Design and Analysis of FSC Formula Racing Car Body

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Abstract—This article satisfies the design rules of the FSC College Student Formula Contest. Based on the existing frame and other relevant data, CATIA and Profili are used to select the airfoil, and draw the three-dimensional model of the body shape and aerodynamic kit A simplified model of a racing car. Using ANSYS Geometry, ICEM-CFD and fluent modules, after setting the boundary conditions, the front wing and tail wing are simulated and analyzed respectively, and the stress of the selected model and the air flow around the car are checked through fluent post-processing. Using the data shown as a reference, the simulation data of each group of car equipped with front and rear wings was analyzed to determine the design of the front and rear wings. The flow field analysis is performed on the vehicle after the selected empty set is installed, and the result is obtained, compared with the data before the installation, and a conclusion is drawn.

1. INTRODUCTION
Formula SAE is a collegiate design competition where groups of students design, build and race their own open wheel racing cars[1]. Since its beginnings in CHINA in 2010. With the development of racing chassis and power technology, aerodynamics has become an important part of the design of FSAE racing vehicles, and it closely affects the power of racing, Economy and handling stability. Based on the characteristics of light weight of the vehicle, high acceleration performance requirements and limited mechanical grip, the main purpose of the FSAE aerodynamic package development is to generate more negative lift while driving.

Predicting the aerodynamics flow around industrial and racing cars, using the CFD codes, is becoming increasingly common both in the research centers and in the car companies[2]. This rise in interest is due to the increasing predictive capabilities of codes together with an ever more interesting reduction in the costs of computing technology. As a consequence, these tools are viable alternatives to the increasingly expensive experimental investigations.

In response to the above requirements, ANSYS CFD is used to design aerodynamic packages.

2. ORIGINAL VEHICLE DESIGN AND ANALYSIS
According to the rules and the existing frame, after designing the body shape, the model is partially simplified.
Figure 1. Schematic diagram of the simplified model of the whole vehicle

Use ANSYS for simulation analysis. The size of the wind tunnel used is as follows, the length is 14.18m, the width is 3.1m, and the height is 2.3m.

Set the driving conditions of the racing vehicle to 20m (s) per hour for solving, and get the data and effect diagram.

Figure 2. Surface pressure diagram and velocity streamline diagram

| TABLE I. ORIGINAL VEHICLE AERODYNAMIC PARAMETERS |
|-----------------------------------------------|
| Speed | Total lift | Total drag | Lift-to-drag ratio |
|-------|------------|------------|-------------------|
| 20m(s) | 80.52      | 65.1       | 1.23              |

3. FRONT TAIL DESIGN

3.1 Front wing:
The front wing is composed of its main structure and many additional structures. The frontmost horizontal wing or the wing with the largest area is the main wing of the front wing. The inclined wing with an angle of attack at the rear end of the front wing is called the auxiliary Wings or flaps [4].

3.2 Rear wing:
Similar to the front wing, the rear wing is also an aerodynamic package consisting of the main wing, flaps and end plates. The rear wing is located at the rear of the car and generates about 30% of the negative lift of the whole car. A slot is reserved between the main wing and the flap, To guide the air flow to the lower side of the wing surface, so that the overall aerodynamic performance of the tail is improved and the performance is improved[5].

3.3 Airfoil selection:
The role of the fixed airfoil is to use the pressure difference when air flows across its surface to form downforce. Due to the higher lift resistance and better aerodynamic characteristics of Wortmann FX 74-CL5-140 Modified, GOE 285, S1210 12% airfoil, the front and rear fixed airfoils of this design select the above three airfoils for combination and matching.
The main wing of the front wing uses the Wortmann FX 74-CL5-140 Modified airfoil, the chord length is set to 400, the inner flap uses the GOE 285 airfoil, and the chord length is 150; the outer flap ① uses the S1210 12% airfoil, and the chord length is 150, outboard flap ② use S1210 12% airfoil, chord length is 50.

The main airfoil of the rear wing adopts Wortmann FX 74-CL5-140 Modified, and its chord length is 300; the flap adopts the airfoil S1210 12%, and its chord length is 250.

The three-dimensional model are presented in Fig. 3.

![3D model of the front and rear wings](image)

4. ANALYSIS PROCESS

The lift-to-drag ratio of the fixed airfoil changes with the change of the angle of attack of its fins, so the angle of attack of the fixed airfoil must be optimized.

Create a three-dimensional model of the fixed wind wing, import the model into ANSYS to divide the mesh, and then set and calculate the boundary conditions in Fluent. According to the actual working conditions of the vehicle, the future flow speed is taken to be 20m(s) for calculation.

4.1 Front wing

4.1.1 Main wing:

The main wing of the front wing is located under the front nose cone of the vehicle body. Considering the backpressure effect of the body nose cone on the airflow, it will pressurize the upper part of the wing, and in order to reduce the airflow separation and deliver a more stable airflow for the side box, the angle of attack of the main wing should not be too large.

The inflow velocity is taken as 20 m (s), and the attack angles of the main wing are taken as 0°, 1° and 2° respectively for separate analysis. The analysis and calculation results are presented in Table 2.

| Degree | FL | FD | Lift-to-drag ratio |
|--------|----|----|--------------------|
| 0°     | -88| 9.48| -9.28              |
| 1°     | -98.5| 10.5| -9.38              |
| 2°     | -107.2| 11.6| -9.24              |

The main wing's angle of attack takes the maximum lift-to-drag ratio, which is 1°.

4.1.2 Outboard flaps (①and②):

The front wheels are behind the Outboard flaps, so the guidance of downforce and airflow is the focus of its design. Direct airflow over the front wheels to reduce drag and turbulence in the front wheels. In order to slow down the airflow separation, the double-piece Outboard flaps are used here.

The incoming flow speed is set to 20m (s), the main wing takes 1°, and the Outboard flaps ① takes different angles of attack for analysis. The results are presented in Table 3.
TABLE III. OUTBOARD FLAPS\(^1\) AERODYNAMIC PARAMETERS OF THE FRONT WING WITH DIFFERENT ANGLES OF ATTACK

| Degree | \(F_L\)  | \(F_D\)  | Lift-to-drag ratio |
|--------|--------|--------|-----------------|
| 15°    | -84   | 10.2   | -8.23           |
| 20°    | -89.36| 9.76   | -9.15           |
| 25°    | -94.4 | 13.38  | -7.05           |
| 30°    | -96.56| 14.8   | -6.52           |

It can be seen from the table that when the lateral flap\(^1\) is 20°, the front wing lift-to-drag ratio is the largest. However, it is found that the lateral flap\(^1\) when the angle of attack is 20° is not conducive to the installation of the lateral flap\(^2\), so the lateral flap is initially taken Wing\(^1\) is 15°.

Take 1° for the main wing of the front wing and 15° for the Outboard flaps\(^1\), and set the incoming flow speed to 20m(s). The analysis results of the Outboard flaps\(^2\) taken at 40° and 45° are shown in Table 4.

TABLE IV. OUTBOARD FLAPS\(^2\) AERODYNAMIC PARAMETERS OF THE FRONT WING WITH DIFFERENT ANGLES OF ATTACK

| Degree | \(F_L\)  | \(F_D\)  | Lift-to-drag ratio |
|--------|--------|--------|-----------------|
| 40°    | -115   | 15.2   | -7.56           |
| 45°    | -120.4 | 17.7   | -6.8            |

By observing the velocity streamline diagram, it is known that when the outer flap\(^2\) is 40°, not only does the front wing increase drag, but also the airflow can flow above the front wheel to a certain extent, so it is initially determined that the outer flap\(^2\) takes 40°.

4.1.3 Inboard flaps:
Behind the inner flaps are the water tank and the rear wing. Its main function is to provide air cooling to the water tank and provide a straight and clean wake for the rear wing. Therefore, the inner flap can be used at a small angle. Install the inside flaps under the premise of the above-mentioned wing angle determination, take the inside flaps as 0° and vehiclery out simulation analysis with the original vehicle model. The results are presented in Table 5.
TABLE V. AERODYNAMIC PARAMETERS OF THE VEHICLE WITH THE INNER FLAPS AT 0°

| Degree | $F_L$ | $F_D$ | Lift-to-drag ratio |
|--------|-------|-------|-------------------|
| 0°     | -130  | 18.5  | -7.02             |

The angle of attack of the front wing is set as shown in Table 6.

TABLE VI. FRONT WING ANGLE OF ATTACK SETTINGS

| Main wing | Inboard flaps | Outboard flaps | Outboard flaps⁠ |
|-----------|---------------|----------------|-----------------|
| 1°        | 0°            | 15°            | 40°             |

4.2 Rear wing

4.2.1 Main wing:
The main wing of the rear wing is installed at a higher position and is mainly used to comb the airflow behind the racing vehicle. The angle of attack can be increased appropriately.

The processed tail model is calculated in Fluent, and the incoming flow speed is set to 20m (s). The calculated tail analysis results are shown in Table 7. The angle of attack with the highest lift-to-drag ratio is taken, that is, the main wing takes 5°.

TABLE VII. AERODYNAMIC PARAMETERS OF MAIN WINGS WITH DIFFERENT ANGLES OF ATTACK

| Degree | $F_L$ | $F_D$ | Lift-to-drag ratio |
|--------|-------|-------|-------------------|
| 4°     | -89.28| 11.48 | -7.78             |
| 5°     | -95.64| -11.3 | -8.46             |
| 6°     | -101  | -12   | -8.41             |
| 7°     | -106.8| -12.94| -8.25             |

4.2.2 Flaps:
Based on the determined angle of attack of the main wing, a flap is added to the tail wing, and their different angles of attack are analyzed respectively. The results are presented in Table 8.

TABLE VIII. TAIL AERODYNAMIC PARAMETERS OF FLAPS WITH DIFFERENT ANGLES OF ATTACK

| Degree | $F_L$ | $F_D$ | Lift-to-drag ratio |
|--------|-------|-------|-------------------|
| 15°    | -181.5| 27.28 | 6.65              |
| 20°    | -214  | 35.4  | 6.04              |
| 25°    | -249.4| 45.5  | 5.48              |
| 30°    | -281.2| 56    | 5.02              |

Table 8 displays that the lift-to-drag ratio of the tail wing is the largest when the angle of attack is 15°, but in order to ensure greater downforce under the premise of controllable resistance, the flap angle of attack is chosen to be 20°.

In conclusion, the setting of each angle of attack of the tail is presented in Table 9.

TABLE IX. TAIL WING ANGLE OF ATTACK SETTING

| Main wing | Flaps |
|-----------|-------|
| 5°        | 20°   |
5. ANALYSIS OF AERODYNAMIC PERFORMANCE OF RACING VEHICLE AFTER ADDING AERODYNAMIC PACKAGE

After determining the design scheme of the front and rear wing, the aerodynamic performance analysis is vehicle-determined on the simplified model of the vehicle after the installation of the aerodynamic package, and the optimal installation position of the aerodynamic package is determined. The simplified model of the vehicle after the addition of the aerodynamic package is presented in the Fig. 5.

Figure 5. Simplified model of the whole vehicle after adding an aerodynamic package

Analyze the aerodynamic performance of the vehicle at a speed of 20m/s, compare the calculation results with Table 1, and obtain the aerodynamic parameters of the vehicle before and after installing the aerodynamic package as shown in Table 10.

|                   | Before | After   |
|-------------------|--------|---------|
| Lift of the front wing | —      | -130    |
| Drag of the front wing | —      | 18.5    |
| Tail lift         | —      | -215.3  |
| Tail drag         | —      | 29.12   |
| Tire resistance   | 19.36  | 20.22   |
| Total lift        | 80.52  | -267.58 |
| Total drag        | 65.1   | 151     |
| Lift-to-drag ratio | 1.23   | -1.77   |

Table 10 displays that the lift characteristic of the car changes from positive to negative after adding the empty cover, which significantly improves the grip and handling stability of the car when driving. After adding the aerodynamic package, the resistance of the vehicle increased by 85.9N, but the downforce increased by 348N. It shows that although there is a side effect of increasing resistance after adding an aerodynamic package, it also significantly increases the downforce of the vehicle.

6. RESULTS AND DISCUSSION

Based on the existing frame and related information, this article designs the body shape and aerodynamic package that meet the requirements of the competition, including the front and rear wings. The simulation analysis of the aerodynamic characteristics of the racing car before and after the installation of the aerodynamic package shows that the designed aerodynamic package can significantly increase the downforce of the racing car under the premise of controllable drag, which effectively improves the grip and maneuverability of the vehicle.
Through the research, we can get the following conclusions[3]:

6.1 **The lift coefficient and drag coefficient of the joined-wing are changed with the position of itself.** Main variables include relative attack angle, gap and longitudinal separation. The flap attack angle increases with the increasing attack angle of the main wing.

6.2 **The lift coefficient and drag coefficient are changed when curved rear wings are used.** And rear wing which contains a main straight wing and upwarp flap get the maximum downforce. A sword cured front wing can decrease the front car body drag.

6.3 **The diffuser can improve the downforce effectively.** With the DRS, a rear wing can optimize the flow field around the formula car.

**REFERENCES**

[1] Dean E, "Formulda SAE - Competition History 1981-1996", SAE Technical Paper 962509, 1996, doi:10.4271/962509.

[2] Francesco Mariani, Claudio Poggiani, France Risi and Lorenzo Scappaticci, “Formula-SAE Racing Car: Experimental and Numerical Analysis of the External Aerodynamics,” Energy Procedia 81 (2015) 1013-1029

[3] Zhou Tao, “Aerodynamics Kits Design for Formula SAE Race Car Based on CFD,” Chongqing University, 2017.

[4] Wan Tingting, “Research on control strategy of adjustable rear wing system for FSE electric racing car,” Guangdong University of Technology, 2018.

[5] Wang Jian, Lin Haiying, Liang Yinghua and Zhou Wenli, “Formula Racing Design For College Students,” Beijing Institute of Technology Press, 2016.