The Influence of Bird's Shape and Attitude on Bird-strike Analysis of Structure

J.F. Kou, F. Xu
School of Aeronautics
Northwestern Polytechnical University
Xi'an, China

Abstract—**In order to research the influence of bird shape and attitude on structure for bird strike, bird-strike on elastic panel investigated with various length-to-diameter aspect ratio and different attitude angle of bird through numerical simulation. The results indicate that aspect ratio of bird strongly affects the stress distribution of impacted panel, and the stress of panel incresases with the decreasing of aspect ratio. Meanwhile, different attitude causes little change of stress near the impact region but obvious change far away from the impact region. When the angle of attitude is less than 45 degree, the difference of stress distribution of panel caused by angle of attitude is not obvious compared to the results of 0 degree angle. In addition, the influence of large angle of attitude should be considered if the weak part of structure is far away from the impact region.**

Keywords-bird-strike; shape of bird; attitude of bird; structure stress

I. INTRODUCTION

Bird strikes are a major threat to aircraft structures. Early in 1975, the bird-strike was systematically studied by JP Barber and others through theoretical and experimental approach with the influence of bird's mass, porosity, velocity and impact direction on the impact pressure [1-3]. However, the experimental results are not coinciding with the theoretical results well for the deviation of the theoretical model and the restriction of experimental conditions [4].

There is no standard shape of bird model although the influence of bird-shape on impact force had studied by many researchers. In the current study, four different typical shapes, namely: sphere, straight-ended cylinder, hemispherical-ended cylinder and ellipsoid were selected, and all of them mainly reflect the shape and quality of bird's torso [5, 6]. Nizampatnam [7] investigated the influence of the bird shapes on the shock and steady-flow pressure. Although similar pressure results are showed in the study, the hemispherical-ended cylinder was closest to experimental data of Wilbeck [2]. Moreover, Anghileri [8] showed that the untrue large local stress result from the large instantaneous contact area in straight-ended cylinder model. Therefore, hemispherical-ended cylinder was selected by most researchers.

The influence of the length-to-diameter aspect ratio of the bird was found to have large influence on the impact force but little on the pressure [9, 10]. Moreover, a bird model with geometry similar to a real bird (Bufflehead Duck) was introduced and compared to traditional bird models by Reza [11], and the impact pressure were compared with the four typical shapes. It was found that the impact force of realistic shape was lower than the typical shapes when impact from bird's tail or head, but higher than the typical shapes when impact from bottom .Previous studies about the influence of bird model focus on the impact pressure rather than the structure, the response of structure stress is unknown.

The quality, impact velocity and impact position were stipulated by the industry standards [12], but not identical regulations for the attitude of bird. Furthermore, little researcher focus the influence of bird attitude on the structural safety. In the bird-strike tests, there will be a constant angular velocity when the bird launched from the air gun, and the bird deflects before impact the structure is shown in Fig.1, the white line represents the bird with no deflected body attitude, the red one is the bird realistic attitude during the test. The problem is: to what extent is the change of attitude effect the structure safety?

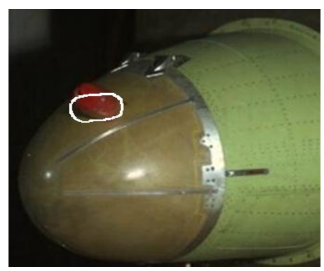

FIGURE I. THE DEFLECTION OF BIRD IN BIRD-STRIKE TEST.

The aim of the present investigation is to compare and analyze the numerical results for bird's various length-to-diameter aspect ratios and attitudes in two parts of this paper respectively, and to draw a conclusion of the influence of test result that the bird deflected.

II. THE INFLUENCE OF BIRD'S SHAPE ASPECT RATIO ON IMPACT RESISTANCE OF STRUCTURE

A. *Numerical Model for Different Bird'S Shape*

The influence of aspect ratio on impact resistance of structure is analyzed by numerical simulation. Bird is modeled through SPH method in which the particle distance is 4mm and the mass of bird is 1.8kg. since the bird acts as fluid dynamical behavior during high-velocity impact procedure, the state equation is selected, as follows:

$$P = P_0 + B((\rho/\rho_0)^{\gamma} - 1) \quad (1)$$

where P_0 is initial pressure, B is stiffness and γ is dimensionless parameters, ρ_0 and ρ are the initial density and current density of bird respectively. the parameters are shown in table1.

TABLE I. PARAMETERS OF BIRD.

P_0/MPa	B/ GPa	ρ_0/(ton mm^3)	γ/1
0	9.3	9.5e-10	7.14

Five different shapes of bird have been modeled according to different length-to-diameter aspect ratio, with the hemispherical-ended cylinder. The aspect ratio 1.0 is sphere, as shown in Fig.2, the bird with the velocity of 116.7m/s impact the center of the panel which the area of 1m×1m and the thickness of 4mm. The elastic modulus of the panel is 70 GPa, the finite element model of elastic panel has been built using solid hexahedron element, with 4 elements through the thickness of panel, and the element dimension for the impact region is 1.4mm×1.4mm×1mm.

In all simulation, the node to surface contact algorithm was selected in order to model the contact between the bird and the plane. All the nodes placed on the SPH particles were used as the slave set and all the plane elements were used as the master set.

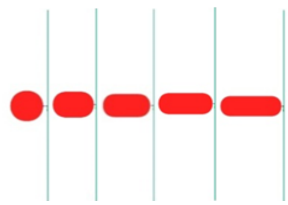

FIGURE II. THE NUMERICAL MODELS OF BIRD-STRIKE WITH DIFFERENT BIRD ASPECT RATIO.

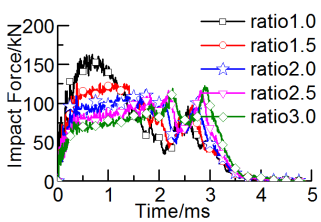

FIGURE III. THE IMPACT FORCE OF BIRD-STRIKE FOR DIFFERENT ASPECT RATIO.

Fig.2 plots bird-strike model with different aspect ratio, the red and green parts present bird and impacted plate respectively, in which the aspect ratio of bird is 1.0,1.5,2.0,2.5,3.0. from left to right.

B. The Contact Force for Different Bird'S Shape

The contact force between bird and plate from simulation is the bird impact force , Fig.3 depicts the impact force with different aspct ratio of bird. Examing Fig 3, it can be seen that the impact force becomes large with the decresing of aspect ratio. and impact force with aspect ratio 1.0 is twice as much as that with aspect ratio 3.0, which illustrates aspect ratio has great influence on impact force which agree with the conclusion from Meguid SA [8]. In Meguid's research, the impact force is normalized by the cross-section of bird model. The normalized impact force would have little relationship to aspect ratio of bird. And, it is concluded that the aspect ratio has slight influence on simulation results. However, the sturctures stress that we should foucus on is not directly related to the impact pressure. Therefore, in this paper, the influence of aspect ratio in calculation results is obtained according to the stress distribution of impacted structures.

C. The Stress of Panel for Different Bird'S Shape

As stress distribution is symmetriced about the center of panel and the maximum stress occurs in the center piont O, as illustrated in Fig.4, it is resonable to analyse the stress in noly six monitoring position denoted O,A,B,C,D,E in Fig.5, Position A is 50mm from the center of the panel and located inside the impact region result from the bird with radius of 53mm, the distance between position B and center of the panel is about 100mm, as a result, position B is considerd as proximal monitoring position, while positons C~E are over 200mm from the center, those positons are distal monitoring position.

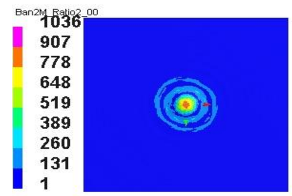

FIGURE IV. THE DISTRBUTION OF STRESS FOR PLATE IMPACTED BY ASPECT 2.0 BIRD.

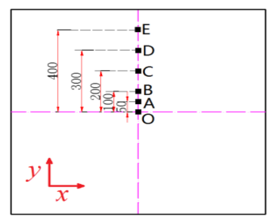

FIGURE V. THE MONITORING POSITION FOR PLATE STRESS.

Fig.6 shows the von-mises stresses located in the center, versus time with different aspect ratio for bird strike, the stress reaches apeak corresponding to the time of 0.3ms, and the contact force reaches apeak corresonding to the time of 0.6ms shown in Fig.3, it's shown that the maximum stress didn't cause by maximum force directly.

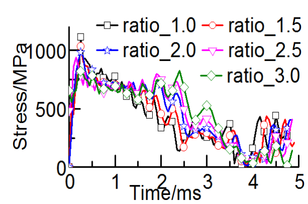

FIGURE VI. STRESS PROFILE AT THE CENTER OF PLATE.

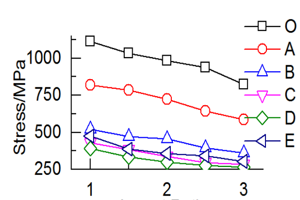

FIGURE VII. THE MAXIMUM STRESS AT MONITORING POSITION.

Fig.7 shows the comparion of stress versus aspect ratio at each monitoring position, the horizontal and vertical axis represent aspect ratio and stress respectively. the results indicate that aspect ratio influences stress of impacted plate greatly. In general, the larger of the distance form the impact position, the more ovbious the influence is. In the impact position, the stress resulting from aspect ratio 1.0 of bird is 13% and 35% larger than stress with aspect ratio 2.0 and 3.0 respectively. However, the corresponding percentage is 32% and 55% respctively in the most remote monitoring position E.

III. THE INFLUENCE OF BIRD'S ATTITUDE ON IMPACT RESISTANCE

In aviation, the birds impact the aircraft by all kinds of attitude, however, in bird-strike test, bird can only impact specimen from head or tail side due to the limit of test equipment at present. Two problems should be solved in present condition: 1) whether the attitude of bird in recent test is most harmful to specimen; 2) whether the test date is efficient if the bird has rotation as illustrated in Fig.1, few papers has proposed these two issues.

A. *Numerical Model for Different Bird'S Attitude*

In order to analyze these two issues above mentioned, the bird with different attitude impact plate was simulated, in which the velocity direction of bird is the regative of axis z, and bird of aspect ratio 2.0 is utilized, as shown in Fig.8. the angle of attitude of those bird are 0°,22.5°,45°,67.5°,90°, respectively, from left to right, and the center of gravity of the birds are coincide with the center of plate in velocity direction.

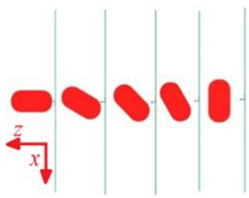

FIGURE VIII. THE NUMERICAL MODELS OF BIRD-STRIKE WITH DIFFERENT BIRD ATTITUDE ANGLE.

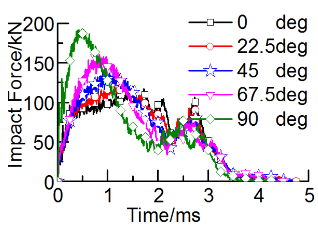

FIGURE IX. THE IMPACT FORCE OF BIRD-STRIKE FOR DIFFERENT ATTITUDE ANGLE.

B. *The Contact Force for Different Bird'S Attitude*

Fig.9 plots the influence of angle of attitude on impact force, the maximum and minimum impact force are correspond to 90°and 0°, respectively. that is, when the bird impacts the plate with bottom side, the impact force reaches maximum, while it gets to minimum with tail side.

C. *The Stress of Panel for Different Bird'S Attitude*

Impact point vary with angle of attitude resulting in different stress distribution in impact region. The maximum stress is located beside the impact point instead of center of the plate. the impact point means the position where the bird contact with plate very initially. And the position of maximum stress offset to positive direction of x axis due to the impact point deflect along with the same orientation.

It should be noted that the maximum stress of plate appears in the back side instead of front. And, the stress in coreponding position of front is much too low when the maximum located in back side of the plate. This appearance indicateds the contact pressure in this poistion is low, which impies the relationship between pressure and stress of structures is not distinct as shown in Fig.10, the study of structure stress can't be substituted by pressure in previous papers.

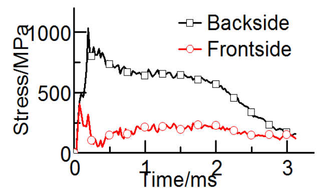

FIGURE X. STRESS PROFILE ON FRONT AND BACK SIDE FOR 0° ATTITUDE.

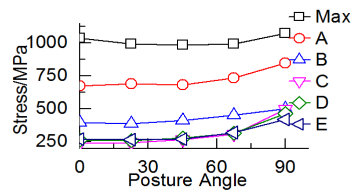

FIGURE XI. THE MAXIMUM STRESS AT MONITORING POSITION.

Five monitoring position ,A,B,C,D,E,shown in Fig.5 are slected to study impact stess response of the plates with different angle of attitude. As piont O lies in *x* coordinate and is close to impact piont, the stress in piont O was much affected by the changing of impact point, thus, maximum stress located near impact point instead of stress in piont O in Fig.11 which depicted the maximum stress and stress in monitoring position with different angel of attitude. It is shown that stress increases with the increasing of angle of attitude varying from 22.5° to 90°. the maximum stress appears corresponding to 90 angle. Table 2 gives stress deviation in in senor pionts relative to 0 angle of attitude.

TABLE II. DEVIATION OF PLANE STRESS BETWEEN 0° ATTITUDE AND THE OTHERS(%).

Attitude Angle	Max	A	B	C	D	E
22.5	-4.1	2.0	-0.6	2.6	-1.5	-1.3
45	-2.5	0.8	1.0	11.7	6.1	0.0
67.5	1.4	8.5	4.0	28.9	19.2	18.7
90	3.6	25.5	7.3	109.7	75.8	55.0

Attitude has little influence on maximum stress near impact position. the deviation of maximum stress with 0° angle relative those of other angles is less than 5%. However, the deviation in positions far away from impact position is evident. In the remote position C,D,E, the deviation between stress with 90° and 0° angle of attitude is more than 50%, and especially reaches 100% in position C. Meanwhile, for each monitoring position, stress deviation between 0° angle of attitude and other angle less than 45°, is not more than 10%. when anlge of attitude is over 67.5°, this deviation for distal monitoring position is more than 20%.

It can be found that impact force increases with the increasing of angle of attitude varing from 0° to 67.5°, as shown in Fig.9, nevertheless, the increase amplitude is lower associated with angle of attitude from 67.5° to 90°. Accordingly, the stress of monitoring position shown in Table.2 expresses a similar phenomenon, that is the stress and impact force of plates increase suddenly from 67.5° to 90°. Moreover, the stress of plate with 0° ~ 67.5 °angle of attitude is identical approximately and symmetric about center of the plate, but the stress distribution with 90° angle of attitude is symmetric about *xoz* plane and *yoz* plane. The reason for those phenomenons is that the initial contact part of bird with plate is the semisphere at ends of bird model in the case 0°~67.5° angle of attitude and the contact type is piont contact.However, for 90 °angle of attitude, the initial contact part of bird is the lateral of cylinder in the middle of bird model and this contact type is line contact. In addition, the maximum stress appears within 0.3ms after the contact between bird and plate, and the displacement of bird is less than the radius of semmisphere which is 53mm. Bease on it, the contact surface is almost circular in the case of the 0°~67.5 °angle of attitude, while the corresponding contact surface is ellpse with 90° angle of attitude. The difference between these two shape of contact area results in the derivation of stress and conpact load corresponding to 90° angle of attitude relative to other attitudes.

IV. CONCLUSION

The aspect ratio of bird plays an important role on stress distribution of impacted plate. the stress of plate incresase with the decreasing of aspect ratio. Stress of plate with aspect ratio 1.0 is 13% larger than that with aspect ratio 2.0, furthermore, this influence of aspect ratio on stress located far away from impact position is more obvious, the correspinding percentage is 35%.

The attitude of bird affects stess distrbition little for regions near the impact position and the devivation is less than 5%. However, this effect of attitude on stress located far away from impact position is distinct and the maximum devivation is over 100%. And the devivation of stress in all position of structure is less than 12% associated with angle of attitude varying from 0° to 45°, therefore, deflection of attitude in small range has little influnce on test results. Eventually, the influence of large angle of attitude should be considered if the weak part of structure is far away from the impact region.

ACKNOWLEDGEMENTS

This research has been financially supported by 111 Project B07050.

REFERENCES

[1] Barber JP, Taylor HR, Wilbeck JS. Characterization of bird impacts on a rigid plate: Part 1. Technical Report AFFDL-TR-75-5, Air Force Flight Dynamics Laboratory; 1975.

[2] Wilbeck James S. Impact behavior of low strength projectiles. AFML-TR-77-134,Air Force Materials Laboratory; 1977

[3] Barber JP, Taylor HR, Wilbeck JS. Bird impact forces and pressures on rigid and compliant targets. Technical Report AFFDL-TR-77-60, Air Force Flight Dynamics Laboratory; 1978

[4] Lavoiea M.A., Gakwaya A., Nejad Ensan M., et al, Bird's substitute tests results and evaluation of available numerical methods, International Journal of Impact Engineering 36, pp1276–1287,2009

[5] McCallum SC, Constantinou C. The influence of bird-shape in bird-strike analysis. In: 5th European LS-DYNA users conference, Birmingham, UK, May 25–26; 2005

[6] Sebastian Heimbs, Computational methods for bird strike simulations: A review, Computers and Structures 89, pp2093–2112, 2009

[7] Nizampatnam LS. Models and methods for bird strike load predictions. PhD thesis, Wichita State University; 2007

[8] Anghileri M, Sala G. Theoretical assessment, numerical simulation and comparison with tests of birdstrike on deformable structures. In: Proceedings of the 20th ICAS congress, Sorrento, Italy, September 8–13; pp. 665–74, 1996,

[9] Meguid SA, Mao RH, Ng TY. FE analysis of geometry effects of an artificial birdstriking an aeroengine fan blade. Int J Impact Eng 35(6), pp487–98, 2008

[10] Mao RH, Meguid SA, Ng TY. Transient three dimensional finite element analysis of a bird striking a fan blade. Int J Mech Mater Des 4(1), pp79–96, 2008

[11] Reza Hedayati，Saeed Ziaei-Rad, A new bird model and the effect of bird geometry in impacts from various orientation, Aerospace Science and Technology 28, pp9–20, 2008

[12] HB 7084-1994, Requirements of anti-bird impact design and test for civil aircraft, 1994(in Chinese)