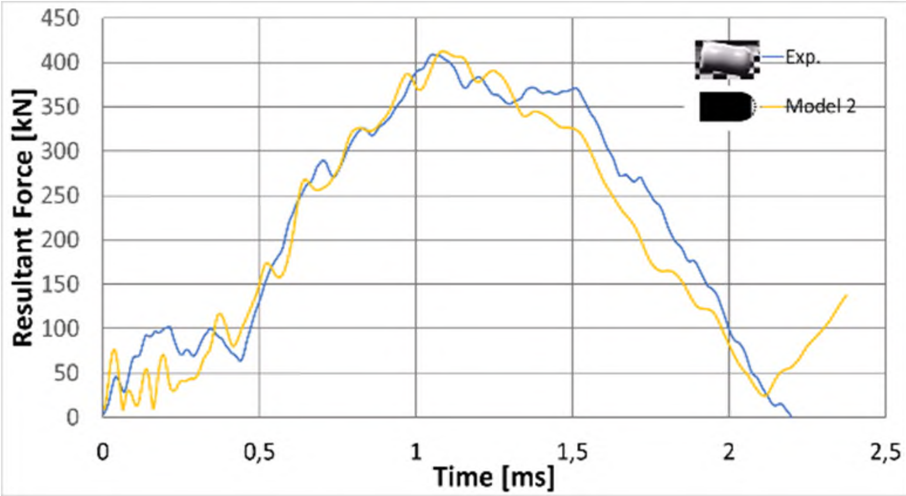


Fig. 5. Impact forces (test and model 2)

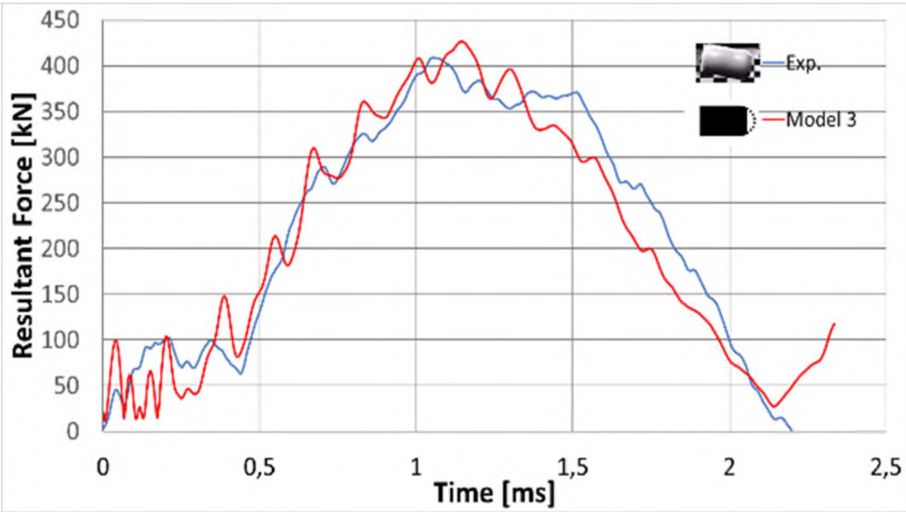


Fig. 6. Impact forces (test and model 3)

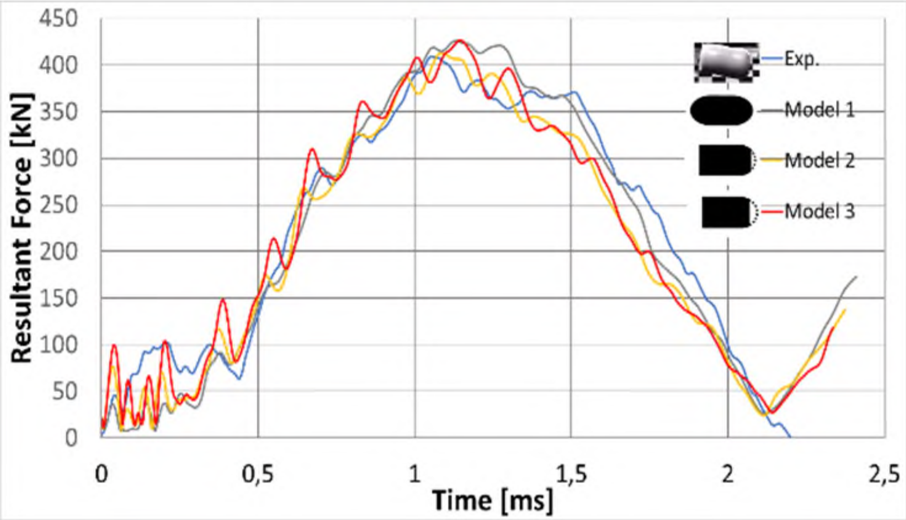


Fig. 7. Impact forces (test and models 1, 2, 1)

In order to confirm this phenomenon, a series of simulations were performed with a progressively flattened forehead of the bird model (figs. 4, 5, 6, 7). The developed models had the same mass and density (fig. 3). The comparative analyses were started by determining the effect of the bird model ending upon the course of the simulation (spherical, slashed) in relation to the experimental model. As it is visible in the figures above, an increase in flattening leads to a rise in force at the time of impact. It is linked with an increased contact area at the time of impact.

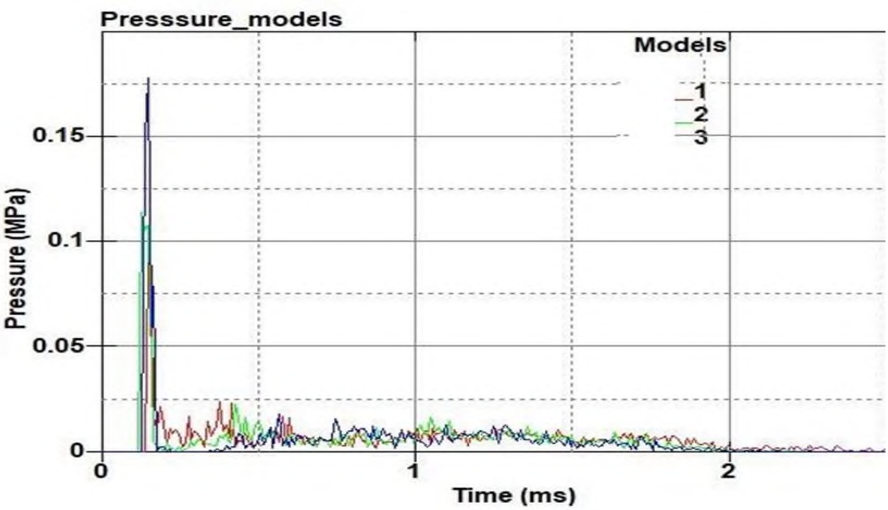
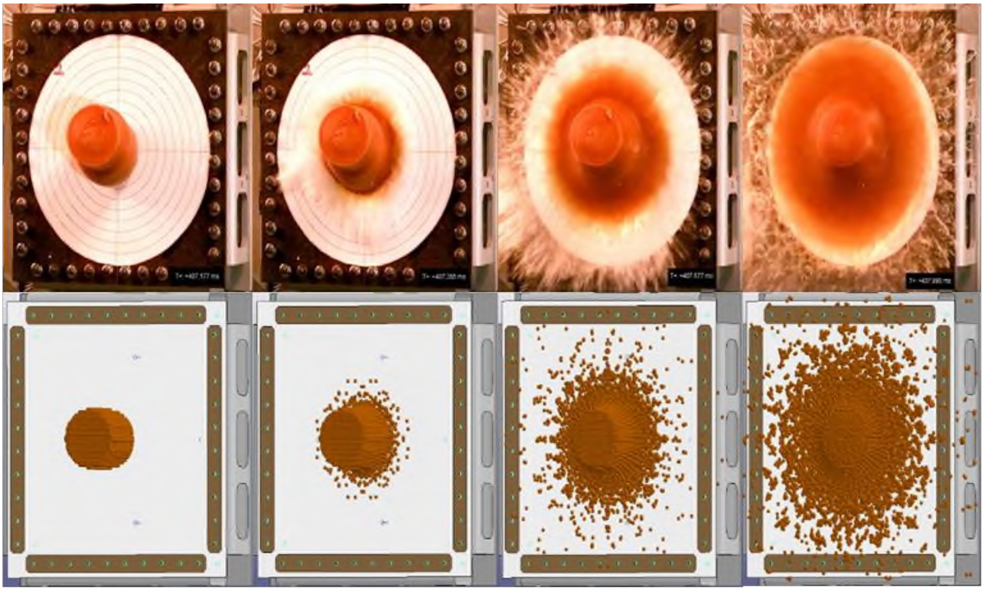


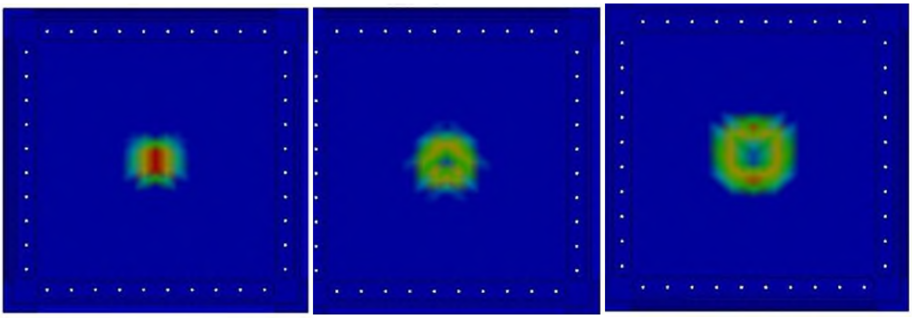
Fig. 8. Distribution of pressure depending on model type



(a) t_0=0 ms (b) t_0=0.3 ms (c) t_0=0.8 ms (d) t_0=1.2 ms

Fig. 9. Projectile deformation phases (test and model 1)

One of the parameters analysed during the numerical tests was distribution of pressure. When analysing the course of the curves, it is possible to formulate a statement that their shape is similar. It must be observed that the maximum values (Hugoniot peak) differ depending on the degree of flattening of the model ending. They are equal to 91.51 MPa for model 91), 114.8 MPa for model (2), and 178.75 MPa for model (3), respectively (fig. 8). It appears that the area of immediate contact between the model and the target, similarly to the magnitude of the impact force, exerts a significant influence on the Hugoniot pressure value.



Model 1 Model 2 Model 3

Fig. 10. Stress distribution on the target surface depending on the shape ending of the numerical model of the bird

However, it does not affect the value of the set pressure flow, in which the value and the shape of the curves are similar for all models. It was also crucial to compare the deformation of the projectile at selected time steps (fig. 9).

Analysing the individual time steps of the impact process, it can be concluded that the shape of the projectile deformation obtained during the simulation is similar for all the tested models.

It is interesting to observe the distribution of stresses in the target surface in the aspect of different surface of the model endings. As it can be seen in fig. 10, the highest stress value occurred in case of model 1 (34.25 MPa), where it was characterized by a smaller diameter compared to models 2 (31.28 MPa) and 3 (28.86 MPa). In this situation it can be concluded that an impact with a smaller surface causes a greater increase in stresses, yet over a smaller surface.

4. Summary and conclusions

Summarizing the results of the tests carried out, it can be seen that the shape of the impact force curves from the experimental and numerical tests are similar, also the maximum values correlate well with each other. In contrast, the shape of the model ending affects the Hugoniot pressure value. However, it does not affect the set pressure flow value. Overall, the shape of the pressure distribution curves is similar. Taking the above into account as well as correlation with the experimental results of other researchers, a bird model with spherical ends was selected for the needs of further numerical analyses.

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