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Numerical Modelling of Bird Strike on Aerospace Structures by means of Coupling FE-SPH

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Abstract: This article offers a parametric mechanics investigation in defining the correlation between the parameters of a wing-body during a bird strike collision. A commercial software of LS-Dyna is used to compute the numerical modelling manifested in this research. In this study, it is an attempt to form a definitive work based on the Smoothed Particle Hydrodynamics (SPH) formulation by recognising the most critical influencing parameters in the bird-strike computation and verify the simulation with the experiment data. For instance, an idealised bird is modelled as a cylindrical shape with hemispherical ends to maintain the homogeneity and symmetry using SPH approach. Moreover, an aluminium alloy rigid flat plate is modelled as a shell element plate in the finite element model (FEM). Here, internal energy vs time for different plate thickness graph are plotted to observe the difference of absorbed energy during the impact. Such conditions are considered in this research from the sight of bird strike impact under multiple states (structural thickness) and constraints (bird size). The obtained computational results are in adjacent agreement with the experimental results published in another literature.

Keywords: Bird strike, smooth particle hydrodynamics (SPH), impact, finite element model (FEM)

1. Introduction

Bird strike phenomenon is common and can pose significant intimidation to a flying aircraft. A collision happened through an air display routine; a bird flew into the propeller of the Edge 360 aircraft which lead to a crash [1]. The aircraft was damaged beyond repair and the pilot suffered two cracked vertebrae. Aircraft manufacturers felt the need to study the effects of bird strike on different parts of the aircraft to find the right material that can withstand the impact. In the experimental point of view, real birds are not preferred to be used in bird strike tests are the lack of repeatability, unable to control the orientation and lack of symmetry [2]. In one experiment, a killed chick on the spot was used to replicate a bird [3]. The chick was encased in a plastic covering to prevent debris from spreading after the collision. It is stated that this method is employed to sustain the symmetry and orientation for the impact test. Moreover, in some research, the real bird has been substituted by other material, such as gelatin with 15v% microballoons [2] and rubber in the shape of a ball [4].

The usage of gelatin as the experimental bird model for the test is also conducted by several researchers as well [5]–[10]. One of the advantages of using gelatin is that it has the same density as of in real birds which is around 900 – 950 kg/m³. Numerical bird strike simulations are growing more critical, predominantly during the certification stage of a new aircraft design. Some of the cases of bird strike simulation conducted on aircraft structures such as for trailing edge of

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the wing [6], tailplane [7], and leading edge of the wing [8]. The application of finite element modelling in numerical simulations are able to replace the time consuming and expensive bird strike experiments. In addition, the numerical simulation can also be done repeatedly with a much more accurate precision compared to the experimental methods and hence, improve the current structural design. Until now, there are three approaches have been widely used in computational modelling of bird strike impact, which are the Lagrangian method, the Arbitrary Lagrangian-Eulerian (ALE) method and the Smooth Particle Hydrodynamics (SPH) method.

The Lagrangian method has a disadvantage when the structural deformation is exposed to be enormous since it will increase the complexity to compute the state and stress in the elements due to the time step. Thus, the accuracy of the results obtained had decreased. In that sense, the ALE method is commonly utilised as a conventional approach to bird impact modelling since the method did not create much deformation [11]. However, that did not stop the researchers from looking for better ways to model the bird strike impact. The researchers found out a way that can model the bird as fluid is known as the Smoothed Particle Hydrodynamics (SPH) method [2] that practically applied to compute the mechanics of continuum media, such as solid mechanics and fluid flows. Another significant aspect of bird strike is from the aerostructure perspective. During bird strike occurrence, shock waves are developed since particles on the front surface of the impactor are instantaneously brought to rest [2]. For that reason, the idea of considering the bird structure as fluid is to be equipped to examine the circumstances of failure due to substantial distortions. Following the bird strike impact, a shock wave region will be established enclosing the impact spot. In the shock region, the pressure is very high at the beginning and becomes constant throughout the shock region. When the shock propagates, high-pressure gradients lead to the development of the stress field in the projectile. On that assumption, if the stress obtained happens to exceed the strength of the material, the material ‘flows’ like a fluid [7].

Nomenclature

T duration of Bird Strike Impact
U_0 initial impact velocity
L_B length of bird
P_H hugoniot pressure
ρ_0 initial density of fluid
U_S shock velocity
ρ density
E young’s modulus
G shear modulus
υ poisson’s ratio
σ_y yield stress
E_h plastic hardening modulus

On that particular review, this research intends to investigate the parametric mechanics in defining the correlation between a wing-body's parameters during a bird strike collision. The development numerical schemes in this research would be utilised for the manufacturing constraint on the structural integrity, principally as preliminary aircraft design.

2. Methodology

Bird strike occurrences are regarded as soft body impact in the structural examination since the targeted body has a higher yield point compared to the bird. Consequently, the bird at the impact can be deemed as a fluid element. The soft body collision results in damage over a more extensive region compared to the ballistic impacts.

2.1 Continuum Approach

LS-Dyna employs the three significant equations, i.e., conservation of mass, conservation of momentum, and the constitutive relationship of the material and is essential to solving the soft body impact problem. Throughout this approach, several parameters such as the velocity, density, and pressure of the fluid for a specific position and time will be computed s. The conservation of momentum can be affirmed as in (1);

$$-\nabla P = \frac{d}{dt}(\rho V) \qquad (1)$$

where P signifies a diagonal matrix containing only normal pressure components, ρ the density, and V the velocity vector. Following that, the conservation of mass per unit volume equation can be expressed as in (2).

$$\frac{d\rho}{dt} + \rho\nabla . V = 0 \qquad (2)$$

2.2 Smooth Particle Hydrodynamics (SPH)

The SPH technique could better portray the bird fragmentation into smaller particles with better efficiency than Lagrange and ALE method with shorter solution time and fewer elements needed. It is an essential element to identify which particle will interact with its acquaintances because the interpolation depends on these interactions when employing the SPH method. On that basis, the integration cycle in time of the SPH computation process [13] is depicted as in Fig. 1.

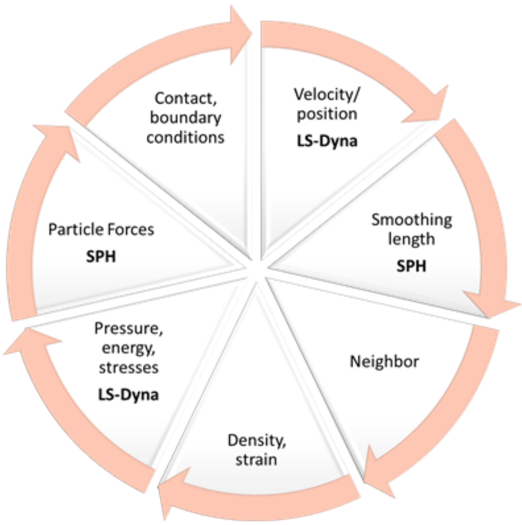

Fig. 1 - Integration cycle in time of the SPH computation process [13]

The problem of high distortion of debris during the bird strike impact could be eliminated. In this study, an idealised cylindrical with hemispherical ends SPH model was used as the bird model shown in Fig. 2.

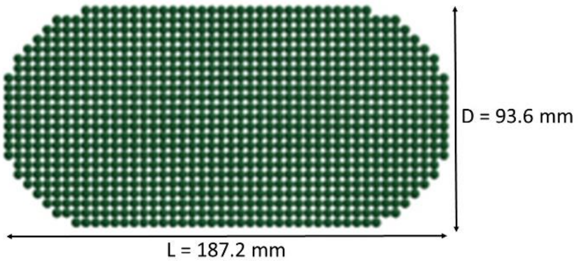

Fig. 2 - Idealised bird model using SPH method

The bird model constructed in the numerical analysis should replicate the qualities of a real bird structure. The bird is modelled as a cylindrical shape with hemispherical ends to maintain the homogeneity and symmetry. These features are crucial elements in determining the right results for the bird strike impact. The modelled bird length, *l* is twice the diameter of the bird model, where the parameter D is referred to as diameter. In the validation process, the diameter and length are determined to be 93.6 mm and 187.2 mm, respectively.

The bird model is defined using the keyword in the LS-DYNA software as EOS_LINEAR_POLYNOMIAL and could be formulated as in (3) where C_0, C_1, C_2 and C_3 are material constants. The constant C_1 is the bulk modulus of the bird projectile. The parameter μ is obtained in (4) from the initial density value, ρ_0 and the current density value, ρ. The physical properties of the bird model are shown in Table 1. In this work, Johnson-Cook for the material damage modelling of the impacted wing. Johnson-Cook strength material model is regularly employed in finite-element analyses of various production methods, including plastic deformation of metallic materials [14].

Table 1 - Parameters for the presented bird model [13]

ρ (kg/m^3)	G (GPa)	σ_y (MPa)	E_h (MPa)
930	2.0	0.1	0.001

$$P = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3 \quad (3)$$

$$\mu = \frac{\rho_0}{\rho} - 1 \quad (4)$$

It is essential for the numerical method follows the exact arrangement and experimental set up of the real bird strike test. This is to ensure that the results obtained from the numerical methods could be close as possible to the real experimental results by replicating the conditions of the real bird strike experiment.

2.3 Aluminium Alloy Plate Structure

In this work, a Q235 steel type of material plate is modelled by using shell elements via finite element model. The dimensions for the sides of the plate was set to be equal that is 600 mm x 600 mm with 2 mm thickness as the experimental work done by [3]. The structural plate contains 60 shell elements in the x-direction (horizontal) and 60 elements in the y-direction (vertical). For the boundary condition, the plate is fixed at all sides and in 6 degrees of freedom so that there will be no recoil of the bird strike impact. The material used for the validation process is Q235 steel or also known as as shown in Table 2.

Table 2 – Mechanical properties of Q235 steel [13]

ρ (kg/m^3)	E (GPa)	υ	σ_y (MPa)
930	198	0.32	153

2.4 Arrangement of Model

To simulate the bird strike impact, first the bird model and the plate has to be in contact, see Fig. 3. The contact involved in this process is in between the nodes and the surface. To replicate the same model made by [3], the nodes of the SPH bird model is set to hit the surface of the square plate.

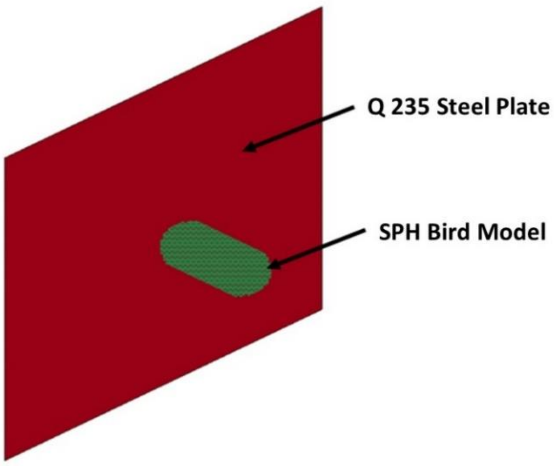

Fig. 3 - The isometric diagram of the plate against a bird model

The same approach used in assessing the bird strike impact on the plate is been applied in this subsection. For this analysis, Aluminum 2024 T3 or also known as Aerospace Alloy is adopted for the wing construction as the material been used widely in the aerospace industry. The mechanical properties of this Aluminum 2024 T3 is presented in Table 3. In that case, the bird model and the wing has to be in contact, specifically at the middle of the wing section. As the assumption is same as the previous approach, the contact involved in this process is in between the nodes and the surface. In that case, the nodes of the SPH bird model is set to hit the surface of the wing as presented Fig. 4.

Table 3 - Mechanical properties of Aluminum 2024 T3

ρ (kg/m^3)	E (GPa)	υ	σ_y (MPa)
2768	73.08	0.33	280

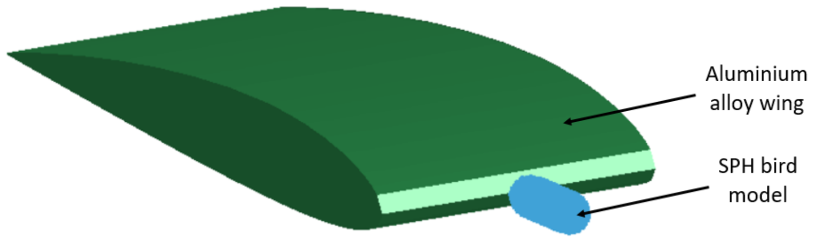

Fig. 4 - The isometric diagram of an aircraft wing against a bird model

3. Results

3.1 Results Validation

The obtained numerical data presented in this part is compared with the results of experimental and computational modelling obtained by [3]. Technically, the data gained from this work is basically modelled by using the SPH method in the commercial LS-DYNA software. For the computational procedure validation, a sample plate of Q235 steel with 10 mm thickness is used. The impact simulation is taken at different time intervals as demonstrated in Fig. 5.

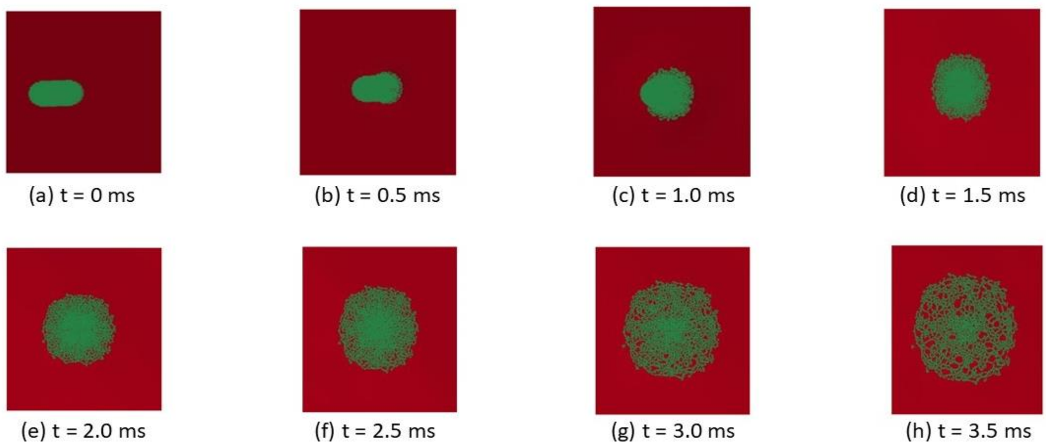

Fig. 5 - Computational results of bird impact against Q235 steel plate at time intervals of 0 ms to 3.5 ms.

It is observed that the images for experimental and numerical analysis conducted by [3] are in good agreement with the computational results via SPH-FE presented in this work. For more detail procedure validation verification, a graph of displacement vs time of the plate after the bird strike impact is plotted in Fig. 6. The same plate model is implemented for Q235 steel plate as presented by Hu et al. [3].

t is proven that the present work has successfully validated with the experimental and numerical analysis conducted by previous literature. The displacement vs time result for the present work show an average percentage error of 4.598% compared with the experimental results and an average percentage error of 3.559 % when compared with the previous numerical analysis results established by [3].

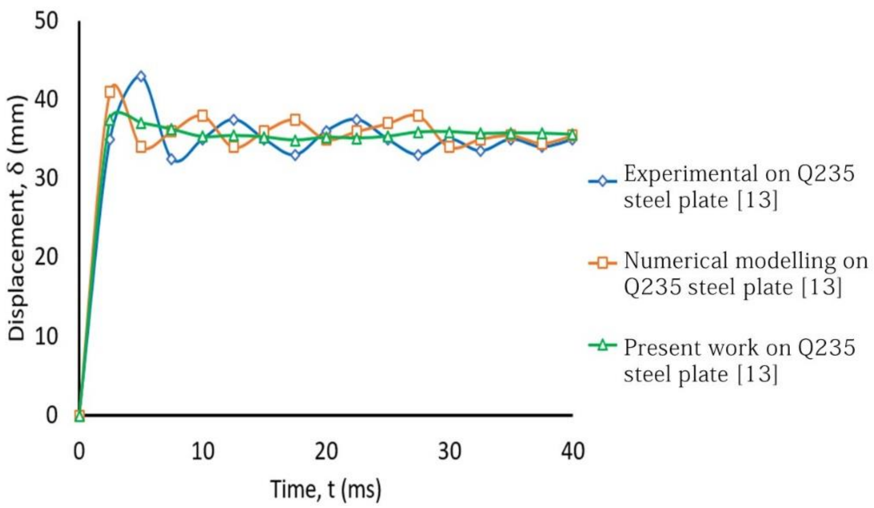

Fig. 6 - Numerical validation of present work (computational) with experimental and numerical analysis by Hu et al. [3]

3.2 Parametric Studies

In this section, the benchmarking sample of the plate has been investigated related to its thickness variation. The material used for the plate was Aluminium 2024 T3, also known as Aerospace Alloy. The thickness of the plate is varied from 2 mm to 4 mm, 6 mm, 8 mm and 10 mm. The objective of this subsection is to study the effects of the bird strike on the plate with different thickness. The displacement-time graph is plotted for all thickness as shown in Fig. 7.

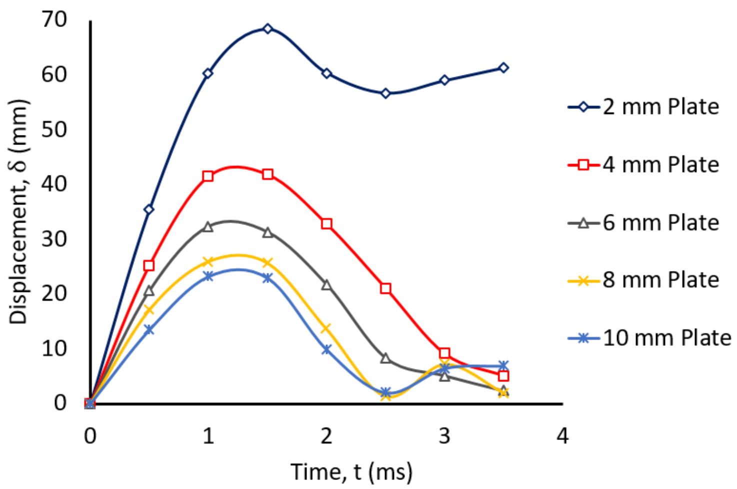

Fig. 7 - Comparison of displacement vs time for various plate thickness

Based on the observation, the 2mm plate is unable to return to its shape after the bird strike impact, where the displacement of the structural deflection is increased after 3 ms. Hence, the stress distribution is plotted to examine the possibility of a structural failure due to the impact in Fig. 8. This circumstance is not observed in the other plates with higher thickness values when comparing the structural displacement subjected to the bird strike impact load. For further investigation, the internal energy at that nodal hit spot of the bird strike is plotted for the computational validation, see Fig. 9.

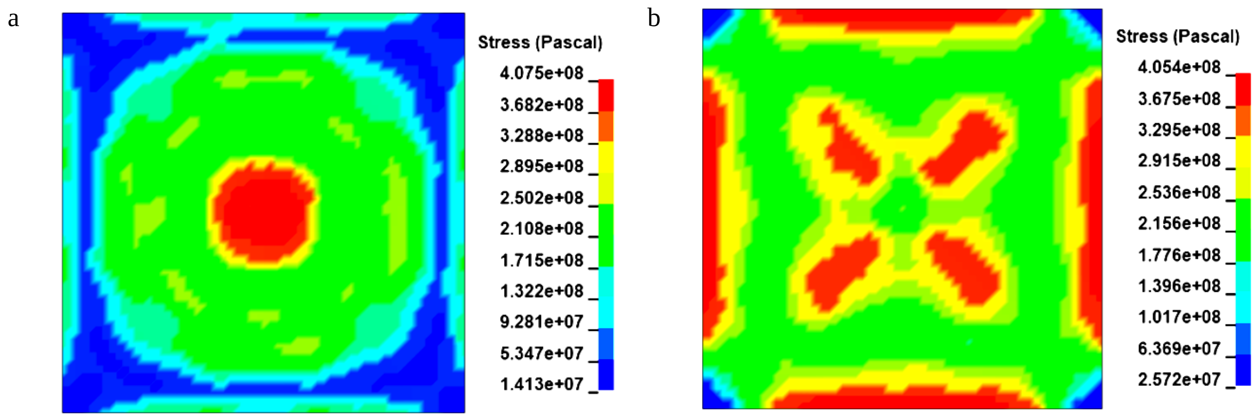

Fig. 8 - Von Mises stress distribution of 2mm thickness plate (a) at 0.5 ms; (b) at 2.0 ms

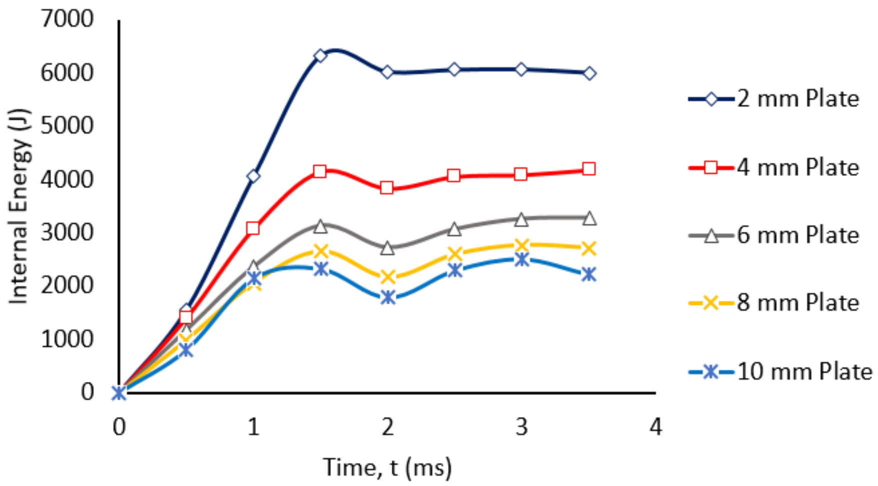

Fig. 9 - Internal energy vs time for different plate thickness

3.3 Application on an Aircraft Wing Segment

A similar concept is conducted on an aircraft wing segment using the aluminium alloy as the material for the wing skin. In this study, a wing part throughout a division of wing rib is being analysed under the bird strike impact. The impact simulations are taken at different time intervals in Fig. 10. It is observed that the wing is deflected without any breaking part after the bird strike.

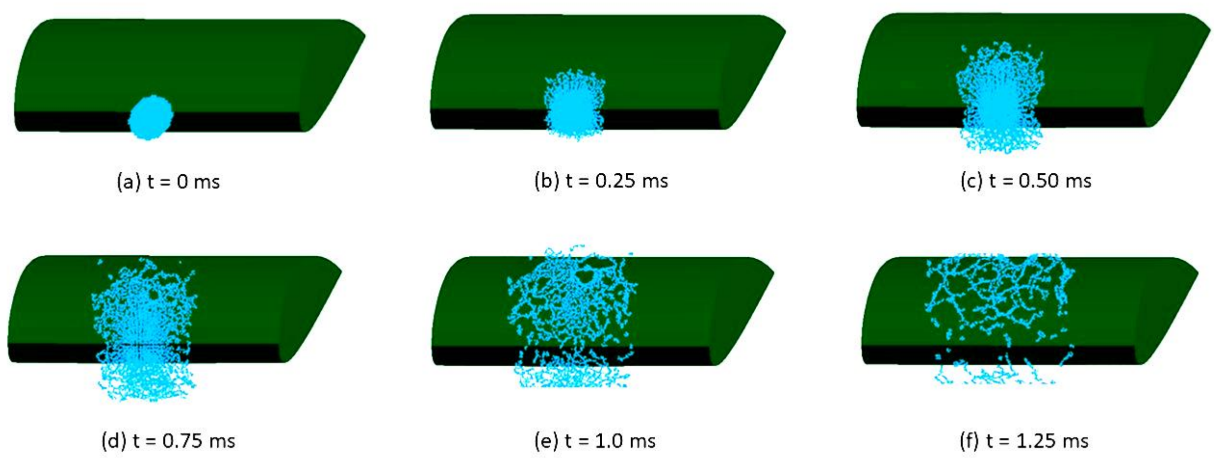

Fig. 10 - Computational results of bird strike against 2mm aluminium alloy wing at time intervals of 0 ms to 1.25 ms

The same internal energy at the bird strike locality on the present wing segment is plotted to verify the results obtained as demonstrated in Fig. 11. The Von Mises stress is observed on the surface of the wing at two-time intervals to investigate the conditions of the surface of the wing after the bird strike impact as shown in Fig. 12.

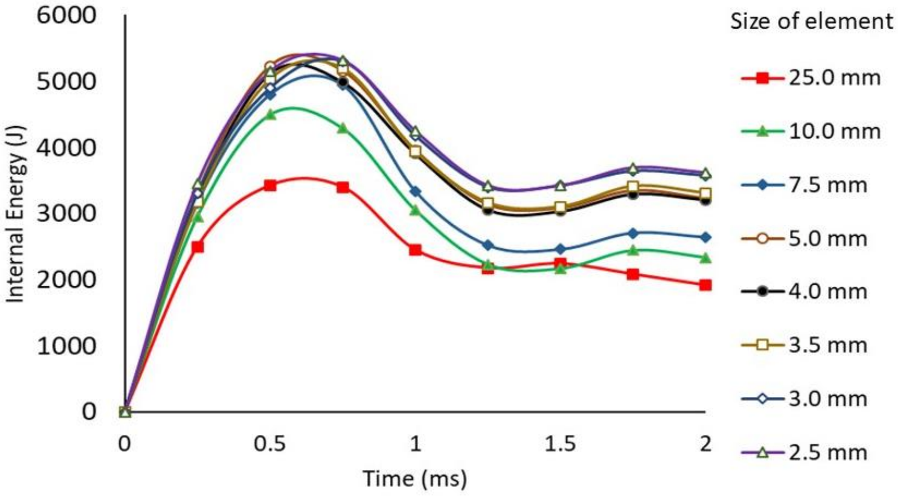

Fig. 11 - Internal energy vs time for different element size

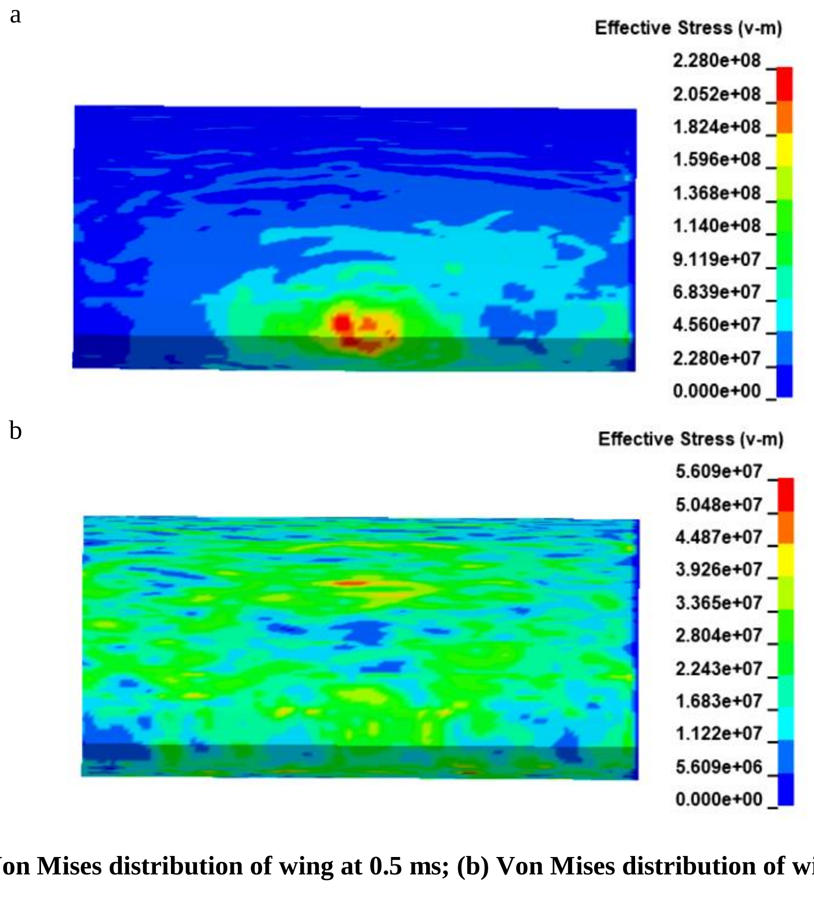

Fig. 12 - (a) Von Mises distribution of wing at 0.5 ms; (b) Von Mises distribution of wing at 2.0 ms

The von Mises stress is utilised to predict yielding of materials under complex loading from the results of uniaxial tensile tests. In this study, as the bird has impacted the aluminium wing surface, the wing structure tends to deflect, and it could cause a fracture in case of the impact occurs at very high speed. Hereabouts, the von Mises stress meets the characteristic where two stress states with regular distortion energy possess an equivalent von Mises stress.

4. Conclusion

This study intends to employ a numerical procedure in evaluating bird strike impact on aerospace alloy structure by circumscribing the relationship between the parameters of the thickness of the plate during bird strike impact simulation. The study has been successfully conducted in the LS-DYNA software version R11.0.0. The method adopted to model the bird for the simulation is by smoothed particle hydrodynamics (SPH) which contributes less computational time. Furthermore, this approach is believed does not have the numerical errors that are caused by distortions after the bird impact.

The bird model shape is maintained to be symmetrical cylinder with hemispherical ends to make sure that the results are consistent. The target which is while the aluminum alloy plate is developed as a shell element plate in finite element model. Such conditions are considered in this research from the view of bird strike impact under various conditions (structural thickness) and constraints (bird size). The results of the bird strike impact obtained is validated with the research conducted by [3] and it show an average percentage error of 4.598% compared with the experimental results.

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