Supporting mechanism design of parachutes for 2.4m×2.4m transonic wind tunnel in CARDC

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Abstract. In order to carry out the wind tunnel test of the parachutes in 2.4m×2.4m transonic wind tunnel of CARDC which is located at Mianyang, a supporting mechanism for the attack angle from 0 to 25 degrees at Mach 0.4 and 0.8 is designed and optimized in the present paper. Three section shapes (circle, ellipse, and airfoil) are utilized to analyze the aerodynamic characteristics and mechanical performances of the designed supporting mechanism. The aerodynamic and mechanical simulated results of the three different section shapes are compared and discussed. The optimized design is verified by wind tunnel experiments. The results show that the section shape of circle has the largest modal frequency of first order (53.497Hz), the smallest Mises stress (34.1MPa) and displacement (0.4735mm). It is the best section shape of the three for the supporting mechanism. The investigation in the present paper has a good significant meaning to the testing technologies of the wind tunnel experiments for parachutes.

1. Introduction

With the abilities to slow the motion of an object through the atmosphere by creating drag forces, the parachutes have been widely used and it is very necessary to accurately get the aerodynamic characteristics of the parachute [1-4].

Two approaches are usually utilized to obtain the aerodynamic performances of a parachute: numerical computation [5-10] and wind tunnel test [11, 12]. In the parachute’s descent process of deployment, inflation and terminal, the aerodynamic environment is so complex that the numerical computational method usually owns large errors. For many years, the wind tunnel test is still an invaluable, accurate and cost-effective approach to investigate the aerodynamic characteristics of a parachute [13]. The construction of a series of asymmetrical wind tunnel model parachutes which was designed to a modular concept was described by Klimas et al. [14]. The effect of the arm ratio of the cross canopy on the transverse profiles of velocity, vorticity, and Reynolds stress was stated by Jin et al. [15]. The Stereoscopic Particle Image Velocimetry (SPIV) technique was adopted in his research and the flow structures of the cross parachute were measured and analyzed. The parachutes used in Mars exploration missions were also studied through the wind tunnel tests by NASA [16, 17] and Mars Science Laboratory [18-20]. Most previous literatures were on the topic of simulating the parachute aerodynamic behaviours. And only some of them were investigated in wind tunnels.
Especially, most of the wind tunnel tests were carried out under the condition of low speed flow and zero attack angle [21].

In the present paper, a supporting mechanism of parachutes for testing in 2.4m×2.4m transonic wind tunnel of CARDC is designed and optimized. The main configuration of the support mechanism is given according to the constraints of the testing model and facility. The section shapes (circle, ellipse, and airfoil) are adopted and the aerodynamic and mechanical analysis of them is also provided. The comparisons of the three section shapes are discussed and the section shape with best aerodynamic and mechanical performances is given. Summing up, the purposes of this paper are (i) to design three different section shapes (Section 2), (ii) to compare, discuss and verify the designation (Section 3), (iii) to give some conclusions in the last (Section 4).

2. Support mechanism design

In this section, the main configuration is designed according to the constraints of the testing model and facility (full model testing section of 2.4m×2.4m transonic wind tunnel). The circle, ellipse and airfoil shaped section are selected to design the support mechanism.

2.1. Main configuration

According to the constraints of the testing parachute model and facility, the main configuration of the supporting mechanism used in 2.4m×2.4m transonic wind tunnel is designed as figure 1 and the three dimensional coordinates of the main configuration is illustrated in table 1.

![Figure 1. Sketch of parachute.](image)

**Table 1. Coordinates of the main configuration.**

| Point | Coordinate (mm) | Point | Coordinate (mm) |
|-------|----------------|-------|----------------|
| A1    | (359, 0, 0)    | A2    | (-359, 0, 0)   |
| B1    | (1910, 0, 714)| B2    | (-644, 0, 850) |
| C1    | (0, 399, 0)    | C2    | (0, 240, 0)    |
| D1    | (1810, 0, 668)| D2    | (-594, 0, 701) |
| E1    | (0, -399, 0)   | E2    | (0, -240, 0)   |
| F1    | (1710, 0, 622)| F2    | (-544, 0, 552) |

2.2. Section design

For the purpose of getting a better design of the supporting mechanism, three different section shapes are adopted to design the supporting mechanism of the parachutes for the 2.4m×2.4m transonic wind tunnel of CARDC. The optimum section shape of the three is obtained according to the aerodynamic and mechanical simulating results. The three section shapes are circle, ellipse and airfoil, separately. The sizes of them are given in figure 2. In the part of the aerodynamic analysis, the reference length of the three section shapes is all 0.12m and the reference areas are respectively 0.011304m², 0.005652m²,
and 0.0026m².

![Figure 2. Sizes of three section shapes.](image)

3. Results and discussions

3.1. Aerodynamic analysis

According to the real experimental condition, the worst set of Mach number 0.8 and angle of attack 25 degrees is adopted to carry out the aerodynamic analysis of the three different section shapes. In aerodynamic simulations, the total temperature and the total pressure are set as 298K and 160kPa. The mesh information of the three section shapes is illustrated in table 2 and the grid structures are plotted in figure 3. The elements of the section shapes are structurally modelled in ICEM software [22] and the aerodynamic results are computed in PHengLEIv2.1 which is a platform for hybrid engineering simulation of flows published by CARDC [23]. The maximum iteration step is set as 10000, the SA turbulence model [24] is utilized and the time-discrete format of LU-SGS is applied to solving Navier-Stokes equations in the aerodynamic simulation [25].

| Items          | Element number | Node number | Quality |
|----------------|----------------|-------------|---------|
| Circle section | 12948          | 12797       | ≥0.75   |
| Ellipse section| 6308           | 6232        | ≥0.75   |
| Airfoil section| 12782          | 12628       | ≥0.75   |

![Figure 3. Grid structures.](image)

The pressure fields of the three section shapes are shown in figure 4 and the Mach fields of the three section shapes are displayed in figure 5. As is seen from figure 4 and figure 5, the circle section shape has the largest influence areas of pressure and Mach number. The influence distance of the circle section shape is about 200mm and the installation position of the parachute in the wind tunnel is out of the influence scope. So both the three section shapes meet the aerodynamic requirements of the wind tunnel test for parachute. And the airfoil section shape has the smallest influence scope.
3.2. Mechanical analysis
In this subsection, the mechanical properties of the main configuration with the three section shapes are discussed. The modal results and the static results are also described. In the mechanical analysis, the finite element model is carried out in ABAQUS and the tetrahedral element is used to obtain the grid. The material is 30CrMo and its material parameters are given in table 3. The mesh information of the mechanical finite element model is supplied in table 4.

Table 3. Parameters of 30CrMo.

| Yong modulus (Pa) | Poisson ratio | Density (kg/m³) | Yield strength (Pa) |
|-------------------|---------------|-----------------|---------------------|
| $2.11 \times 10^{11}$ | 0.279 | 7850 | $7.85 \times 10^8$ |

Table 4. Mesh information of mechanical finite element model.

| Items             | Element number | Node number | Element type  |
|-------------------|----------------|-------------|---------------|
| Circle section    | 66299          | 102054      | Tetrahedral   |
| Ellipse section   | 128775         | 197813      | Tetrahedral   |
| Airfoil section   | 138765         | 231468      | Tetrahedral   |

In the mechanical analysis procedure, A1, A2, C1, C2, E1, and E2 are set as fixed condition. The load at B1 is (-20000N, 0, 0) and at B2 is (-8000N, 0, 0). The modal frequencies of the three section shapes are given in table 5 and the static results are described in table 6. The first modal shapes, the stress clouds, and the displacement clouds of the main configuration with the three section shapes are given in figure 6, figure 7 and figure 8, separately.

Table 5. Modal frequencies of three section shapes.

| Modal order | Circle section | Ellipse section | Airfoil section |
|-------------|----------------|----------------|-----------------|
| 1<sup>st</sup> | 53.497Hz | 46.590Hz | 21.935Hz |
| 2<sup>nd</sup> | 118.51Hz | 59.674Hz | 30.088Hz |
| 3<sup>rd</sup> | 164.17Hz | 96.279Hz | 42.565Hz |
| 4<sup>th</sup> | 181.67Hz | 132.25Hz | 46.652Hz |
| 5<sup>th</sup> | 237.70Hz | 141.64Hz | 71.475Hz |
Table 6. Static results of three section shapes.

| Items                  | Circle section | Ellipse section | Airfoil section |
|------------------------|----------------|-----------------|-----------------|
| Maximum stress (MPa)   | 34.1           | 50.19           | 141.3           |
| Maximum strain         | $2.53 \times 10^{-4}$ | $2.431 \times 10^{-4}$ | $6.365 \times 10^{-4}$ |
| Maximum displacement (mm) | 0.4735       | 1.047           | 2.759           |

Figure 6. First modal results of three section shapes.

Figure 7. Stress results of three section shapes.

Figure 8. Displacement results of three section shapes.

From table 5, it can be concluded that the main configuration with circle section shape has the largest first modal frequency and the its second modal frequency is far larger than the other two. The circle section shape offers the largest stiffness of the main configuration. As is shown in table 6, the circle section shape has the smallest stress (34.1MPa) and the airfoil section shape has the largest stress (141.3MPa). The maximum strain of the circle section shape ($2.53 \times 10^{-4}$) is equivalent to the ellipse circle shape ($2.431 \times 10^{-4}$), less than the airfoil section shape ($6.365 \times 10^{-4}$). The maximum displacement of the circle section shape (0.4735mm) is the smallest, far less than the ellipse (1.047mm) and airfoil section shapes (2.759mm). As is seen in figure 6, figure 7 and figure 8, the maximum stress and displacement both occur at B1 part of the main configuration.

According to the results of the aerodynamic and mechanical analysis, in a summary, the circle section shape makes the main configuration own the largest stiffness and smallest stress and displacement. Its aerodynamic influence distance meets the requirements of the wind tunnel experiments.

3.3. Experimental verification

Considering the capacity of the manufacture and mechanical connection, the final supporting mechanism of the parachute for 2.4m×2.4m transonic wind tunnel is shown in figure 9. Two sensors are applied to obtaining the aerodynamic coefficients (4N6-70E and 4N6-64E). 4N6-70E is mounted at B1 part and 4N6-64E is positioned at B2 part. The state of the supporting mechanism in the experimental process is figured in figure 10. The measured data were sampled at 300 Hz and handled by 1 Hz lowpass filter. The directly obtained data include the influences of two parts: the contributions of the parachute and the effects of the supporting mechanism.
Figure 9. Final supporting mechanism.

Figure 10. State of supporting mechanism in experimental process.

The results of the wind tunnel tests are given in figure 11. The measured data of the lift, drag and pitch moment coefficients are smooth and reasonable. The law of the aerodynamics versus the angle of attack is in accordance with physical reality. The designed supporting mechanism is effective on the wind tunnel tests of the parachutes in the 2.4m×2.4m transonic wind tunnel and achieves the requirements of the experiments.

Figure 11. Results of wind tunnel tests.

4. Conclusions
In this paper, a supporting mechanism is designed for the wind tunnel tests of the parachutes in the
2.4m×2.4m transonic wind tunnel. In order to achieve an optimized design, circle, ellipse and airfoil section shapes are adopted and discussed. The aerodynamic influences of the three section shapes are given and the mechanical properties of the main configuration with the three section shapes are analyzed. As a result, the circle section shape is the most suitable one to design the supporting mechanism. The aerodynamic influence distance of the section shape is about 200mm and the circle section shape has the largest stiffness, smallest stress (34.1MPa), strain (2.53×10⁻⁴) and displacement (0.4735mm). The designed supporting mechanism is verified by the wind tunnel experiments of the parachutes and is able to assure the success of the wind tunnel tests. The investigation of this paper is significant to the development of the parachute applications.

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