Study on bird impact response of windshield glass of all general aviation aircraft

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Abstract. With the improvement of aircraft flight speed, bird impact is easy to cause serious accidents such as windshield breakdown, aircraft destruction and human death. In order to improve the bird impact resistance of aircraft windshield glass, the dynamic response of windshield glass (YB-3 plexiglass) after bird impact of small general-purpose aircraft flying at cruise speed was studied. By establishing the bird impact windshield glass model and adopting the fixed restraint mode around, the windshield glass is impacted at the speeds of 200km/h, 220km/h and 250km/h and the angles of 30°, 60° and 90°, respectively. The changes of stress-strain, displacement and energy absorption of the windshield glass under the impact of bird body, as well as the effects of different impact speeds and impact angles on the dynamic response of the glass are analyzed. It is found that during the whole impact process, the stress and strain of YB-3 plexiglass will reach the peak in a short time, then oscillate back and forth in a period of time, and the final residual deformation is small. With the increase of impact velocity, the stress, strain and displacement of glass will increase accordingly; With the increase of the impact angle, the energy absorbed by the windshield glass decreases accordingly, and the damage and deformation around the impact point are reduced. By studying the bird impact of the windshield of small general-purpose aircraft, it provides a theoretical basis for the airworthiness certification of general-purpose aircraft and the design optimization of windshield glass.

Keywords: Bird strike; Windshield glass; Dynamic response; Deformation.

1. Introduction

Bird strike has always been one of the major hidden dangers affecting aviation safety. With the continuous development of the aviation field, the problem of bird strike has attracted much attention in recent years, but the solutions, preventive measures and systems for this problem are not perfect. In particular, bird impact on windshield glass needs to be strictly prevented. From 1990 to 2020, the number of bird impact on aircraft windshield glass in the United States reached 30678, of which 1240 caused serious harm to aircraft and personnel on board [1]. Regardless of the total number of impacts or the proportion of damage, windshield glass is the highest in all parts of the aircraft. Therefore, it is necessary to conduct further Bird Impact Research on windshield glass.

At present, the experimental method and the numerical analysis method using the finite element method are two mainstream bird impact research methods. The bird impact experiment can provide the basis and experience for the theoretical research of bird impact and other types of impact experiments [2], and the numerical analysis can provide the theoretical basis for the pre design of aircraft structure. The numerical simulation is divided into decoupling method and coupling method. The decoupling method needs to predict the bird impact load waveform; The coupling law uses the collision theory to solve the bird body and the impact object simultaneously with the constraints, in which the grid division method will have a certain impact on the simulation results.

Zhang [3] studied the bird impact load waveform in the decoupling method and obtained a half sine wave. Zhang [4] found that if the speed of the bird is less than 100m/s, the results of establishing the bird model by Lagrange method are closer to the test results than by Euler method; Li [5] found that SPH method is very suitable for high-speed impact.

Nimmer [6] obtained the triangular bird impact load waveform; Saeed [7] found that the coupled Eulerian Lagrangian method can also simulate the high-speed flying birds; Anghileri [8] found that when using particle flow to simulate bird body, the results obtained have a certain relationship with the density of particle flow, and dense particle flow is more conducive to the simulation of bird body. In addition, Haslc [9] also used the fully connected neural network to estimate the overall deformation of bird impact of laminated plates, and the results are also close to the actual situation.

In this paper, using the display dynamics module in Workbench, the bird impact model is established by Lagrange method, and the simulation of multiple groups of preset working conditions is carried out. The obtained data are sorted and analyzed, and the dynamic response change law of glass after impact is obtained, which provides a theoretical basis for the design optimization of new windshield.

2. Bird body and windshield model

2.1 Windshield model

The size of windshield glass is 800mm × A 600mm thick, 2.5mm thick single-layer YB-3 plexiglass is used to describe the constitutive characteristics of YB-3 plexiglass by Zhu Wang Tang nonlinear viscoelastic constitutive equation [10].

$$\sigma = E_0\varepsilon + \alpha\varepsilon^2 + \beta\varepsilon^3 + E_1\int_0^t \dot{\varepsilon}\exp\left(-\frac{t-\tau}{\theta_1}\right)d\tau + E_2\int_0^t \dot{\varepsilon}\exp\left(-\frac{t-\tau}{\theta_2}\right)d\tau \qquad (1)$$

Where, σ is the stress of the material; ε is the strain of the material; E0, E1, and E2 respectively represent the elastic modulus of the material and the elastic parameters determined by the viscoelastic dynamic response at low and high strain rates.

a, β is the nonlinear elastic constant; θ1, θ2 is the relaxation time determined by the viscoelastic dynamic response at low and high strain rates respectively (Table 1).

Table 1. Parameters of YB-3 organic glass

E_0	E_1	E_2	θ_1	θ_2	μ	a	β
2.95GPa	0.832GPa	5.24GPa	7.33s	40.5μs	0.4	-10.9GPa	-96.4GPa

2.2 Bird model

When modeling a small bird, the shape of the bird's trunk is mainly simplified (Fig. 1). Among them, the simulation effect with hemispheres at both ends and similar capsule shape is the best [12]. In the problem of bird impact, the impact angle should be considered. Generally, the bird body and the glass do not impact vertically at 90 °, but impact obliquely at a certain angle. This capsule shaped geometric model makes the impact contact area largest, which is closer to the actual situation. The bird's geometric model adopts a capsule cylinder with a length diameter ratio of 2:1 [13].

The properties of the body material are closely related to the speed of the bird. Generally, the bird body shows the properties of elastic-plastic materials in low-speed flight; In high-speed flight, the fluid material properties of bird body are more obvious. Therefore, when selecting the bird body constitutive model, the bird body flight and impact speeds set in the simulation should be fully considered. In the numerical simulation of bird impact, the impacted object is usually fixed, and the speed of the bird body should be set as the relative speed of the aircraft and the bird in the actual impact process, that is, the sum of the algebraic value of the actual aircraft flight speed and the algebraic value of the bird body flight speed. The actual bird impact often occurs in the take-off and landing stages of aircraft. The take-off speed of the small general aviation aircraft studied in this paper is about 150km/h, and the actual flight speed of birds generally does not exceed 50km/h. Therefore, the bird impact speed set in the simulation is about 200km/h. At this speed, the bird body has obvious elastic-plastic material properties, so the material model of the bird body is an elastic-plastic material model.

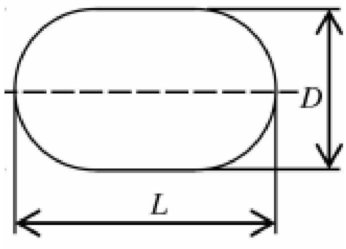

Fig. 1 Simplified side shape of common bird torso

Table 2. Bird body material model parameters [14]

Density	Modulus of elasticity	Poisson's ratio	Yield stress	Shear modulus	Failure strain
900 kg/m^3	10 GPa	0.3	1 MPa	5 GPa	1.25

3. Finite element simulation

3.1 Modeling

The Workbench software is used to establish the three-dimensional models of the two. Considering that the elastic-plastic properties of the bird model are more obvious, the Lagrange method is used to establish the model in this paper, as shown in Fig. 2.

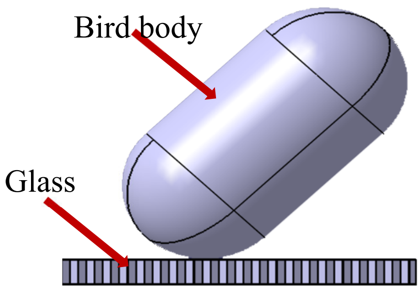

Fig. 2 Bird body and glass finite element model

3.2 Meshing and constraints

Mesh the model by mesh element. Although the overall geometry of the whole model is relatively regular, there is still a surface transition between the two ends and the middle cylinder of the capsule bird model. In order to improve the accuracy of calculation, hexahedral mesh is used to divide the model, especially at the surface of the bird model, and the mesh is appropriately sparse in the more regular area, While ensuring the calculation accuracy and accuracy, it also reduces the running time as much as possible.

In the numerical simulation of bird impact problem, there are mainly several ways to constrain the windshield glass, such as whether or not to constrain, constrain X and Y directions, hinge support, and fully fixed support. At the initial stage of the impact process, the boundary conditions have little effect on the normal displacement and pressure of the center point of the inner surface of the windshield; A few milliseconds after the impact, the stronger the boundary condition is, the more degrees of freedom are constrained, the smaller the normal displacement of the center point of the inner surface is, and the greater the maximum value of the absolute pressure at that point is; When the boundary is not constrained, the normal displacement of the center point of the inner surface continues to increase, and the absolute value of the pressure at this point slowly decreases. However, after the bird impact, the windshield as a whole moves horizontally, which is greatly deviated from the results caused by the actual impact accident. The simulation effect is not as good as that of hinged or fixed support constraints [15]. In this paper, the fixed boundary around the windshield is used to constrain the windshield.

3.3 Set working condition

The angles between the bird body and the windshield glass were taken as 30 °, 60 ° and 90 ° to explore the different effects of different impact angles on the impact of the windshield glass; Take the impact speed of bird body as 200km/h, 220km/h and 250km/h to explore the dynamic response of windshield glass after being impacted by bird body at different speeds. The windshield is restrained.

4. Results and analysis

4.1 Stress strain analysis

Fig. 3 and Fig. 4 respectively show the stress nephogram and curve of the stress on the windshield glass as a function of time after the bird strikes the glass at an angle of 30 ° with the impact speed of 200km/h. Since the stress is equal to the product of strain and elastic modulus, and the elastic modulus is a constant, the change law of the stress and strain on the glass is roughly the same. 0.3ms is the beginning time of bird impact process. Between 0.3ms and 2.2ms, the bird body collides violently with the windshield glass, and the stress borne by the glass continues to increase, reaching the maximum value of about 225MPa in about 2.2ms. The stress fluctuates greatly from 2.2ms to 7ms. After 7ms, the stress changes slightly and tends to be stable with the increase of time. This is because after the bird body and the windshield glass have completed a violent impact, the bird body is far away from the windshield, and the direct stress generated by the bird body on the windshield glass gradually decreases. However, the stress residual wave generated during the impact process still does not dissipate in the windshield glass, and oscillates and reflects, making the stress on the windshield glass fluctuate for many times. After a period of time, it gradually becomes stable and decreases until it approaches zero.

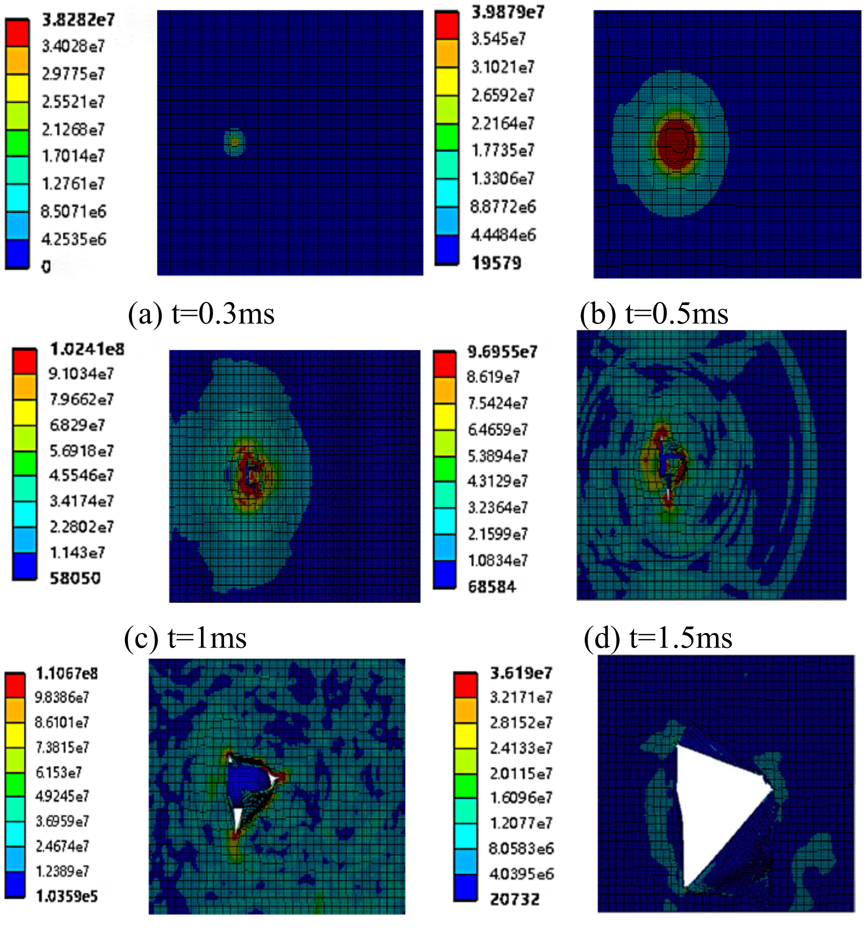

Fig. 3 Stress nephogram change after windshield glass impact

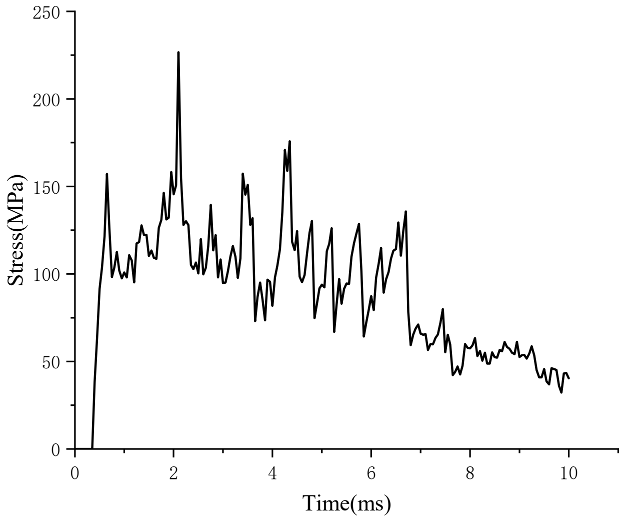

Fig. 4 Time dependent stress curve of windshield glass with impact speed of 200km/h and angle of 30 °

Fig. 5 shows the strain curve of windshield glass with time under three different speeds. It can be seen that when impacting the same position at the same angle, the strain variation trend of the windshield under the three impact speeds is roughly the same, but the strain produced by the windshield will increase with the increase of the impact speed, and will reach the peak value of stress and strain in a shorter time. When impacting at the speed of 220km/h, the peak value of strain is about 0.5ms ahead of the peak value of strain produced by the impact at the speed of 200km/h, The peak value of strain produced by impact at the speed of 250km/h is earlier, about 0.3ms earlier than that at the speed of 220km/h. Under the three different impact speeds, the stress and strain of the windshield glass fluctuated up and down in a period of time after reaching the peak value. After the impact, the residual stress wave gradually dissipated after a few milliseconds and finally became stable.

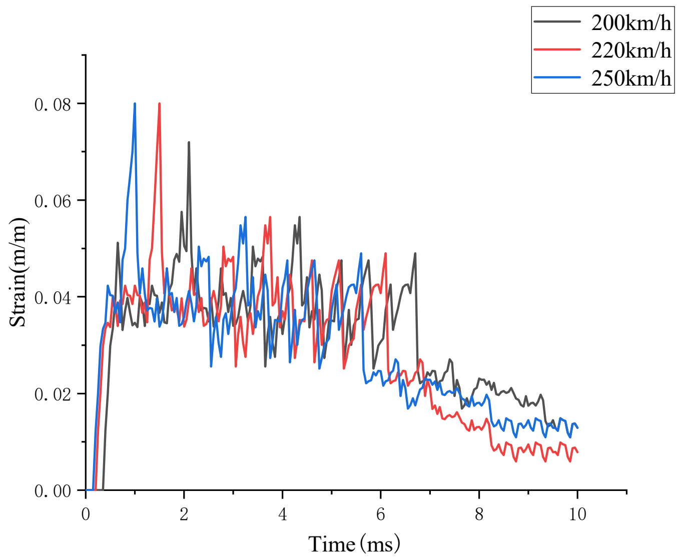

Fig. 5 strain curve of windshield glass with time at different speeds

4.2 Displacement analysis

Take points A, B and C at different positions on the windshield glass, where point a is far from the impact point, and points B and C are around the impact point.

The displacement changes at three different positions are measured respectively, as shown in Fig. 6. Since point a is a certain distance from the impact point, no obvious deformation occurs at point a at the beginning of the impact. However, with the progress of the impact process, the deformation around the impact point gradually increases. Finally, the displacement of point a exceeds the thickness of the windshield glass, and the glass is broken. The displacement values of points B and C reach the thickness of the glass immediately after the impact, and continue to increase. After the bird leaves the windshield glass, the displacement has reached more than 3 times the thickness of the windshield glass. Therefore, it can be found that the deformation of the glass during the bird impact is large, that is, after the deformation of the glass, the magnitude and direction of the force may change with the deformation of the glass (Fig. 6).

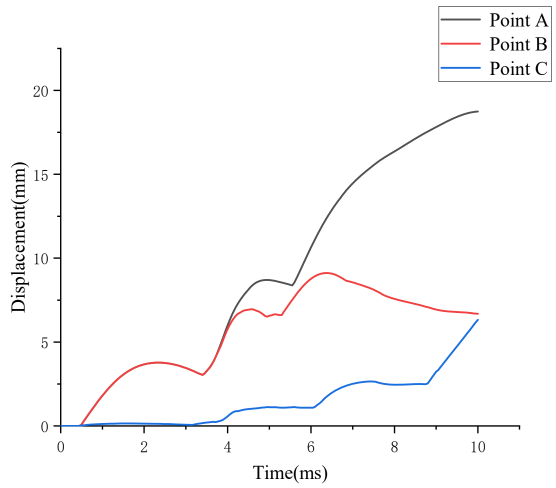

Fig. 6 Displacement change at different positions

4.3 Energy analysis

In the process of bird impact, complex energy conversion occurs between the bird body and the windshield glass. The initial total energy is the kinetic energy of the bird body. After the impact, the speed of the bird body gradually decreases, and the kinetic energy also decreases. Part of the lost kinetic energy is converted into the internal energy of the bird body, part is dissipated through contact energy and heat energy, and the other part is transferred to the windshield glass, so that the internal energy and kinetic energy of the windshield glass gradually increase. After the energy absorbed by the windshield reaches a certain degree, the windshield glass is deformed and damaged. With the end of the bird strike process, the fluctuation of the energy value of each part gradually flattens out. In this paper, the internal energy and kinetic energy of bird body and windshield glass are analyzed and studied.

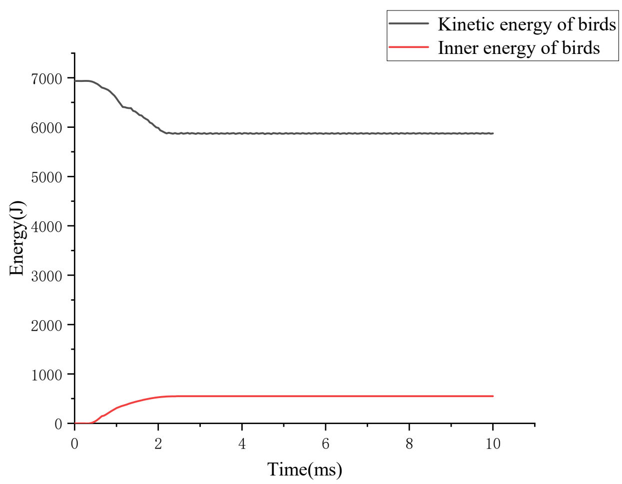

Fig. 7 Changes in bird body energy

Fig. 7 shows the change curve of kinetic energy and internal energy after the impact between the bird and the windshield glass. The initial kinetic energy of the bird is 6935.4j. After 0.3ms of bird impact, the speed of the bird decreases sharply. At the same time, the bird deforms to a certain extent, and the internal energy increases. After 2.2ms, the impact process ends, the bird leaves the windshield glass, and the speed and deformation basically do not change. Finally, the internal energy of the bird reaches 547.44j, the kinetic energy stabilizes at 5872.2j, and a total of 1063.2j of kinetic energy is lost.

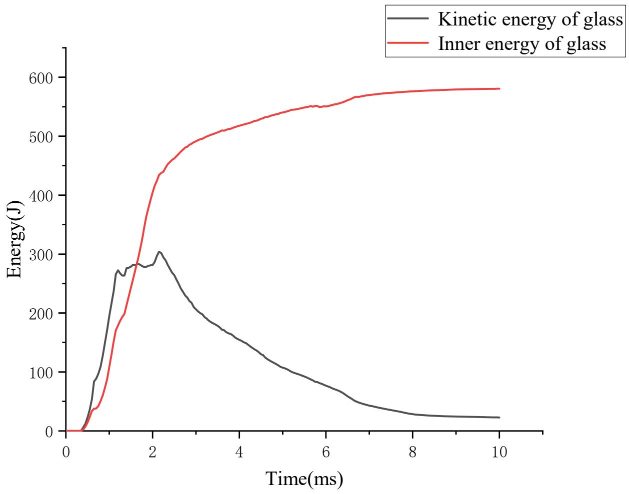

Fig. 8 Energy change of windshield glass

Fig. 8 shows the energy change curve of windshield glass after impact. From 0.3ms, the windshield glass and the bird body collided violently. The glass broke at the impact point, resulting in obvious velocity increment and deformation, and the internal energy and kinetic energy rose rapidly. However, due to the fixed constraints of boundary conditions, the rest of the glass except the impact point did not break significantly, and there was no obvious velocity increment. The increase of kinetic energy of the glass slowed down at about 1.2ms, and the bird body gradually left the windshield glass at 2.2ms, The glass is no longer broken, and the kinetic energy gradually decreases after reaching the peak value of 304.05j, but there are still some fragments moving, so the kinetic energy of the glass does not completely fall to zero in the end. After the windshield glass is impacted, the deformation is large between 0.3ms and 2.2ms, and a large part of the kinetic energy lost by the bird is absorbed by the windshield glass. After the 2.2ms bird impact process, the deformation continues to increase, but the amplitude slows down, so the internal energy continues to increase, and becomes more stable with time. Finally, the internal energy increment of the windshield glass reaches 580.5j. It can be seen that the windshield absorbs nearly half of the energy during the impact.

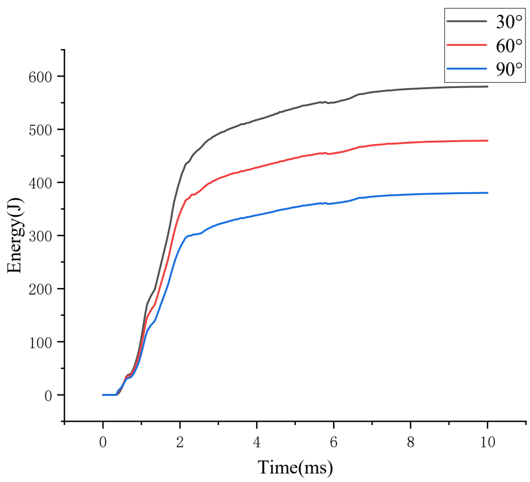

Fig. 9 Energy change of windshield glass under different impact angles

Fig. 9 shows the energy absorption of windshield glass after impact at different angles. Set the angles of bird and glass to 30 °, 60 ° and 90 ° respectively to impact the glass at three different incident angles. It can be seen from the figure that the energy absorption of glass first increases and then decreases with the increase of impact angle. This is because the larger the impact angle, the more concentrated the impact range of bird on windshield glass. When bird and glass impact at 90 °, Almost all the impact force acts on the impact point vertically, while the force around the impact point is relatively small. When the impact angle is small, the contact area between the bird and the glass will increase. In addition to acting on the impact point, some of the impact force will be transmitted to the surrounding of the impact point. The positions of the impact points are finally punctured by the bird body, but the damage degree around the impact point is slightly different. During vertical impact, cracks are mainly generated around the impact point, but no large area is punctured. However, when the impact angle is small, the breakdown area is relatively increased, so the total deformation of the glass increases. The size of the deformation is directly related to the energy absorbed by the glass. When the impact angle is large, the total deformation will decrease, Therefore, the overall energy absorption is also reduced.

5. Conclusions

(1) Bird impact is a millisecond large deformation impact process. When a small general-purpose aircraft flies at cruising speed, it will encounter bird impact, which will lead to failure and damage. During the impact process, elastic deformation and plastic deformation mainly occur around the glass. A large number of cracks are generated at the impact point and spread rapidly, and finally the impact point and surrounding positions are punctured.

(2) During the whole impact process, the stress and strain of YB-3 plexiglass will reach the peak in a short time. After the bird leaves the windshield, the residual stress wave makes the glass stress and strain oscillate back and forth for a period of time until they drop, stabilize and tend to zero, and the final residual deformation is small.

(3) The dynamic response of YB-3 plexiglass is related to the impact velocity and angle. With the increase of impact velocity, the stress, strain and displacement of the glass will increase correspondingly, and the deformation at and around the impact point is the largest. With the increase of the impact angle, the kinetic energy of the bird body decreases, the energy absorbed by the windshield glass decreases correspondingly, and the damage and deformation around the impact point decrease.

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