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# The Influence of Wheel Rotating to FSAE Racing Car Aerodynamic Characteristics

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**Abstract.** In this paper, the numerical simulation analysis of *jlu fsae* racing car aerodynamic character based on *star-ccm*+ was introduced. Several simulated situations had been set and the results of the situations were compared. The effect of the wheel rotating situation of the racing car out flow and aerodynamic character was concluded. It was found that the air flows surrounding the wheels and the wings of the racing influenced each other. When the rotating wheel situation was set during the simulation, the effect that the air flows influenced could be simulated more clearly and the result could be more calculatedly. It was necessary to set the wheel rotate when to simulate the racing car aerodynamic character. From the simulated results, it also could be seen that it was also necessary to take care of the wheel rotate when to do the racing car wind tunnel test.

## Introduction

As a key characteristic of the vehicle, aerodynamic characteristics have close relationships with handling stability, safety, dynamics, fuel economy and so on. [1]The aerodynamic characteristics' influence to the vehicle performance is particularly obvious, for formula car with exposed wheels, the car wheel resistance accounted for the proportion of the total resistance sometimes can go to over 45%. [2]In the car development process researchers pay great attention to the car aerodynamic characteristics research and optimization, aerodynamics package has become an important part of the car.

Fsae car belongs to the formula car whose wheels are completely exposed, in order to obtain the high down pressure at high speed, often there are fixed wings mounted on the racing car. [3]As the distance between the fixed wing and the wheels is small, airflow around the wheels and the fixed wing will interact, then this interaction will influence the integral external airflow around the car.

In order to study the car aerodynamic characteristics, we can adopt a method which combines numerical simulation, wind tunnel test and theoretical method.[4,5] At present, techniques which are used in the wind tunnel and numerical simulation to study the external air flow around racing cars are more mature, but in many automobile wind tunnel, it is difficult to rotate the wheels when the test is processing, furthermore, the traditional method of measurement cannot get reliable data of the rotating wheels. The rotation of the wheels can make the airflow around wheels change greatly, the rotation of the wheels or not is a qualitative difference in racing wind tunnel test and numerical simulation. [6] This paper analyzes the aerodynamic characteristics of the *jlu fsae* car, and compares the simulation results of the airflow in different conditions, at last, we summarize the influences of the rotation of wheels to the external flow field and the aerodynamic characteristics of the racing car.

## Numerical Simulation Overview

**Model of Simulation.** Based on the *star-ccm*+ software, we do a external flow field numerical simulation of the *jlu fsae* car. In this paper, a 1:1 racing *cad* model is established according to the actual situation including the car inside and outside surface, wings, frame, engine, seat, roll cage structures, etc. This paper adopts the large calculation domain method, and the specific set is: in the x direction, the distance between the entrance and the head of the car is four times the car length, the

distance between the exit and the rear of the car is eight times the car length; in the y direction, the distance between the racing center plane and the domain wall is 4.5 times the car width; in the z direction, the distance between the car top and the domain top is 5 times the car height.
In this paper, the grid is generated by the *star-ccm+* software. The function of the surface wrapper can greatly reduce the work of model surface processing. In figure 1, it is the grid distribution of wrapped surface of the complex features' racing engine cad model, as we can see, the engine keeps complete typical geometric features.

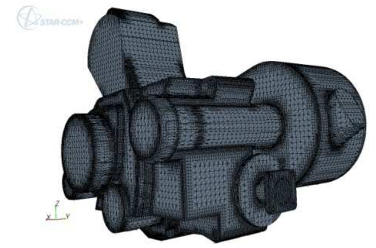


Fig. 1 The wrapped surface of the engine

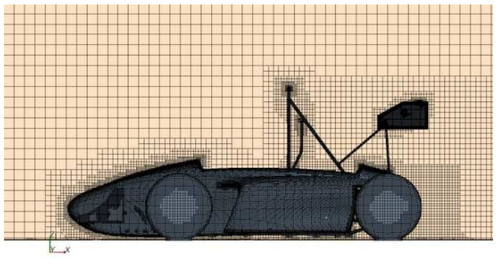


Fig. 2 Volume mesh

Fig. 3 Structure of the *jlu fsae*

The author uses the Trim form of grid to do the outflow field area mesh division, and has the boundary layer of the body and ground done by the Prism, also dose grid refinement processing in the area of around the wings and the rear. The Trim of the *star-ccm+* not only has the characteristic of stable convergence of the structured grid, but has the well adaptive characteristic of the unstructured mesh, so it is suitable to car outflow which demands many grids. Figure 2 is for body grid pattern.
**Different Settings of the Calculation.** In this paper, by comparing the simulation results of the four kinds of condition for the car flow field numerical simulation, we search for the appropriate boundary condition setting and study the influence to simulation results by the rotation of the wheels. Table 1 shows the four kinds of condition.

Table 1 Conditions

| | Condition 1 | Condition 2 | Condition 3 | Condition 4 |
|---|---|---|---|---|
| ground | No-slip | slip | No-slip | slip |
| wheels | No-rotating | No-rotating | rotating | rotating |

**Analysis of the Simulation**

*Jlu* calculated *fsae* racing total *cd* is 1.222, and compared with the modern car's cd which is around 0.3, this value is obviously big. [7,9] This is because of the fsae racing specific structure. In figure 3, there is the structure arrangement of the racing car, as we can see, the car body surface is smooth and it has good streamline features, fixed wing and seat etc are completely exposed in air, these parts will produce large aerodynamic drag.

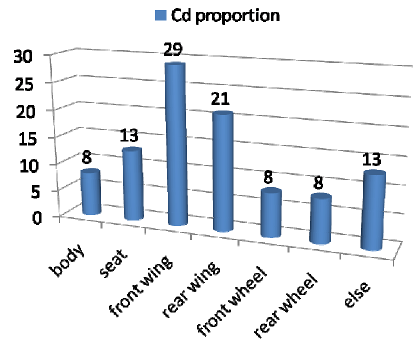
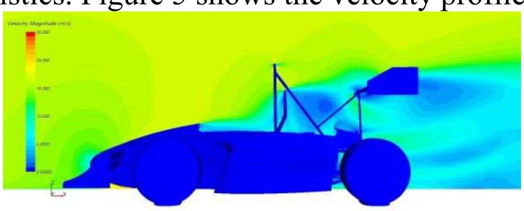
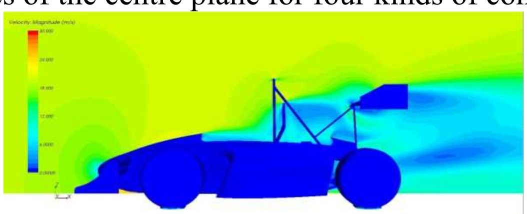



Figure 4 Part's *cd* proportion to the total car *cd*

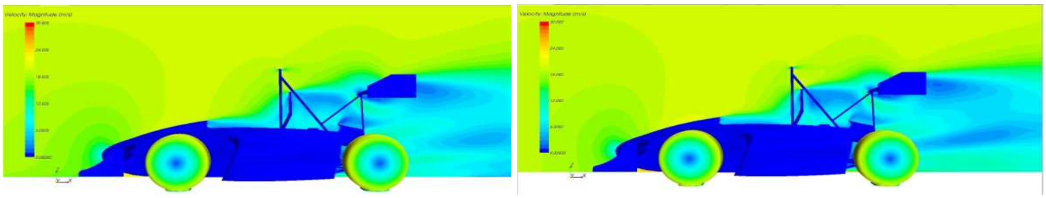
Figure 4 shows the parts' *cd* proportion to the total car *cd*. The wings' proportion which is 50% is the largest, secondly is the exposed wheels and seat which is 30%. Thus it can be seen, in the car flow field numerical simulation and wind tunnel test, the accuracy of simulating racing fixed wings and the flow field distribution around the wheels determines whether we can get the accurate aerodynamic characteristics. Figure 5 shows the velocity profiles of the centre plane for four kinds of condition.



Condition 1



Condition 2



Condition 3 Condition 4

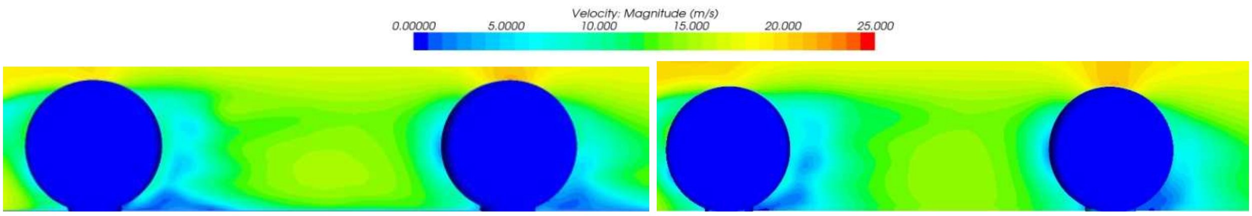
Fig. 5 Velocity scalar scene of four conditions

Table 2 Part's aerodynamic coefficient

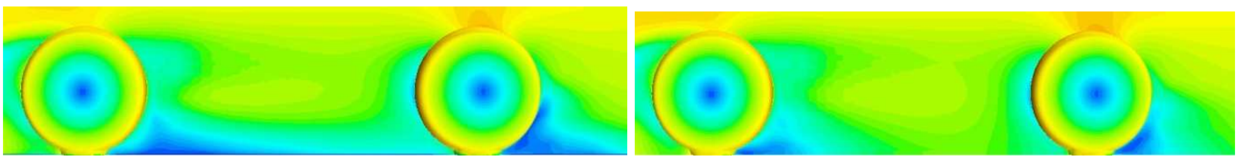
| | Condition 1 | | Condition 2 | | Condition 3 | | Condition 4 | |
|---|---|---|---|---|---|---|---|---|
| part | *cd* | *cl* | *cd* | *cl* | *cd* | *cl* | *cd* | *cl* |
| body | 0.106 | -0.161 | 0.111 | -0.167 | 0.101 | -0.187 | 0.110 | -0.204 |
| seat | 0.149 | -0.068 | 0.151 | -0.072 | 0.150 | -0.087 | 0.149 | -0.091 |
| front wing | 0.352 | -0.667 | 0.387 | -0.705 | 0.347 | -0.793 | 0.382 | -0.888 |
| rear wing | 0.230 | -0.437 | 0.228 | -0.443 | 0.250 | -0.608 | 0.228 | -0.624 |
| front wheel | 0.088 | 0.048 | 0.090 | 0.061 | 0.089 | 0.068 | 0.097 | 0.088 |
| rear wheel | 0.104 | 0.057 | 0.106 | 0.063 | 0.101 | 0.067 | 0.110 | 0.083 |
| else | 0.151 | 0.028 | 0.145 | 0.025 | 0.140 | 0.029 | 0.146 | 0.029 |
| total | 1.180 | -1.200 | 1.218 | -1.238 | 1.178 | -1.511 | 1.222 | -1.607 |

In the comparison of car outflow velocity distributions for four operating conditions, we see that the velocity have obvious difference between car-front and car-rear, this lies in the change of the airflow characteristic around the wheels and the wings because of the rotation of the wheels. Table 2 shows the parts' *cd* and *cl* for four conditions.

In the comparison of data in table 2, we can see that there is a certain influence to the total aerodynamic coefficient value whether we make the wheels rotate or not. When we make the ground slip, the *cd* increases and the *cl* decreases. Figure 6 shows the velocity profile around the wheels for four conditions.




Condition 1 Condition 2

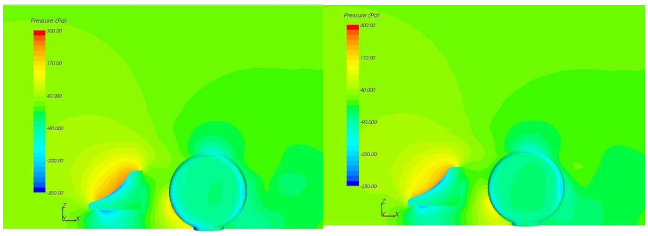


Condition 3 Condition 4

Fig. 6 Velocity scalar scene around wheels

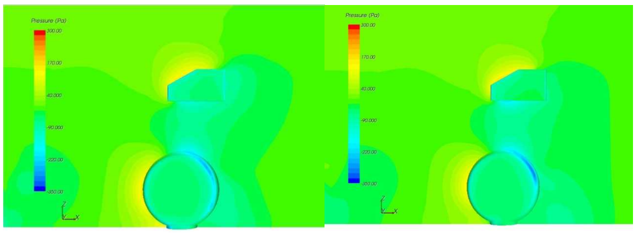
The influence to the velocity distribution around the wheels is very obvious whether we make the wheels rotate or not. In figure 6, we see that the velocity behind the wheels increases and the region of low speed decreases behind the wheels because of the rotation of wheels. Combined with the data in table 2, we see that the airflow around rear wheels is more sensitive to the rotation of wheels.

In the 3th and 4th conditions having rotating wheels, the obvious difference of airflow between the two conditions lies behind the wheels close to the ground, this is due to the interaction of ground boundary layer and the vortex behind wheels. In Condition 4, the simulation is more close to reality because of the slip-ground setting, so this set is more suitable to simulate the outflow around racing car.



Condition 1 Condition 3

Fig. 7 Pressure around front wing and wheel



Condition 1 Condition 3

Fig. 8 Pressure around rear wing and wheel

In figure 7, when the wheels rotate, the pressure in front of the front wing decreases and the surface pressure differential before and after the front wing is also decreases, so the *cd* of front wing decreases. We also see that the negative pressure zone area below the front wing increases and the surface pressure differential below and above the wing increases, so the *cl* of front wing decreases. In figure 8, the situation of the rear wing is the same with front wing except the *cd* of the rear wing increases.

## Summary

Through the study, we conclude:

1) By the restriction of the fsae racing structure, the airflow around the wings and wheels interacts, so the rotation of wheels has a obvious influence to the airflow distribution around the racing car.

2) Compared with the no rotating-wheels condition, the *cd* and *cl* with rotating wheels both decrease. Due to the big difference in the wings' aerodynamic characteristics between the two conditions, it is very necessary to set the wheels to rotate in the simulation of the outflow around the racing car.

3) In the wind tunnel test, we should consider the wheels' rotation, if the condition allows, we should not simplify the wheels to be static, else we should make a correction for the test data in order to obtain accurate results.

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