Fluid-structure Interaction Characteristics of Spin-on Fairing Structure of Aerodynamic Simulation Static Load

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Abstract. With the rapid increase of aircraft speed, the impact of aerodynamic load on the aircraft is more significant, and aerodynamic load will cause the severe deformation of the structure, which will in turn affect the change of aerodynamic load. This paper takes a typical spin-on fairing structure as the study object with the finite element method, using simulated aerodynamic static load to study the effect of aerodynamic pressure on the load and deformation of the spin body structure, which could provide an effective method for the dynamic characteristics of the spin-on body structure, and for the study of aerodynamic load as well. And the results could also provide the initial finite element calculation data support for the damage evolution characteristics of fluid-solid coupling and long-term interaction of spin-on fairing structures.

1. Introduction
With the rapid improvement of aircraft flight performance, for the aircrafts such as missiles, airplanes, and rockets that need to interact with the atmosphere, because the working environment conditions of their flight are quite severe and complicated, especially among the high flying speed (up to supersonic speed or high sonic speed flight). The aircrafts usually need to bear the severe aerodynamic loads accompanied by aerodynamic heating problems, which results in significant changes in the load-bearing performance, flight performance and deformation characteristics of the aircraft structures [1-3], and in severe cases it may even cause the whole aircraft damage and failure with the aerodynamic load and structural deformation, which have attracted more and more attention [4,5]. Visbal and others [6-7] have studied the simplified boundary layer viscous fluid equation for subsequent research, which made a foundation pavement and a good start for subsequent in-depth research based on factors such as dynamic pressure, frequency, and Mach number. Liu, Kramer et al [8,9] studied the stiffness model for the unfolded and inflated flexible film inflatable tubes, and it was found that the unfolding of the folded inflatable tube was an unsteady and unstably fluid-structure coupling process, and the nonlinear dynamic calculation model was also developed. Mohammad et al [10-12] studied the aerodynamic fluid-solid coupled dynamic expansion response of the thin film unit for the flexible film paraglider wing, constructed a cell model of the film unit, and combined with wind tunnel tests, and the flow response was also expounded around the film and the structure characteristics. Wangwei et al [13-15] used fluent software to simulate the aerodynamic dynamics of the inflatable wing, and studied the finite element analysis method for simulating aerodynamic loads.

Based on the existing research results, taking the typical spin-on fairing structure as the object, the finite element method was used to study the effect of aerodynamic pressure on the bearing load and
deformation of the structure by using simulated aerostatic load to obtain the simulated aerodynamic load on the spin-on structure. The influence law of deformation, and then the bearing deformation characteristics of different stress states and different deformation directions were obtained as well, which could provide an effective model for the comprehensive design and analysis of the thermal-fluid-structure coupling of aircraft structures, and provide the technology for the overall optimization design and performance analysis of missile fairings and flexible wings. Moreover, the results could provide the initial finite element calculation data for studying the fluid-solid coupling and damage evolution characteristics of the spin-on body structures.

2. The spinner fairing modelling

2.1. Aerodynamic load and structural deformation characteristics

The structure of the aircraft deformation usually occurs under the action of aerodynamic loads, and the bearing state of the fairing structure also changes accordingly. The finite element discrete method was used to study the model of the finite element mesh unit, and the displacement characteristics of any unit structure could be obtained.

\[
\{u(x, y, z, t)\} = [N(x, y, z)]\{u'(t)\}
\]

(1)

Where, \(\{u\}\) represents the displacement of any structure in the unit; \([N]\) representative shape function matrix; \(\{u'(t)\}\) is the node displacement vector, and the element strain and stress characteristics matrix of the structure deformation is obtained.

\[
\{\varepsilon\} = [B]\{u'\}
\]

(2)

\[
\{\sigma\} = [D]\{\varepsilon\} = [D][B]\{u'\}
\]

(3)

Where, \([B]\) is the geometric matrix, which represents the conversion relationship between displacement and strain; \([D]\) indicates the constitutive relationship matrix, which represents the conversion relationship between stress and strain.

For the aerodynamic load acting on the structured spinner fairing, the aerodynamic flow field satisfies the laws of conservation of mass, momentum, and energy. So the basic model for the description of the flow field parameters could be developed. And the air flow parameters field could be also obtained under the certain definite solution conditions. In order to simplify the finite element analysis model, the simulated aerodynamic static loads were used for the simulation calculations, and the simulated aerodynamic distributed pressure load was assumed directly acted on the spinner fairing structure to study the influence of aerodynamic pressure load on the structural load and deformation.

2.2. Finite element simulation model

The spinner fairing structure is susceptible to large aerodynamic loads. The influence of aerodynamic loads on the load and deformation of the head rectifier is mainly considered, and the corresponding local connection is simplified. The structure and dimensions of the fairing are shown in Figure 1, and the diameter is 2m, and the overall wall thickness is 7mm.

![Figure 1. Schematic of fairing geometry model.](image-url)
The fairing structure is generally made of natural or man-made dielectric materials, so that it could better adapt to maintain better heat resistance, wave permeability and higher structure strength in the harsher environment under the condition of meeting the aerodynamic shape, so as to protect the internal antenna or radar from the external environment, the new type of low-cost quartz ceramic composite material with good heat resistance was selected for simulation calculation, and the material parameters are shown in Table 1.

### Table 1. The material parameters of spinning body fairing composite

| Material name          | density g/cm³ | Poisson's ratio | Elastic Modulus/GPa |
|------------------------|---------------|-----------------|---------------------|
| Composite material     | 2.2           | 0.15            | 48                  |

The finite element software is used to divide the grid, and the structured grid is used to generate fast, good quality, and high calculation accuracy. Applying aerodynamic simulation loads, the forces under the actual working conditions are analysed and loaded on the hood to achieve simulation analysis. And the boundary condition is that the tail is fixed, and the front of the hood is loaded with aerodynamic pressure, which simulates the aerodynamic load at 3M, and the dynamic pressure is 577422Pa. Therefore, the above-mentioned load is loaded to the head cone, and the cylindrical surface of the fairing is not added with pneumatic Load simulation.

### 3. Coupling analysis of simulated aerodynamic static load on the fairing structure

As for the load bearing and deformation characteristics of the fairing, it could be seen from the Mises stress distribution cloud diagram of the fairing that the Mises stress of the fairing has a circular distribution, which is due to its symmetrical properties. And the maximum stress is 73.85Mpa, which is close to the head, and the connection between the cover and the cylinder section is the minimum at the top of the head, which is almost 0, this is due to the small simulation aerodynamic load on the head, so the stress increases from the head to the tail direction, while the basic distribution of the segments is relatively uniform, which is about 40Mpa.

The compressive pressure of the spinning-on fairing structure presents a ring-shaped distribution, as shown in Figure 3, which is due to its symmetrical properties and loading with a circumferentially symmetrical load. The maximum compressive pressure is 55.43Mpa, which is close to the hood and the cylinder, and the connection point of the segment is the smallest near the vertex of the head. Therefore, the cylindrical segment from the warhead to the head cone has an enlarged form. Moreover, the cylindrical segment is basically evenly distributed, and most of them maintain almost about 10Mpa.
Figure 3. Cloud load distribution of spinner fairing pressure.

The displacement distribution of the whole fairing head cone could be seen in Figure 4, the displacement of the head is the largest (reaching 3.788mm). From the head to the cylindrical section, the displacement gradually decreases. And the whole displacement distribution also shows a ring, this is consistent with the symmetrical pressure distribution law of the rotating body. The displacement of the whole projectile head is around the range of 3.4-3.788mm, furthermore, the displacement of the rear section of the cylindrical section is gradually decreasing.

Figure 4. Cloud map of displacement of spinner fairing structure.

The maximum deformation strain cloud of the fairing head cone is shown in Figure 5, which shows a circular distribution law as a whole. The deformation strain of the head and the cylindrical section is relatively small, while the deformation strain of the rear part of the head cone is relatively large. So it could be seen that the deformation strain of the middle and rear parts of the head cone is large, and this area could be used as the key area for the optimal design.

Figure 5. Cloud map of the maximum combined strain distribution of a spinner fairing.
4. Conclusions

1) the Mises bearing stress of the fairing and the simulated aerodynamic pressure load are both distributed in the ring shape. And the maximum stress is close to the connection between the head cover and the cylindrical section, and the smallest is at the top of the head, and gradually increases along the axial direction, and the cylinder segment stress is more evenly distributed.

2) The displacement distribution of the head cone of the fairing has the largest displacement of the head, which gradually decreases along the axial direction, and has a circular distribution, and the displacement of the rear section of the cylindrical section gradually decreases.

3) The strain is also distributed in the ring shape, but the deformation strain of the head and the cylindrical section is relatively small, and the strain in the middle area is relatively large, so it is necessary to focus on the optimal design of this area.

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