Numerical Simulation and Analysis for Aerodynamic Devices of FSAE Racing Car

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Abstract. Improving the aerodynamic characteristics of racing cars is one of the important means to improve the performance of FSAE. This paper completed the FSAE car body and aerodynamics device design and development, based on the CFD technology in the car's aerodynamic characteristics are studied. Through the analysis of the aerodynamic characteristics of the car body with and without aerodynamic devices, and the comparative analysis of airflow pressure and velocity distribution around the car body and aerodynamic devices, the simulation results show that the aerodynamic devices effectively improve the aerodynamic characteristics of the car, and better improve the control stability and driving safety of the car.

1. Introduction

The method to enhance the performance of race cars by adding downforce producing devices is well established and started in the 1960's when wings were first used [1]. In short, wings enhance the effectiveness of the tires by increasing the load on the tires without adding the equivalent mass [2]. The extra load increases the lateral force which can be produced by the tires according to the following equation [3]:

$$F_y = \mu F_z$$  \hspace{1cm} (1)

Where $F_y$ is the lateral force, $\mu$ is the friction coefficient of the tires and $F_z$ is the vertical load. Many teams competing in Formula SAE have also tried this approach, but ever since wings were first used in FSAE the debate about whether or not they aide or reduce performance has be on-going. That in favor obviously claim that they do help and those oppose usually claim that wings will not do much in the given speed range while they do add weight and drag which will in the end reduce rather than increase the performance[4].

As mentioned earlier, wings increase race car performance by providing “massless” load to the tires[5]. The wings will obviously add weight to the vehicle and the performance gain must outweigh the drawbacks of this extra weight and the addition of drag that wings also cause. How much downforce a wing produces can be described by the following equation[6]:

$$L = \frac{c_l A_w \rho v^2}{2}$$  \hspace{1cm} (2)
Where \( L \) is the lift or downforce, \( \rho \) is the density of the medium in which the wing travels, \( c_l \) is the coefficient of lift, \( A_w \) is the wing area and \( v \) is the wing speed relative to the medium it passes through. The coefficient of lift depends on the shape and angle of attack of the wing.

As mentioned earlier equation (1) describes the amount of lateral force the tires can provide. The tyre's coefficient of friction is not constant and will decrease as the tire load increases[8]. This suggests that the available lateral force will decrease as the vertical force increase. The overall increase in lateral force is however larger than the decrease in friction coefficient[9]. The addition of the vertical aerodynamic force, \( L \), to equation (2) gives total vertical force.

\[
(F_x + L)\mu = \left( mg + \frac{c_l A_w \rho v^2}{2} \right) \mu = F_{y,\text{total}}
\]  

(3)

The negative effect of adding wings, mainly drag and added mass, must also be analyzed in order to get a more complete picture of the effect on performance. The drag force on a body can be calculated using equation (4) in the same way as the \( c_l \), the \( c_d \) is dependent of the shape and angle of attack of the wing. The drag force has a counteracting effect on the available traction force which propels the vehicle forward[10].

\[
D = \frac{c_d A_w \rho v^2}{2}
\]  

(4)

Being aware of the \( c_l \) and \( c_d \), we can know the actual forces of the car when racing, so the final performance of the car can be seen, whether it is good or bad. By taking the addition of the theoretical drag into account, and knowing the efficiency of the engine, it is possible to estimate how much extra fuel the car would consume with wings[11].

2. Parts design process

2.1. Body design concept

We always want to create a great racing body. Before we start to design, through the existing relatively complete vehicle model, we began to design the body model under the premise of ensuring that other systems can work well, combined with our design concepts at the same time. Considering aesthetics, we must also consider the aerodynamic performance. According to optimize the External Airflow analysis model, and get the goals of designing a high performance, pleasing racing body.

2.2. Wing theory

There are a number of ways to increase the amount of downforce a wing can produce. As equation (2) shows, from a design point of view, that the size or area of the wing is influential as well as the coefficient of lift, which depends on the cross section shape, or the aerofoil, of the wing. The area of the wing is determined by the width or span of the wing and the depth or chord. The maximum span of the wing is determined in the FSAE rule as is the chord in effect since the rules regulates how far ahead of the vehicle aerodynamic devises can protrude.

2.3. Wings selecting

As the drag of the wings depends on the wings size and shape which in turn determine the downforce, this makes it difficult to decide the downforce distribution without investigating different wing concept's downforce to drag ratio. As a result of this, it is an iterative process to determine the downforce distribution. As the maximum size of the wings is determined by the rules it is easiest to look to the coefficient of lift to acquire the desired amount of downforce. By iteratively testing wings with different aerofoils and thus different downforce to drag ratios it is possible to determine suitable aerofoils to meet the required pressure distribution of the car. We choose the airfoils from profili, after doing many analyses and compares; we finally decided the airfoil profile of main wing and flaps. If a highly cambered wing is not enough to produce the required downforce, or results in flow separation, a multi-
element wing can be used. The most usual application on race cars is the use of flaps, which are smaller
wings placed behind and above the main plane. This will increase the wing area but will also increase
the effective camber without causing flow separation. One of the key parameters to consider when
designing a multi-element wing is the size of the gap between the flap and the main wing. After doing
many CFD simulations, we finally determined the parameters of our wings.

| Table 1. All the analyzed parameters in optimization process |
|-------------------------------------------------------------|
| Performance parameter                                      |
| Down force  | Drag force         |
| $C_1$    | Value (N)          | $C_d$ | Value (N) |
| -3.167   | -377.06            | 1.27  | 152       |
| -4.01    | -474.23            | 1.18  | 134       |
| -4.61    | -501.62            | 1.26  | 155.7     |
| -4.58    | -43.36             | 1.15  | 124.75    |
| -4.58    | -493.16            | 1.14  | 123.55    |

We choose the final parameters to be our rear wing parameter, for its best performance on the above
all. The geometry parameters are a vertical gap of 3.1% and 5.6% of the chord and longitudinal overlap
of 6.9% and 13.7% of the chord is suitable, so that we can get the best rear wing. As for front wing, we
used the same way to get. An additional method to improve the wing performance is the use of endplates.
An endplate is a plate mounted vertically at the end of the wing. The implementation of endplates can
potentially increase downforce and reduce drag. The general shape of a wing produces a pressure
difference between the upper and the lower surfaces, which is also its purpose. At the side edges of the
wing this pressure difference results in air flowing from the high pressure area to the low pressure area.
This in itself decreases the effectiveness of the entire wing but also creates vortices trailing off from the
wings. This results in an increase in induced drag. Adding endplates to the wing will reduce the amount
of air moving from the high pressure region and in general the larger the endplates the better they will
work.

3. CFD simulation process

3.1. Meshing
To analyze different aerofoils for the front and rear wing and how they affected the overall pressure
distribution CFD was utilized. Firstly, a computer aided design (CAD) model was created using CATIA
V5. Before analyzing, we should simplify the model to decrease unnecessary calculating. Then we
should determine the flow fluid area, according to some papers, it is very important to choose sufficient
intake length in numerical simulation. Assuming the car model length L, width W, height H, recommended based on papers, the computational domain emulated for the former Motorsport 3L, side
4W, taking into account the impact of the car wake aerodynamic characteristics of the car on a very
large, large area, so Racing rear take 7L. That is the flow fluid area is 28000mm long, 8700 wide, 5200
height. And then we used the prepared CAD model for simulation and to create the body surface mesh
and volume mesh. Besides we must encrypted the grid at the area that near to the car.

3.2. CFD-Fluent calculation
The turbulence model used, the realizable k-epsilon model, is a time averaged (Reynolds Average
Navier-Stoke) model using two extra transport equations, the k-equation and the epsilon-equation, in
order to represent the turbulent properties of the flow. This is a suitable model when simulating turbulent
flows and is relatively quick to solve. In order to achieve a good prediction of lift and drag forces it is
important to set the ground plane as a moving wall and the wheels as rotating walls. This will more
accurately simulate real driving conditions, comparable to the use of a moving ground system in physical
wind tunnels.
4. The analysis results

For the rear wing of FSAE racing car, the principle is the multi-wing stack, the induced flow accelerated away from the rear of the car. The influence factor of the aerodynamic characteristics of the basic parameters are: wings angle of attack, and so the gap between the fins. The analysis, a tail model under three different parameters, taking into account the problem stall angle of attack may occur if main wing angle of attack is too big, the main wing angle of attack within 5° -10°, flap angle of attack at 25° -45°. Finally, the downforce is 493N, the drag is 123N, which are achieved desired results.

In fluid mechanics, stall refers to a state of airfoil angle of attack to a certain extent (reaches a critical value), the lift generated by the wing suddenly reduced. Before airfoil angle of attack exceeds the critical value, the airfoil lift is increasing with increasing angle of attack; however the angle of attack exceeds the critical value, the airfoil lift will decrease. The pressure centers should be about 76mm vertical rear the gravity center, according to this conclusion, the way force balance calculations used to estimate the scope of the front wing downforce is about 300N, based on optimized the best rear wing parameters match the parameters of the front wing. But in reality, taking into account of the 10 inch wheel rim of our car, the vehicle height can be further reduced, in order to guarantee a sufficient air flow from the inflow side of the radiator tank, the second sheet off the flaps, the overall gas flow in this way to avoid around the over tires and side boxes. Finally, the downforce is 302N, the drag is 68N, which are achieved desired results. According to structural characteristics of the car, we use the dual-channel diffuser, the middle of two channels are flat surfaces, which is conducive to high speed through the air. Air flow flows through the front-wheel side of the channel into the interior channel, the two channels use venturi effect, the maximum flow rate is at the lowest height of the channel, thus produce maximum pressure. Therefore, downforce are not concentrate on rear wheels, and improve the downforce distribution of the vehicle.
For a racing car, just analyzing of the significance of aerodynamics is of no significant, the aerodynamic packages must be assembled on the car. Only analyzing the car with aerodynamic packages that we can see the performance of the whole vehicle. So after having designed our aerodynamic packages, we did vehicle simulation to compare the performance between aero and no aero.

**Table 2.** Aerodynamics parameters with aero and no aero

|                  | No aero | With aero |
|------------------|---------|-----------|
| Drag force (N)   | 104.2   | 310.59    |
| $C_D$            | 0.34    | 0.65      |
| Lift fore (N)    | 71.7    | -583.02   |
| $C_L$            | 0.27    | -1.18     |

**Figure 10.** Pressure contour  
**Figure 11.** Velocity contour  
**Figure 12.** Velocity streamline

5. Conclusion
The preliminary specification of a high downforce aerodynamic package for a Formula SAE car was described. Using values obtained from experimental measurements described in a companion paper, the net effect of this package on Dynamic Event performance was quantitatively estimated for the our Formula SAE car. This analysis predicted that the 'wing' package described would significantly benefit the car's dynamic event performance.

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