A Study on the Harmfulness of Tire Fragments Impact on Panel Structure Angle and Postures

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ABSTRACT: When a tire bursts, the flying fragments may break through the wing, damage the precision instruments inside it, and cause huge economic losses. In this paper, the impact of tire fragments on the fuselage structure is simulated, and the dynamic response of the structure under different postures of impacting different structures and fragments is analyzed. The damage caused by different impact modes is analyzed and compared, the harshest impact conditions are selected, and the corresponding improvement measures are given according to the impact results. It is found that the strain of the frame truss structure is the smallest when the fragments impacts on the front side, but it may lead to the fracture of the frame truss on the back side, resulting in secondary fragments splashing. When impacting in different postures, the edge impact is the most dangerous. Although it penetrates the skin, it is very close to the failure value.

1.Introduction

With the rapid development of aviation industry today, more and more aircraft have been put into use. The frequency of air crashes is getting higher and higher, among which, tire blowout, as an air crash with high accident rate, has attracted the attention of relevant experts. At present, the mainstream countries in the world have included puncture in the assessment process of airworthiness verification of civil aircraft\textsuperscript{[1-4]}. Mines et al. studied the static and dynamic characteristics of aviation tire rubber with internal reinforcing structure by experimental method, carried out the test of tire fragments impacting aluminum alloy sheet, and examined the dynamic response characteristics of aluminum alloy sheet such as plastic deformation, strain and strain rate\textsuperscript{[5]}. In addition, Karagiozova and Mines established Mooney-Rivlin model of rubber according to the results of rubber mechanical properties test and aluminum alloy sheet impact test, and simulated the dynamic process of small tire fragments impacting aluminum alloy sheet by LS-DYNA software\textsuperscript{[6]}, and some scholars studied the dynamic process of fragments impacting aluminum alloy sheet and wing cover\textsuperscript{[7-9]}. At present, there are few tire fragments impact problems similar to typical fuselage panel structures, and there is no systematic numerical modeling and analysis technology for tire fragments impact dynamics.

In this paper, the impact of tire fragments on the upper panel of the front landing gear cabin is simulated, and the skin position, frame-truss intersection position and stiffener position of the upper panel of the front landing gear cabin are simulated. The results show that the impact of fragments on the frame-truss intersection point is more harmful. Compared with different impact postures, it is found that edge impact is more severe than edge impact panel structure.
2. General conditions of numerical simulation

2.1. Impact range of tire fragments

EASA Notice of Proposed Amendment (NPA) 2013-02 stipulates that there are two types of fragments ejected from tire blasting: one is large fragments and the other is small fragments. The size of large fragments is the width of tire shoulder, the size is \( W_{SG} \times W_{SG} \), and the throwing angle \( \theta \) in the circumferential direction is 15. The size of small fragments is 1.5% of the tire tread size, and the mass is 1% of the whole tire fragments, and the circumferential projection angle \( \theta \) is 30.

The landing gear tires are Michelin Air X radial aviation tires. According to the specified conversion, the size of large tire fragments is 156 mm \( \times \) 156 mm \( \times \) 34.9mm, and the mass is 1.27kg; The size of small tire fragments is 70mm \( \times \) 70mm \( \times \) 24mm and the mass is 0.17kg;

According to the range and angle of tire fragments ejection specified in Notice of Proposed Amendment, a tire fragments ejection range model is established in CATIA. The schematic diagram of the ejection range is shown in Figure 1(a), and the area surrounded by two sectors is the fragments ejection range. Combined with the position of landing gear, the position where tire fragments impact the fuselage can be roughly screened out. The locations that may be impacted are the upper panel, the left panel, the right panel and the lower panel of the fuselage. The schematic diagram is shown in figure 1(b):

![Figure 1](image)

Figure 1 Schematic diagram of impact position of tire fragments on fuselage

It is the most dangerous situation that fragments impacts the upper panel of the front lift cabin. Therefore, this paper chooses the upper panel of the front landing gear cabin as the simulation object to calculate and get its dynamic response law.

2.2. Model boundary and contact condition

For the calculated typical panel members, the real structure of the aircraft is simulated, and the boundary conditions of fixed support on four sides are adopted to constrain the displacements in X, Y and Z directions. Non-reflective boundary conditions are set to reduce the reflection of shock wave at the constraint interface and reduce the interference of reflected wave on the impact simulation results.

When tire fragments come into contact with the airframe structure, the rubber material may be greatly deformed, and the contact surface will have complex interlocking effect due to dynamic performance. In this paper, the classical automatic face-to-face contact algorithm is selected, and the key word is *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE. The algorithm needs to define the contact surface and the target surface, but because the setting of the algorithm is completely symmetrical and the contact between the two surfaces is predictable, it is not necessary to distinguish the contact surface and the target surface deliberately, and the outer surfaces of the two contact objects can be selected. The algorithm is based on the basic principle of penalty function, which has an efficient solution rate for two objects in large-scale contact and relative slip state, and is suitable for solving the contact problem of nonlinear materials.

2.3. Material parameters

Bilinear follow-up model is used for aluminum alloy, the key word is *MAT_PLASTIC_KINEMATIC. This model can describe isotropic hardening and follow-up hardening plastic model, and can also consider the influence of strain rate. It is suitable for beams, shells and solid elements, and has high calculation efficiency. Its constitutive equation is:
\[ \sigma_y = \sigma_0 + \beta E_p \varepsilon_{\text{eff}}^p \]  

(1)

Where, \( \sigma_y \) is the yield strength, \( \sigma_0 \) is the initial yield strength, \( E_p \) is the plastic hardening modulus, \( \varepsilon_{\text{eff}}^p \) is the effective plastic strain.

Failure criterion of panel structure criterion, which is assumed that when the equivalent plastic strain \( \varepsilon \) reaches its threshold \( \varepsilon_f \), the material microelement breaks, and the criterion is expressed as follows:

\[ \varepsilon_{eq} = \varepsilon_f \]  

(2)

For the principal strain space, \( \varepsilon_{eq} \) is defined as:

\[ \varepsilon_{eq} = \frac{2}{3} \sqrt{\varepsilon_1^2 + \varepsilon_2^2 + \varepsilon_3^2} \]  

(3)

Where, \( \varepsilon_i \) is the main strain component. This criterion is applicable to various stress states.

### Table 1 Material parameters of aluminum alloy

| E/GPa | \( \mu \) | \( \rho/\text{tonne/m}^3 \) | SIGY/MPa | ETAN/MPa | FS |
|-------|----------|-----------------|---------|---------|----|
| 72    | 0.33     | 2.72            | 620     | 350     | 0.2 |

Note: E——Young's modulus, \( \mu \)——Poisson's ratio, \( \rho \)——Mass density, SIGY——Yield stress, ETAN——Tangent modulus, FS——Failure strain for eroding elements

Ogden constitutive model is used for fragments, and Ogden strain energy density function is defined as:

\[ W = \sum_{k=1}^{N} \mu_k \left( \frac{\lambda_1^{\alpha_k} + \lambda_2^{\alpha_k} + \lambda_3^{\alpha_k}}{\alpha_k} - \ln(J) \right) + \frac{1}{2\alpha} G^2(J) \]  

(4)

Where, \( J \) is the volume ratio before and after deformation, and has the following relationship:

\[ G(J) = J^2 - 1 \]  

(5)

\[ \frac{4}{\alpha} = \frac{1}{3} \sum_{k=1}^{N} \mu_k \alpha_k \left[ \frac{1+4\nu}{2(1-2\nu)} \right] \]  

(6)

Where, \( \lambda_1, \lambda_2, \lambda_3 \) are the main stretching amount; \( \alpha_k \) is the dynamic coefficient; \( \mu_k \) is the material constant; \( \nu \) is poisson's ratio.

In order to make the model stable in the solution process, we generally limit \( \sum_{k=1}^{N} \mu_k \alpha_k > 0 \).

### Table 2 Ogden model coefficients

| \( \mu_1 \) | \( \alpha_1 \) | \( \mu_2 \) | \( \alpha_2 \) | \( \mu_3 \) | \( \alpha_3 \) | \( \mu \) |
|----------|-----------|----------|-----------|----------|-----------|-------|
| 0.05     | 21.63     | 43.31    | 0.64      | 3.52     | 0.61      | 0.49  |

NOTE: \( \mu \)——Poisson's ratio, \( \rho \)——Mass density

### 3.Fragments impact different positions

In this part, the most dangerous parts selected according to the influence range of tire fragments are simulated. Airworthiness clause stipulates that fragments ejection may produce large fragments and small fragments. Because the energy of large fragments is greater than that of small fragments during impact, the damage caused by large fragments is far greater than that of small fragments. Therefore, this paper chooses large fragments to study the damage area, normal displacement and the variation law of fragments kinetic energy. Impact positions are panel skin position, stiffener position and frame truss intersection position.
3.1. Front impact skin position
In this paper, the front impact of tire fragments on the skin of landing gear cabin is simulated, and the real structure of landing gear cabin panel is taken for simulation, including skin, stiffener and back frame truss. Schematic diagram of frontal impact skin is shown in Figure 2.

![Stress distribution nephogram of wallboard](image)

(a) 0.05ms  (b) 0.1ms  (c) 0.4ms  (d) 1ms

Figure 5 Stress distribution nephogram of wallboard

The simulation results show that the panel structure oscillates obviously after the tire fragments impact the panel structure. At the moment of impact, the stress is mainly concentrated at the impact site. With the change of time, the shock wave gradually spreads around and finally spreads to the whole wall. The variation and distribution of stress on the wall plate are shown in Figure 5. It can be seen from figure 4 that the most dangerous part of impact lies in the center of impact point. When fragments impact the panel structure, part of its kinetic energy is converted into deformation energy of the panel structure. In the process of impact, the maximum stress can reach 660MPa. Subsequently, the fragment were bounced back, and the panel structure oscillated repeatedly, and its stress also showed some repeated rise and fall.

3.2. The intersection point position of frame truss under frontal impact impacted by front
The schematic diagram of the intersection point of frame truss impacted by the front of tire fragments is shown in Figure 3. The front of impact position is skin, and the back is the intersection point of frame truss.

![Strain nephogram of wallboard](image)

Figure 6 Strain nephogram of wallboard

It can be seen from figure 6 that, unlike the strain distribution of fragments impacting the skin, the plastic deformation is mainly distributed on the frame truss in this case, and it can be found through the simulation process that the stress wave mainly propagates along the frame and truss direction. When the time is 1.8ms, the plastic strain on the frame truss can reach 0.1997, which is very close to the failure strain. Therefore, in the project, this position should be paid attention to. If this position is damaged, it is very likely that the frame truss will break, new fragments will splash out and hit the precision instruments, causing secondary damage.
3.3. The position of frontal the front impact stiffeners stiffener

![Figure 7](image)

Figure 7 strain nephogram of the fragment impacting ribs

The schematic diagram of tire fragments impacting reinforcing ribs on the front side is shown in Figure 4. The front side of the impact position is the reinforcing rib area, and the back side is not supported by frame truss.

It can be seen from figure 7 that the reinforcing rib is directly impacted by tire fragments, and the strain value in this area exceeds 0.2. Therefore, some stiffeners in this area failed and some grids were deleted. Influenced by stiffener materials and overall structure, this regional structure is more fragile than other regional structures. However, the structure is not inside the machine body, and the flying fragments will not damage the internal precision instruments.

4. Impact of fragments with different postures

When tire burst occurs, the attitude of fragments impacting on the fuselage structure is random, which does not necessarily impact in front. In order to study the dynamic response of fuselage structure to different impact postures, different postures are controlled as the only variable, and the impact point is selected as the skin position, so as to study the impact law of different postures.

4.1. Edge impact skin position

Tire fragments impact the skin position of panel structure with edge posture, and the impact schematic diagram is shown in Figure 8.

The nephogram of strain of panel during impact is shown in Figure 10. Comparing figure 10 with figure 6, it can be seen that the strain levels of fragments under frontal impact and edge impact are equivalent, the maximum value of strain is 0.197. The plastic area caused by edge impact is smaller than that caused by frontal impact, because the contact area between fragments and fuselage structure is small and its stress level is slightly higher than that caused by frontal impact.

![Figure 8](image)

Figure 8 Fragment edge impacting skin

![Figure 9](image)

Figure 9 Fragments angular impact skin

![Figure 10](image)

Figure 10 Fragments edge impacting skin

![Figure 11](image)

Figure 11 Fragments angular impacting skin
4.2. The position of edge impact skin

In this paper, tire fragments are simulated to impact the wallboard structure with angular posture, and the impact schematic diagram is shown in Figure 9. The nephogram of stress and strain of the panel during impact is shown in Figure 11. According to figure 13 and the frontal impact and edge impact of fragments, it can be seen that the panel responses caused by impacts with different postures are similar, but the stress and strain levels are slightly different. From the strain level, the frontal and edge impact strain can reach 0.197, and the angular impact can reach 0.191. Comprehensive analysis shows that the danger caused by edge impact is greater.

5. Conclusion

In this paper, the impact of tire fragments on the airframe structure is simulated, and the dynamic response of the structure under impact is analyzed. Screening general conditions in numerical simulation, including the selection of test pieces; Impact conditions of fragments; Model boundary and contact condition, etc.

Simulate the front impact position of tire fragments on the upper panel skin of landing gear cabin, the intersection position of frame and truss, and the position of stiffener. If the examination standard is whether the panel can be broken down and the precision instruments inside the aircraft can be damaged. It can be seen that there is no fragments penetrating the skin at the three impact positions. Although the reinforcement is broken when it is impacted, the damaged area does not contact with precision instruments, so the assessment result is safe. When fragments impacts the frame truss structure, it may lead to the fracture of the frame truss on the back of the frame truss, resulting in secondary fragments splashing, which is the most dangerous phenomenon. Therefore, in design, the flexibility can be increased as much as possible under the condition of satisfying its strength.

The frontal impact, edge impact and angular impact are used to simulate the impact of fragments on the skin position of landing gear cabin panel in different impact postures. By analyzing the impact caused by different impact postures by integrating strain difference, it can be seen that edge impact is the most dangerous. Because the skin thickness of landing gear cabin is 2mm and there are many reinforced structures, the impact of fragments in different postures has not penetrated the skin and caused no secondary damage.

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