Technical University of Varna
Annual Journal
https://doi.org/10.29114/ajtuv.vol8.iss1.310
Vol. 8 Issue 1 (2024)
Published: 2024-06-28
ISSN 2603-316X (Online)

Development and Validation of a Finite Element Model for Bird Strike Test

Nguyen Thi Anh[a], *Tran* Thanh Tung[a]

[a] Faculty of Engineering Mechanics and Automation, VNU University of Engineering and Technology, Hanoi, Viet Nam.

Corresponding author: tranthanhtung@vnu.edu.vn

Abstract. *A bird strike describes a collision between an aircraft and a bird or a group of birds. A bird strike refers to any collision between a moving vehicle and a fly creatures. Bird strike are studied through experiments or simulations. The testing method produces reliable results, close to reality. However, these practical experiments are expensive and time-consuming. This study performs numerical simulation of bird strike phenomenon using SPH technique. This article presents how to build a bird strike model on LS-DYNA software. The results of the simulation were compared with experiments, demonstrating that the numerical method is a reasonable approach to examine bird strike problems.*

Keywords: Bird strike, LS-DYNA, SPH, simulation

1 Introduction

A bird strike describes to a collision between an aircraft and a bird or a group of birds. Bird strikes are a major threat to air traffic, causing extremely serious consequences for people and aircraft (Reza Hedayati et al, 2015; Filiz Ekici et al, 2023; Jaroslav Juračka et al, 2021; B.F. Otero et al, 2023; Qiang Fu et al, 2016; Manuel Lopez-Lago et al, 2017). Studies on bird strikes are conducted using experiments or simulations. The experimental method provides results that are most closest to reality (Wilbeck, 1977; Jun Liu et al, 2014; Jun YAN et al, 2021; Luo Gang, 2021; J. Pernas-Sánchez, 2020) . Nevertheless, the tests are costly and time-consuming.

Conducting many experiments under various conditions incurs significant costs and may, at times, be unattainable. Consequently, simulation has emerged as a method employed in numerous studies focused on examining bird attack phenomena (Dahai Zhang et al, 2019; G. Lamanna, 2023; Ćwiklak, 2022; Olga et al, 2023; Smetankina et al, 2020; Liu et al, 2019) . This study employs the SPH method on LS-DYNA software to simulate the occurrence of bird strikes. The article outlines a methodology for constructing a bird strike model that can forecast various outcomes as a substitute for conducting experiments.

2 Methodology

2.1 Bird strike phenomena

According to the International Civil Aviation Organization (ICAO), a "bird strike" is defined as: *"A collision between a bird and an aircraft which is in flight, or on takeoff or landing roll".* Essentially, this means that during any phase of flight, a bird strike can occur. In basically, this implies that a bird collision can happen at any stage of a flight. The size of the bird or the velocity of the aircraft is unimportant.

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Although the primary threat arises from the convergence of larger avian species at greater aircraft velocities, there remains a minor potential hazard even posed by diminutive birds.

The occurrence of bird strikes can present a substantial hazard to the safety of aviation, potentially resulting in the need for aircraft to change course, make unplanned landings, and cause other related consequences. Colliding with a bird while taking off or landing can result in significant harm to the engine, windshield, and nose cone, frequently necessitating the aircraft to return to its starting point. The following are the potential hazards to aircraft during such a situation.

Most bird strikes happen at or in the area of airports during the landing, takeoff, or when planes are flying at low altitudes. The extent of harm inflicted by a bird on an aircraft is contingent upon the bird's dimensions, mass, velocity, as well as the aircraft's characteristics. The greater the weight and velocity of the bird, the increased likelihood of causing harm to the aircraft.

2.2 SPH method

Smooth particle hydrodynamics (SPH) is a computational technique that uses particles to simulate fluid flows and solid objects, without relying on a fixed mesh or grid(LS-DYNA Keyword user's manual, 2021 ; LS-DYNA theoretical manual, 2006). This method was devised to overcome the constraints of mesh tangling that arise in highly deformed scenarios when using the finite element method. Its purpose is to accurately simulate the intricate behaviors of free surfaces and material interfaces, including the fragmentation of solids.

- Equation of the particle:

$$\Pi^h f(x) = \int f(y) W(x-y,h) dy \tag{1}$$

Where:

- W (kernel function) is determined using the following formula:

$$W(x,h) = \frac{1}{h(x)^d}\theta(x) \tag{2}$$

- The most commonly used function W in the SPH algorithm is defined:

$$\theta(u) = C \times \begin{cases} 1-\frac{3}{2}u^2+\frac{3}{4}u^3, & |u|<1 \\ \frac{1}{4}(2-u)^3, & 1\le |u| \le 2 \\ 0, & 2<|u| \end{cases} \tag{3}$$

- C is a normalization constant that depends on the number of spatial dimensions. The SPH method is based on the perpendicular formula for moving particles $((x_i(t)), i \epsilon \{1 \ldots N\}$, in which $x_i(t)$ is the position of particle I, the particle moves along with velocity (v). The particle approximation of a function can be expressed as:

$$\Pi^h f(x_i) = \sum_{j=1}^{N} w_j\ f(x_i) W(x_i - x_j, h) \tag{4}$$

- $w_j = \frac{m_j}{\rho_j}$ is the weight of the grain. A particle's weight changes in proportion to the divergence of the flow

$$\nabla f(x) = \nabla f(x) - f(x)\nabla(x) \tag{5}$$

- Particle approximation to the gradient of a function:

$$\Pi^h \nabla f(x_i) = \sum_{j=1}^{N} \frac{m_j}{\rho_j}\left[f(x_j)A_{ij} - f(x_i)A_{ij}\right] \tag{6}$$

- And partial derivative formula:

$$\Pi^h\left(\frac{\partial f}{\partial x^\alpha}\right)(x_i) = \sum_{j=1}^{N} w_j f\left(x_j A^\alpha(x_i,x_j)\right) \tag{7}$$

Where: $A(x_i,x_j) = \frac{1}{h^{d+1}(x_i,x_j)}\frac{(x_i-x_j)}{\|x_i-x_j\|}\theta'\left(\frac{\|x_i-x_j\|}{h(x_i,x_j)}\right)$,

The Smoothed Particle Hydrodynamics (SPH) method has been widely utilized in various applications such as incompressible flow problems, heat conduction, high explosives, and high velocity impacts. The SPH method in the ls-dyna software is a powerful and effective tool that can be applied to simulate various problems, including metal cutting (Nanyuan Zhang et al, 2023; Tran Thanh Tung et al,2021; M. Afrasiabi et al ,2021; Md Rushdie Ibne Islam et al, 2020; Nguyen Thi Anh et al ,2020;

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Nanyuan Zhang et al ,2023), and bird strikes (M.H. Siemann et al, 2019; Zhuo Zhang et al, 2018; M. Guida et al, 2022; Feng Sun et al, 2019; B. Arachchige et al, 2020).

3 Finite element model for a bird strike impact

The article implements two models for the problem of a bird hitting a plane and the problem of a bird hitting an airplane propeller. The parameters are designed based on experimental data. The plate and the fan blade were designed according to the experimental tests. The bird model was resized to their actual dimensions

3.1 The plate model

The experimental plane is a steel plate with dimensions of 1000mm by 1000mm and a thickness of 1mm, as specified in Table 1.

Table 1. Material properties of the plate

Mass Density (kg/m^3)	Young Modulus (Gpa)	Poisson's ratio
7650	200	0.3

Figure 1 presents the simulation of planes using the LS-DYNA software. The plane is meshed in 2D with a thickness of 1mm (Auto Mesher) and described in the MAT_RIGID card.

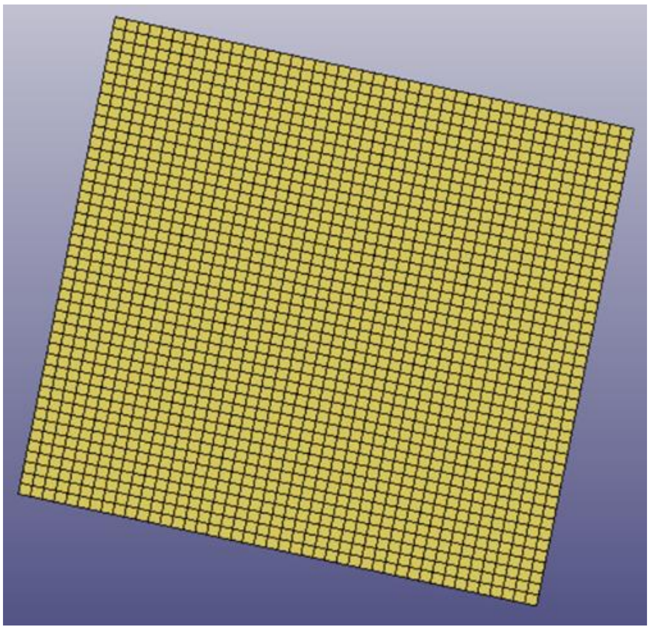

Fig. 1. The plate model

3.2 The fan blade model

Fan blade are simulated using 3D solid and shell elemnet. The fan blade model consists of 112 shell elements and 29740 solid elements as shown in Figure 2. This blade material is described in tab MAT – 015 -JOHNSON – COOK. The fan blade assembly comprises 29 blade sectors that are evenly

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distributed and a central hub section, the diameter of the fan is 2300mm. The width, height, and depth of each individual blade measure 77x20x18 cm.

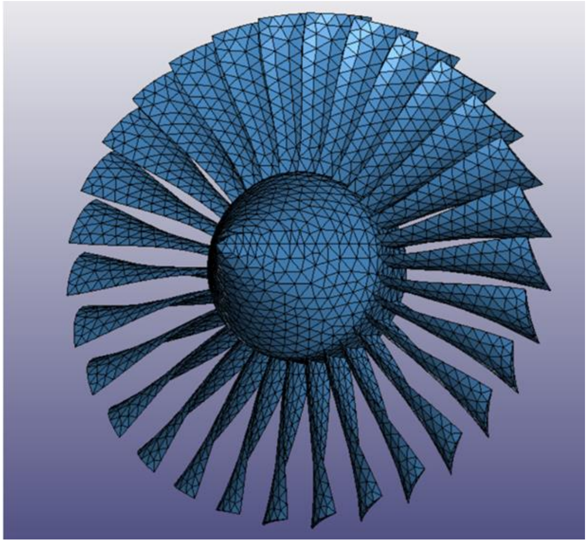

Fig. 2. The fan blade model

3.3 Bird model

The bird used the SPH method for simulation, the tags SECTION_SPH and EOS_LINEAR POLYNOMAL were used to describe the properties of the bird. Figure 3 presents the modelling of the bird, the model consist of 3896 SPH element

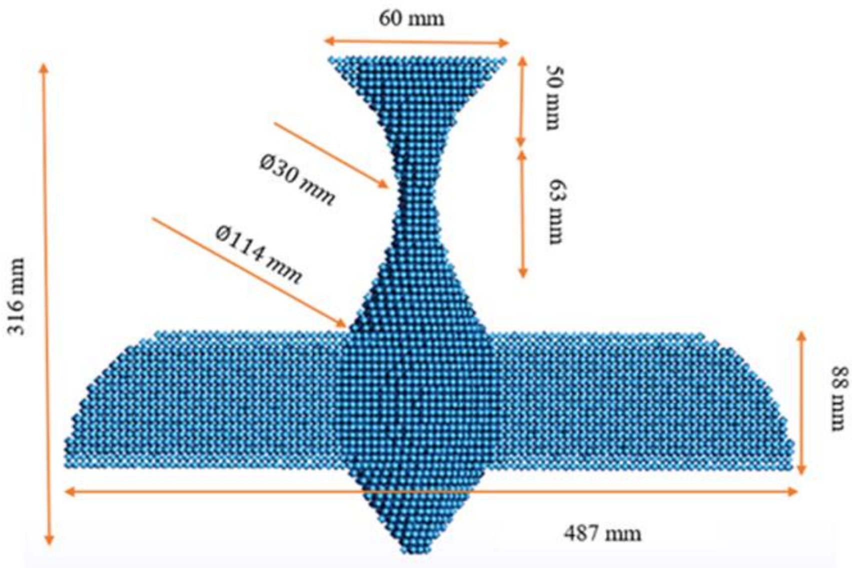

Fig. 3. The bird model (Dahai Zhang et.al, 2016)

3.4 Boundary condition

Figure 4 displays the initial phase of the bird strike simulation test, derived from the experimental tests. The impact test model comprises the bird animal and the plate (or the rotor blade). The bird's initial velocity was set to 170 m/s at an impact angle of 90°.The

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AUTOMATIC_SURFACE_TO_SURFACE card provided as a method of contact between the bird and the object.

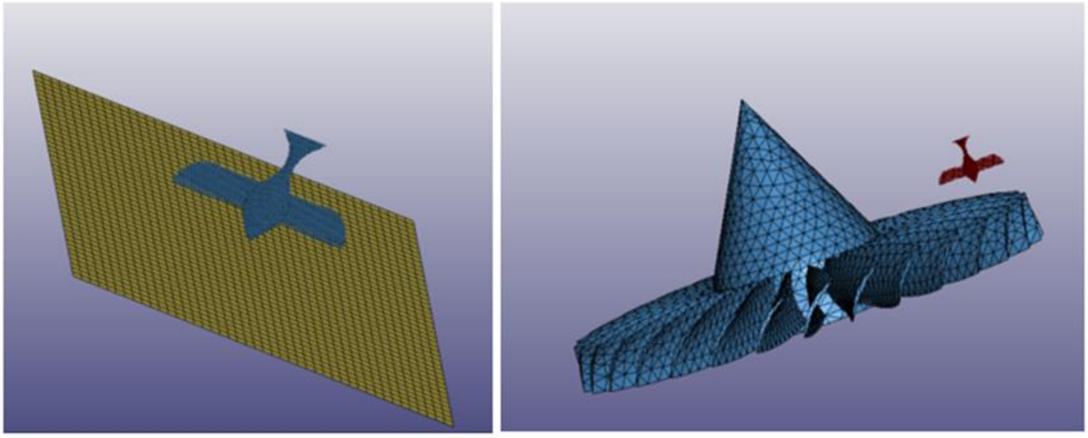


Fig. 4. Boundary condition

4 Results and discussion

Table 2 and 3 present the impact test results of the finite element model of the bird strike. The behavioral simulation results are quite similar to the experiment in both cases where the bird crashes into the flat plate and the fan blade.

Table 2. Bird impact with the plate

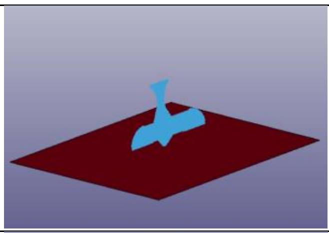
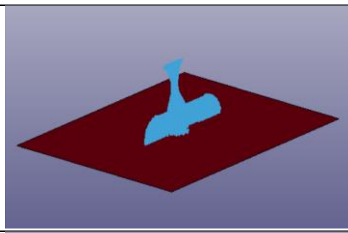
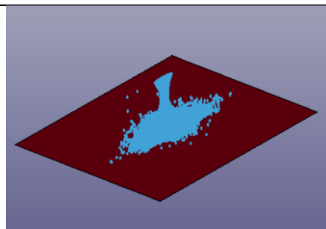
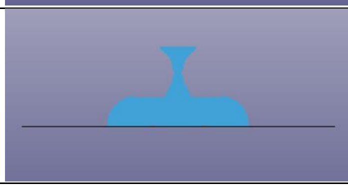
t=0.001s	t=0.002s	t=0.003s
		
		

Table 3. Bird impact with fan blade

t=0.001s	t=0.002s	t=0.003s

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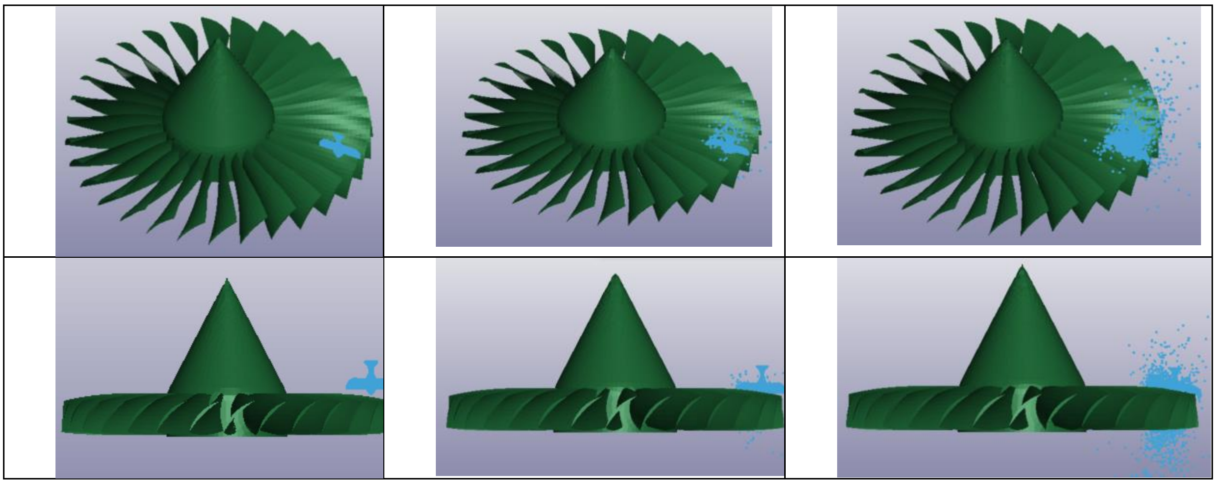

Figure 5 presents pressure value over time for the simulation and experimental when the bird impact, The maximum pressure in both simulation and experimental cases is reached at the time point of 0.23 ms. For the experimental, this pressure is about 2.15 Mpa, in which for the simulation it is 2.6 Mpa, an error of about 20%.

Figure 6 shows the displacement of the plate when the bird collision. The maximum deformation of the flat plate in both simulation and experimental cases is reached at the time point of 2.0 ms. For the experimental, this deformation is about 27mm, in which for the simulation it is 30mm, an error of about 11%. After the 2.0ms time point, the flat plate deforms elastically and returns to nearly its original shape

In both value, the simulation results are quite similar to the experiment. This proves that simulation is a reasonable approach to the bird's nest problem to predict likely outcomes instead of costly experiments.

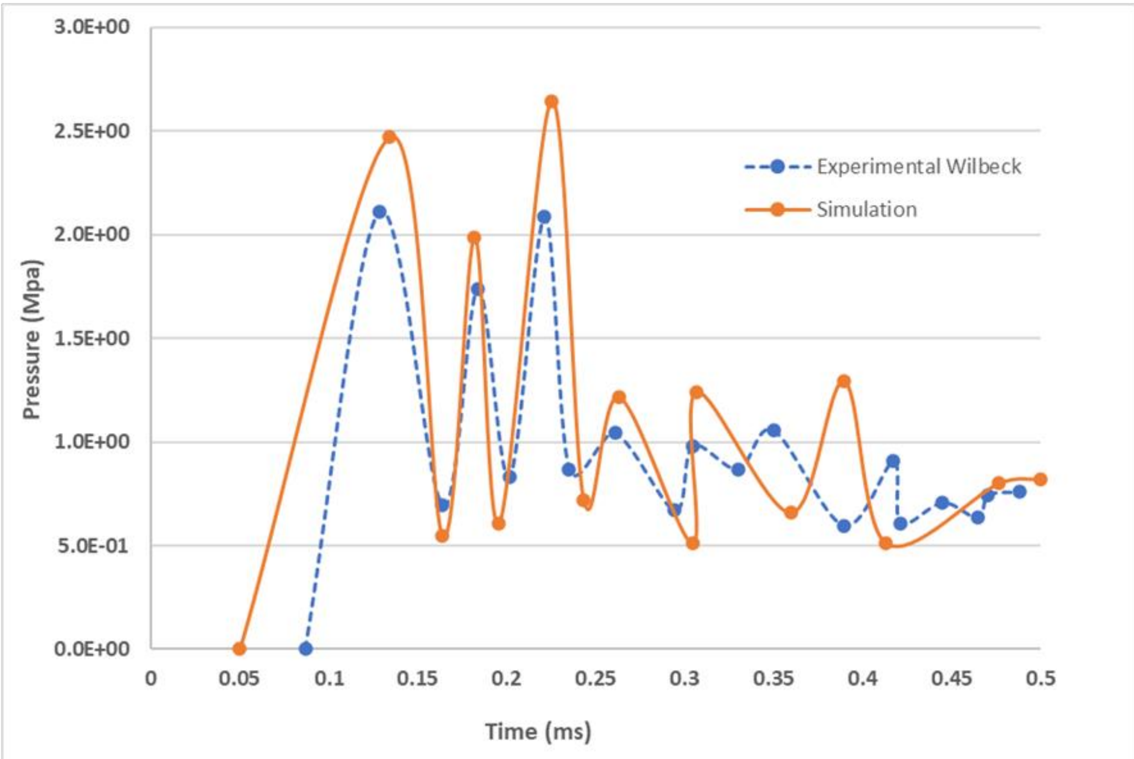

Fig. 5. Comparison pressure result of simulation and experimental (Wilbeck, 1977)

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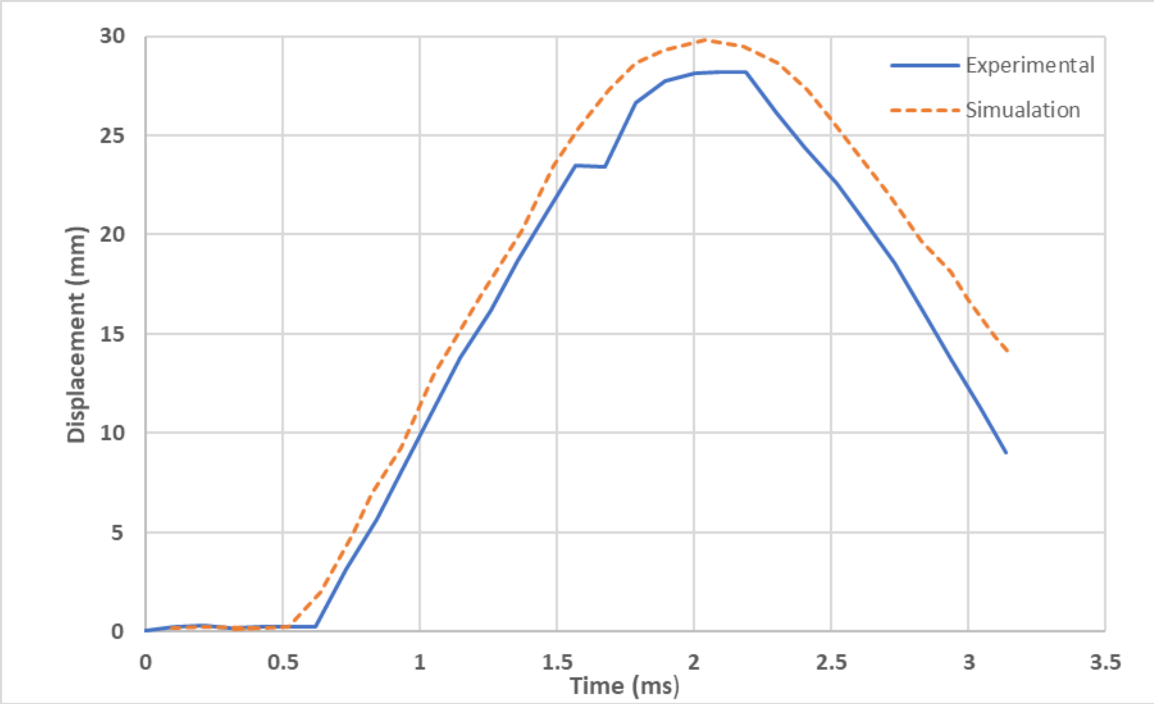

Fig.6. Comparison displacement result of simulation and experimental (Jun Lin et.al, 2014)

Simulating bird strikes is indeed a challenging task due to the complex interplay of various factors involved, such as bird behavior, aircraft dynamics, and environmental conditions. The accurately predicting the exact outcome of a bird strike can be difficult due to the randomness of bird behavior and the many variables involved.

Overall, while simulations of bird strikes have limitations, they can still provide valuable insights into the risks and consequences of bird strikes and help inform efforts to mitigate these risks and improve aircraft safety. However, it's essential to recognize the inherent uncertainties and limitations of any simulation or modeling approach and to supplement these methods with real-world data and observations wherever possible.

5 Conclusions

This paper indicates the development and validation of bird strikes test simulation. Simulations were performed using SPH method based on experimental tests. The accuracy of the model makes it a reasonable method for bird strike testing. The presented model can predict the behavior of flat plates and blades, and evaluate the severity of impact during bird strikes. In addition, the results demonstrate the ability of computers to study the bird strike phenomenon instead of using expensive experimental tests.

References

B. Arachchige , H. Ghasemnejad, M. Yasaee (2020). Effect of bird-strike on sandwich composite aircraft wing leading edge. *Advances in Engineering Software*, Volume 148, 102839. https://doi.org/10.1016/j.advengsoft.2020.102839

B.F. Otero , J. Herranz , J.E. Malo (2023). Bird flight behavior, collision risk and mitigation options at high-speed railway viaducts. *Science of The Total Environment*, Volume 902, 1. https://doi.org/10.1016/j.scitotenv.2023.166253

Ćwiklak, J.; Kobiałka, E.; Goś, A (2022). Experimental and Numerical Investigations of Bird Models for Bird Strike Analysis. *Energies* , 15, 3699. https://doi.org/10.3390/en15103699

Dahai Zhang, Qingguo Fei (2016). Effect of bird geometry and impact orientation in bird striking on a rotary jet-engine fan analysis using SPH method. *Aerospace Science and Technology*, Volume 54, July 2016, Pages 320-329. https://doi.org/10.1016/j.ast.2016.05.003

Feng Sun , Qin Sun , Lei Ni, Ke Liang (2019). Numerical analysis of anti-bird strike performance in structural connection design for a vertical tail leading edge. *Thin-Walled Structures*, Volume 144, 106319. https://doi.org/10.1016/j.tws.2019.106319.

Filiz Ekici, Öner Gümüş , Ahmet Uslu, Utku Kale (2023). An investigation of bird strike cases in the aviation sector with a novel approach within the context of the principal-agent phenomenon: Bird strikes and insurance in the USA. *Heliyon*. Volume 9, Issue 7. https://doi.org/10.1016/j.heliyon.2023.e18115

G. Lamanna, A. De Luca, F. Marzocchella, F. Di Caprio, M. Belardo, L. Di Palma, F. Caputo (2023). Tendency analysis of a tilt rotor wing leading edge under bird strike events. *Forces in Mechanics*, Volume 10, 100173. https://doi.org/10.1016/j.finmec.2023.100173

J. Pernas-Sánchez, J. Artero-Guerrero, D. Varas, J. López-Puente (2020). Artificial bird strike on Hopkinson tube device: Experimental and numerical analysis. *International Journal of Impact Engineering*, Volume 138, 103477. https://doi.org/10.1016/j.ijimpeng.2019.103477

Jaroslav Juračka, Jiří Chlebek, Viktor Hodaň (2021). Bird strike as a threat to aviation safety. *Transportation Research Procedia*. Volume 59, Pages 281-291. https://doi.org/10.1016/j.trpro.2021.11.120

Jun Liu, Yulong Li, Xiaosheng Gao (2014). Bird strike on a flat plate: Experiments and numerical simulations. *International Journal of Impact Engineering*, Volume 70, Pages 21-37. https://doi.org/10.1016/j.ijimpeng.2014.03.006

Jun YAN, Chenguang ZHANG, Sixu HUO, Xianghai CHAI, Zhihui LIU, Kun YAN (2021). Experimental and numerical simulation of bird-strike performance of lattice-material-infilled curved plate. *Chinese Journal of Aeronautics*, Volume 34, Issue 8, Pages 245-257. https://doi.org/10.1016/j.cja.2020.09.026

Liu, J., Liu, Z. & Hou, N (2019). An Experimental and Numerical Study of Bird Strike on a 2024 Aluminum Double Plate. Acta Mech. Solida Sin. 32, 40–49 . https://doi.org/10.1007/s10338-018-0071-1

LS-DYNA Keyword user's manual. Livermore Software. Technology Corporation, 2021. https://www.dynasupport.com/manuals

LS-DYNA theoretical manual. Livermore Software. Technology Corporation, Livermore, 2006. https://www.dynasupport.com/manuals

Luo Gang, Xu Ziming, Shen Haitao, Chen Wei, Haiyang Zhang (2021). Experimental study on the impact load of internally supported gelatin bird projectiles. *Engineering Failure Analysis*, Volume 124, , 105336. https://doi.org/10.1016/j.engfailanal.2021.105336

M. Guida, F. Marulo, F.Z. Belkhelfa, P. Russo (2022). A review of the bird impact process and validation of the SPH impact model for aircraft structures. *Progress in Aerospace Sciences*. Volume 129, 100787. https://doi.org/10.1016/j.paerosci.2021.100787

M. Afrasiabi , H. Klippel, M. Roethlin, K. Wegener (2021). An improved thermal model for SPH metal cutting simulations on GPU. *Applied Mathematical Modelling*. Volume 100, December 2021, Pages 728-750. https://doi.org/10.1016/j.apm.2021.08.010

M.H. Siemann, S.A. Ritt (2019). Novel particle distributions for SPH bird-strike simulations. *Computer Methods in Applied Mechanics and Engineering*, Volume 343, Pages 746-766. https://doi.org/10.1016/j.cma.2018.08.044

Manuel Lopez-Lago, Rafael Casado, Aurelio Bermudez, Jose Serna (2017). A predictive model for risk assessment on imminent bird strikes on airport areas. *Aerospace Science and Technology*, Volume 62, Pages 19-30. https://doi.org/10.1016/j.ast.2016.11.020

Md Rushdie Ibne Islam, Ankur Bansal, Chong Peng (2020). Numerical simulation of metal machining process with Eulerian and Total Lagrangian SPH. *Engineering Analysis with Boundary Elements*, Volume 117, Pages 269-283. https://doi.org/10.1016/j.enganabound.2020.05.007

Nanyuan Zhang, Hagen Klippel, Fabian Kneubühler, Mohamadreza Afrasiabi, Matthias Röthlin, Michal Kuffa, Markus Bambach , Konrad Wegener (2023). Study on the effect of wear models in tool wear simulation using hybrid SPH-FEM method, *Procedia CIRP*, Volume 117, Pages 414-419. https://doi.org/10.1016/j.procir.2023.03.070

Nguyen Thi Anh, Tran Thanh Tung (2020). Drilling Modelling Using Computer Simulation, *International Journal of Scientific & Technology Research*. Volume 9, Issue 10, 171-174

Olga, Rod ; Oleg, Molkov ; Nikita, Lutsenko ; Aleksandr, Bolshikh ; Anna, Storchak (2023). Effect of preloaded state slat structure on the stress–strain state of simulation bird strike. *Aerospace Systems*, https://doi.org/10.1007/s42401-023-00236-3

Fu, Q., Wang, N., Shen, M., Song, N., & Yan, H. (2016). A study of the site selection of a civil airport based on the risk of bird strikes: The case of Dalian, China. Journal of Air Transport Management, 54, 17-30.

Hedayati, R., & Sadighi, M. (2015). Bird Strike: An Experimental, Theoretical and Numerical Investigation. Woodhead Publishing.

Smetankina, N., Kravchenko, I., Merculov, V., Ivchenko, D., Malykhina, A. (2020). Modelling of Bird Strike on an Aircraft Glazing. In: Nechyporuk, M., Pavlikov, V., Kritskiy, D. (eds) Integrated Computer Technologies in Mechanical Engineering. *Advances in Intelligent Systems and Computing*, vol 1113. Springer, Cham. https://doi.org/10.1007/978-3-030-37618-5_25

Tran Thanh Tung, Nguyen Yen Nhi, Nguyen Thi Anh (2021). A Study On Simulation Of Metal Cutting Process Based On LS-Dyna. *Journal of the Technical University of Gabrovo* 62 ,47-55

Wilbeck, J. (1977). Impact behavior of low strength projectiles. AFML-TR-77-134 Air Force Materials Lab, Air Force Wright Aeronautical Lab, Wright-Patterson Air Force Base, OH.

Zhuo Zhang, Liang Li, Dingguo Zhang (2018). Effect of arbitrary yaw/pitch angle in bird strike numerical simulation using SPH method, *Aerospace Science and Technology*, Volume 81, Pages 284-293. https://doi.org/10.1016/j.ast.2018.08.010