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Numerical Simulation of Bird Strike on a Curved Plate

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***Abstract:*— Bird strike, being a catastrophic problem, has led to many horrendous accidents throughout the world in aviation industry. To get over this problem, a lot of research has been done in the past and still new materials and their combinations are being explored for minimal damage under such accidents. In the present work, an attempt has been made to numerically simulate the bird strike on curved plate where bird is simulated using a projectile and curved plate acts as a part of nose of an airplane. In the present investigation, plate is made of aluminum alloy (7075-T6). This alloy is most commonly used in aviation industry due to its high strength to weight ratio, machinability and relatively low cost. Numerical simulation is carried out using commercially available Finite Element (FE) package ABAQUS®. Herein, three birds namely, herring gull, golden eagle, and Canadian geese are studied for considering the effect of mass and size of the bird. In this numerical simulation, sizes and mass of these three birds are chosen due to their frequent strike in many parts of the world. Each bird is given three different velocities and their impact on curved plate are studied considering the effect of variation of mass, plate thickness and velocity. A simpler approach is applied to numerically simulate the complicated phenomenon of bird strike. The results show that with increase in mass and velocity, damage on the curved plate increases whereas, increase in thickness of plate resulteds in reduced damage.**

***Index Terms* - ABAQUS, Aluminum Alloy, Bird Strike, Numerical Simulation.**

I. INTRODUCTION

Bird strike is one of the major problems faced during the flight, as it is fatal and has caused a lot of damage to life and property. Some major accidents due to bird strike included strike of Lockheed L-188 Electra with a flock of common starlings on 4th October 1960, in which the plane was flying from Boston as Eastern Air Lines Flight 375. The plane struck with birds during takeoff, damaging all four engines and hence the aircraft crashed into Boston harbor with 62 fatalities out of 72 passengers [1].

Another strike took place, in which a U.S. Air Force Boeing E-3 Sentry AWACS aircraft was struck with several Canadian geese, and these were ingested by the engines which led the plane to crash and all 24 crew members on board died [1]. Such strikes never stopped but with increase in commercial use of aircrafts, these strikes increased considerably. Therefore, a lot of research was done to find a solution to such strikes but still a proper solution to it has not yet been found.

Hence, this paper aims to study the bird strike in a different way in order to contribute some data on different birds which may be the cause of this problem and also on the effect of the bird strike on the material which is commonly used in aircrafts.

Many researches in the past carried out investigation using flat plate as the subject but it is to be noted that hardly any surface on the plane is exactly flat, in fact most of them are curved hence, in this analysis, a curved surface was chosen. Also, a lot of research has been done using a rigid plate as the object but in this analysis, more stress is given on studying the effect of bird strike on a curved plate rather than on the bird [2-3]. Hence, the bird is designed in such a manner that it is taken to be rigid in nature.

Since, bird strike can now be easily simulated on different software, it has become very easy to retrieve data regarding this problem, instead of spending a lot of money and performing such experiments. Also, the fact that the results that we receive using the simulation in the software are same as performed during experiment thus, resulting into software simulation being more reliable. Hence, this simulated experiment was carried out in software ABAQUS®.

In this experiment, sizes and mass of three birds were studied which may cause bird strike frequently.

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Subsequently three velocities are allotted to each bird and then the effects of variation of mass, plate thickness and velocity are studied on displacement of strike position i.e. at the center of plate.

II. BIRD SELECTION

According to the existing data, most common types of birds struck by civil aircrafts in USA were gulls (19 species), which accounted 15% of the birds identified in bird strikes during 1990-2012. Waterfowl (ducks and geese) accounted 7% of the strikes but were found responsible for 30% of the strikes that caused damage to the aircraft [4]. Raptors (Eagles) were also identified as the cause of the bird strike.

Hence, three birds, which were found as a major threat for bird strike, were chosen. These are,

1) Herring gull,
2) Golden eagle, and
3) Canadian geese.

Herring gull and Canadian geese are the waterfowls whereas golden eagle is a raptor. Bird strike due to Canadian geese normally takes place during its migration months March, April, and August, September, October and November. Also, these flies in dense flocks which creates a problem and bird strike with them becomes hazardous if they are ingested into an engine [5]. Fig. 1, Fig. 2 and Fig. 3 shows images Herring gull, golden eagle and Canadian goose, respectively [6-8].

Bird strike with golden eagle has occurred during each month of the year. It poses a great threat to the aircraft because of the reason that eagles have a relatively large body mass and hence the amount of damage due to this strike is much more as compared to the other bird strikes [9]. Also, the fact that they are counted as one of the fastest birds in the world, poses a great threat for aircrafts.

Gulls regularly fly over the airfield in the morning, while leaving and return in the evening for feeding which results in a bird strike [10]. Also, the movement of gulls' increases while feeding and breeding which may also result in a bird strike.

Fig. 1: Herring gull in flight.

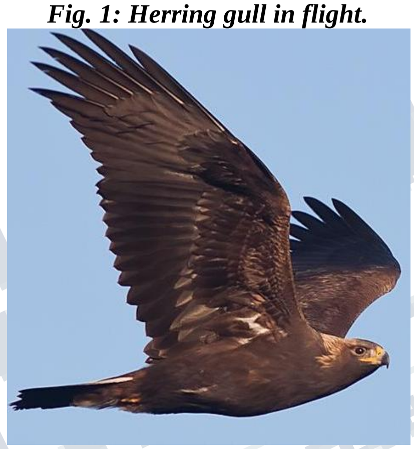

Fig. 2: Golden eagle in flight.

Fig. 3: Canadian goose in flight.

After a detailed literature review, data was collected for designing the bird model and the same is reported in Table I [11-17].

Table 1: Details of birds [11-17].

Size	Bird	Weight (kg)	Length (m)	Radius (m)
1	Herring Gull	1.65	0.66	0.165
2	Golden Eagle	3.6	0.84	0.21
3	Canadian Geese	3.9	0.76	0.19

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III. MATERIALS

The most used material in the aircrafts is aluminum and its alloys of 7000 series. The most used aluminum alloy is 7075 T6 due to its high strength to weight ratio, machinability and relatively low cost. Hence, this material was selected to model the curved plate in this analysis. The material chosen is aluminum alloy 7075-T6, as it is one of the most commonly used alloy in making aircraft skin and structures. It has density of 2810 kg/m^3, Young's Modulus of 71.7 GPa and Poisson's ratio of 0.33. Fig. 4 shows stress-strain curve of the material used in the present investigation.

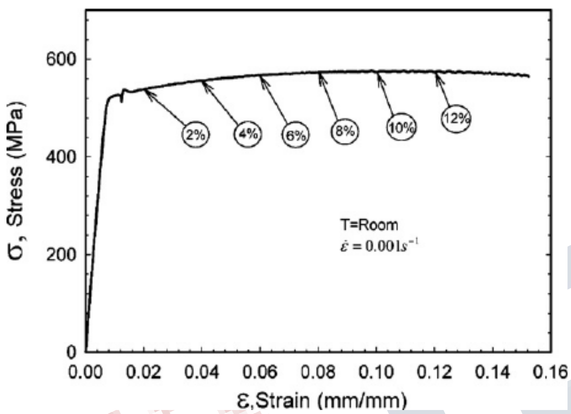

Fig. 4: Stress-strain curve of aluminum 7075-T6.

IV. FINITE ELEMENT (FE) MODELLING

Three curved plates of dimension 2 m × 1.06 m and with a radius of curved surface as 0.86 m was modeled (Fig. 5). The plates were chosen as 3-dimensional deformable shell with shell thicknesses of 0.03 m, 0.02 m and 0.015 m. The most common shape of bird as a cylinder with hemispherical ends was chosen for the analysis. The bird was modeled such that its length to diameter ratio was 2 (the length was decided after studying about the birds and the radius was calculated as per the mentioned ratio) [18, 19]. The bird was modeled as 3- dimensional, discrete rigid solid extrusion and then turned into a solid shell (Fig. 6). As mentioned above, the aim of this analysis was to see the effects of bird strike on the curved plate. The present simulation is carried out using ABAQUS®/Explicit [20]. The model was made such that it consisted of a bird and a curved plate; the bird was instanced at a position just in front of the center of the plate and at a distance of 0.05 m from the center. Three different velocities are assigned as 150 m/s, 190 m/s and 250 m/s using predefined field (in ABAQUS®). The boundary condition Encastre was specified at the edges of the plate and the boundary condition on all the rotations were applied on the bird model. The Fig. 7 shows the assembly of the model.

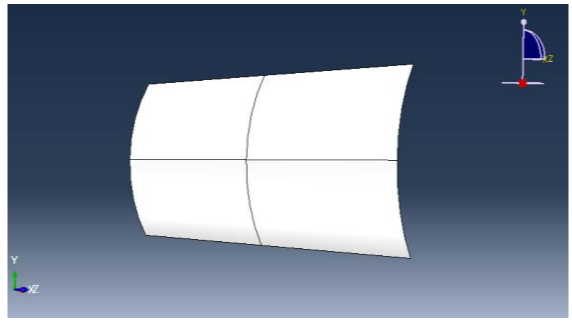

Fig. 5: Curved plate.

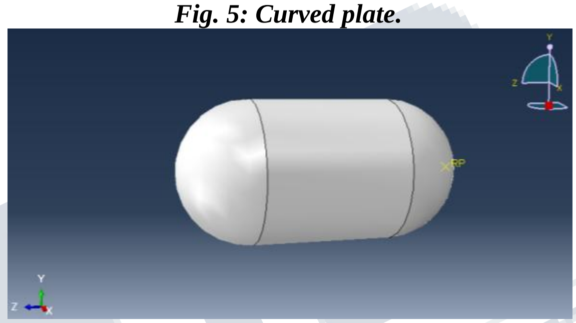

Fig. 6: Bird model.

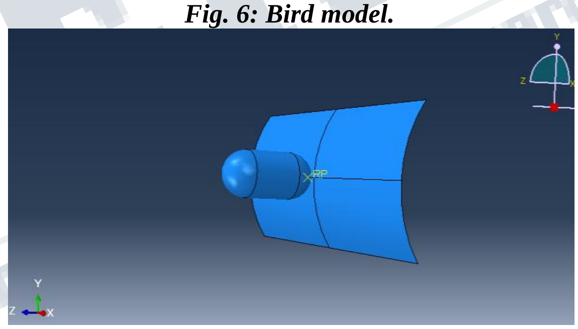

Fig. 7: Assembly of bird and curved plate model.

When an analysis is run, if the meshing is coarse in nature, then the results that are obtained are not accurate. If the mesh density is increased, the results also change but on further mesh refinement, if there is no change seen in the results then, the mesh is said to be converged and the solutions are no more dependent on the mesh. Hence, to get accurate results, the solution has to be checked for different meshes and it has to be decided that which seed will be used for further analysis [20].

Therefore, after completing the assembly of the model, the analysis was run for different seeds in order to find the right seed such that accurate results were obtained and hence the job was run with the bird model of Canadian geese at velocity 250 m/s. The results were obtained as shown in Fig. 8. It was clearly seen that the lines representing the results with seed 0.01 and 0.007 were overlapping and hence

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seed 0.01 was chosen as the seed to mesh all the models since the run time was less with seed 0.01 than with 0.007. First for plate thickness 0.03 m, the jobs were run for all the bird masses and the velocities assigned to them. Similarly, for plate thickness 0.02 m and 0.015 m, the jobs were run. Fig. 9 shows the effect of variation of the mass and Fig. 10 shows the effect of variation of plate thickness. Fig. 11 shows the effect of variation of velocity on the center of the plate in the form of displacement time history.

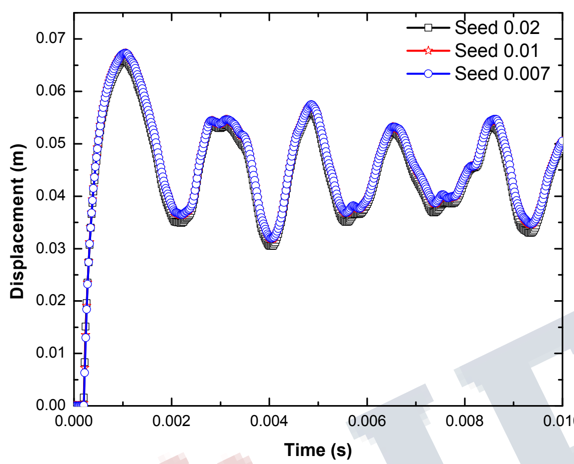

Fig. 8: Mesh convergence.

V. RESULTS AND DISCUSSIONS

The curves reported in Fig. 9, Fig. 10 and Fig. 11, shows displacement time history for effect of mass, thickness and velocity, respectively for the plate considered in the present investigation. Fig. 9 shows displacement time history wherein, velocity and plate thickness were kept constant i.e. 250 m/s and 0.03 m respectively, for understanding the effect of variation of mass i.e. varying mass of 3.9, 3.6 and 1.65 kg. Since, there was a little difference between the bird mass 3.6 and 3.9 kg, the displacement-time history for these mass birds were very close that is the damage at the center of the plate for these two weights was observed to be almost similar. It was also seen that the displacement was maximum at 0.001s for a bird mass of 3.9 kg and 3.6 kg and for 1.65 kg, it was maximum at 0.00068 s. Fig. 10 shows effect of variation of plate thickness for the displacement at the center of the plate. In this case, the bird mass and velocity were kept constant with values 3.9 kg and 250 m/s, respectively and the plate thickness were taken as 0.03, 0.02 and 0.015 m in sequence. Peak displacement was seen at 0.00106 s for plate thickness of 0.03 m; at 0.00158 s displacement was seen to be maximum for plate thickness 0.02 m and at 0.0022 s for plate thickness 0.015m. Later, it is observed that the deviations in the displacement gradually decreased. Fig. 11 shows the effect of variation of velocity on the plate where the bird struck. This was carried out with constant bird mass and plate thickness with values 3.9 kg and 0.03 m, respectively. The velocities taken were 250 m/s, 190 m/s and 150 m/s, respectively. For velocity of 250 m/s, the peak displacement was seen at 0.00106 s, for 190 m/s the peak displacement was seen at 0.00104 s and for 150 m/s the peak displacement was seen at 0.00096 s. It was also seen that with different velocities, though the distance provided between the plate and the bird was constant (i.e. 0.05 m), the time to strike the bird was different for the same time period of 0.01 s.

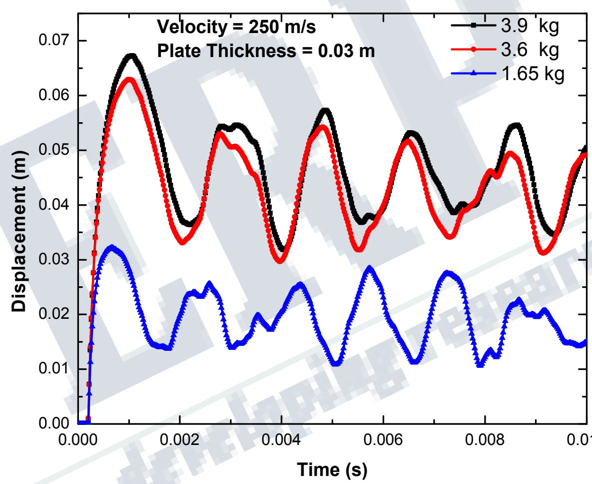

Fig. 9: Displacement-time history showing effect of variation of mass.

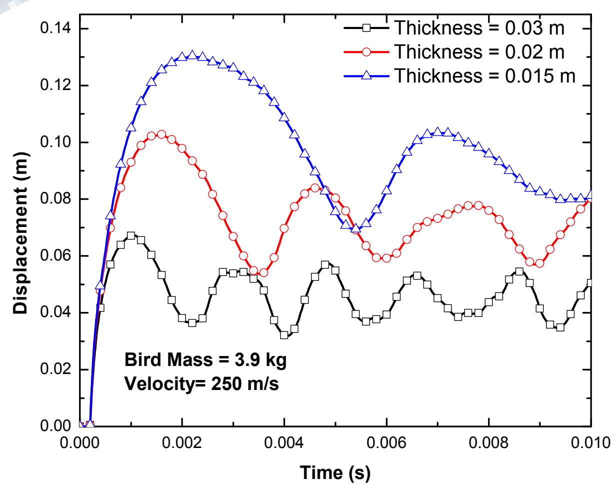

Fig. 15: Displacement-time history showing effect of variation of thickness.

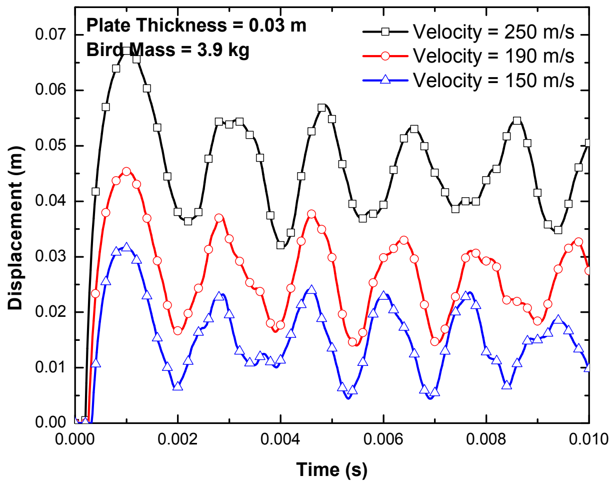

Fig. 15: Displacement-time history showing effect of variation of velocity.

VI. CONCLUSIONS

The analysis was carried out successfully and the results were interpreted using the displacement-time history curves for various parameters which included effect of variation of mass, plate thickness and velocity on the center of the curved plate due to bird strike. Based on above analysis, following conclusions are drawn:

1. With decrease in weight of the bird, the damage (displacement) decreased.
2. As the thickness of the curved plate decreased, the damage at the center of the plate increased.
3. With the decrease in velocity, the amount of damage also decreased considerably.

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