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Car's Aerodynamic Characteristics at High Speed Influenced by Rear Spoiler

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Abstract: *The factors affect the rear spoiler's aerodynamics characteristics are cross-sectional shape, chord length and angle of attack. By changing the three factors that can change the state of the car flow field. Determine the main body size, build models by Solidworks . Use Hypermesh to mesh, increase the number of grid near the body especially at the rear spoiler. Use Fluent for fluid analysis to get the values of aerodynamic lift coefficient CL (at 120km / h) based on orthogonal experiments. After calculating, obtain significance order of factors can obtain the best rear spoiler shape, helping to optimize the automotive styling quickly, improve the car's power and economy, ease the new car quickly seize the market.*
Key words: *Orthogonal Experiments, Rear Spoiler, High Speed, Aerodynamics, CFD*

I. INTRODUCTION

A car will have a greater aerodynamic lift when its speed is high. And the ability of maintain a predetermined route running of the car will be decreased. This will seriously affect vehicle handing and stability at high speed. From the viewpoint of safety, to reduce the car's aerodynamic lift force is more important than reducing the aerodynamic drag.

The role of the rear spoiler is to make the airflow washing down from the roof into a downward force to offset parts of the aerodynamic lift. It also can increase the adhesion of the wheels on the ground to improve the car dynamics and stability at high speed. Therefore, rear spoiler has a certain impact on the field of car tail. The features have impact on rear spoiler are the cross-sectional shape, the chord length and the horizontal angle.

Orthogonal experiment is a significant and effective method of using minimal number of tests to obtain the correct conclusions.

There is little literatures on the factors affecting significant analysis to derive optimum design. Therefore, on the basis of previous studies, this article will use orthogonal experimental design method to analyze the significance of three factors which affect the spoiler, then get the more excellent design of rear spoiler, provides a theoretical basis for the rear spoiler design.

II. MODELING

Based on the quality, momentum and energy three equations, we can get Navier-Stokes equations. This is the general law for fluid flow. Assuming the flow is steady and each parameter of air is constant. When the vehicle speed is less than 200km/h (120km/h is setted in this article), the mach of air is much less than 0.3 relative to the car movement, so air is defined as non-pressure flow and the air around car is turbulent state.

2.1 Cases

There are three factors affecting rear spoiler, cross-sectional shape, chord length and horizontal angle. About cross-sectional shape, there are three types, racing type, flat type and common type. Chord length is the distance between front edge and rear edge. Horizontal angle is the angle between chord and horizontal direction. Show in the fig.1

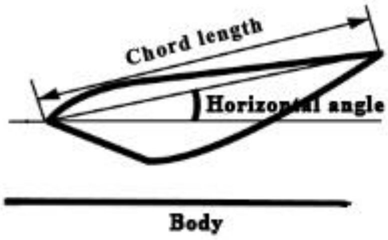

Fig.1 Rear Spoiler Parameters

Use single index orthogonal design, choose four factors and three levels orthogonal table, aim at looking for the best aerodynamic spoiler shape. The indicator is air lift coefficient, the smaller the better. There are three factors cross-sectional shape A, chord length B and horizontal angle C. Each factor has three values. Show in the Table 1.

Table 1 the Values of Each Factor

Values	A	B	C
1	Racing type	130^o	0^o
2	Flat type	150^o	15^o
3	Common type	170^o	30^o

According toTable 1, nine cases with different spoilers are established. The mian study is about the relationship between the rear spoiler and car body, to make calculation easy, so the styling of cases has been simplified. Ignore exterior protrusions such as mirrors, wipers, wheels and other small components. The underbody has been simplified, ignoring the unenen bottom. Ignore the projecting curved portion of the body side.

Using Solidworks software to establish three-dimensional model, the basic parameters are shown in Table 2.

Table 2 the Basic Parameters of Simulatin Model

Body basic parameters		Spoiler basic parameters	
Length	4255mm	length	1799mm
Width	1799mm	Distance from body	72mm
Heigth	1452mm	Cross-sectional shape	Flat Common Racing
Wheelbase	2637mm	Chord length	130mm 150mm 170mm
Ground clearance	130mm	Horizontal angle	$0°$ $15°$ $30°$

Based on orthogonal experiment method, the cases' retails are shown in Table 3.

Table 3 Model Programs

Number	Cases (cross-sectional shape/chord length/horizontal angle)
0	None
1	Racing/130mm/0^o
2	Racing/150mm/15^o
3	Racing/170mm/30^o
4	Flat/130mm/15^o
5	Flat/150mm/30^o
6	Flat/170mm/0^o
7	Common/130mm/30^o
8	Common/150mm/0^o
9	Common/170mm/15^o

2.2 Numerical Simulation

2.2.1 Calculation Area

Define vehicle length as "L", height as "H", width as "W". From the practical situation, the computational domain boundaries should be infinity in the car outside, due to the calculation conditions, circumstances and actual experience of numerical simulation, the entire region is regarded as a rectangular shape. In this paper, the calculation region selection rules are as follows: height is 4H, width is 7W, length is 8L. Thus, the entire computational domain is a rectangular with length 29785mm, width 12593mm, height 5808mm. Show in Fig.2.

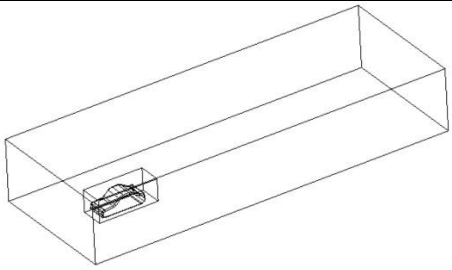

Fig.2 Numerical Simulation Domain

2.2.2 Types and Generates of The Computational Grid

To save computer memory and speed up the computation time, need to refine the computational domain. And in the area near the car, use tetrahedral grids to adapt to complex shapes. But in the large area away from the car, use hexahedral grids to reduce the calculating time. Details are as follows:

(1) Establish a small cube around the car, and use tetrahedral grids to fill the aera between small Cube and car. The distance from small cube front to car forefront is 400mm, the distance from small cube sides to car left and right are all 200mm, the distance from small cube top to car top is 500mm, the distance from small cube tail to car tail is 1000mm.

(2) The simulation focuses the aerodynamic properties of the rear spoiler, therefore, in the vicinity of the rear spoiler a module is needed to divide a denser mesh. The results are shown in Fig.3.

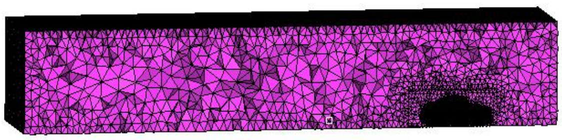

Fig.3 the Grid Graph of Numerical Simulation Model

2.2.3 Boundaries

Using SST k-ε turbulence solver based on pressure in the numerical simulation and the second order upwind discretization scheme. Body is regarded as a fixed surface, ground is non-slip movement, the entrance of the computational domain is 120km/h speed, the export is pressure outlet boundary with a standard atmospheric pressure, the body and rear spoiler are stationary boundary wall.

III. RESULTS AND ANALYSIS OF NUMERICAL SIMULATION

3.1 Results of Numerical Simulation

Using Fluent software to simulate the original model, getting the lift coefficient C_o is -0.438.

Based on orthogonal form, design the test program, and use Fluent software to simulate all cases to obtain all C_i (i=1, 2, 3…), and $\triangle C_L=C_i-C_0$ (i=1, 2, 3...), the results are shown in Table 4.

Table 4 Orthogonal Experimental Results

	A/1	B/2	C/3	D/4	$\triangle C_L$
1	1（Racing）	1（130）	1（0^o）	1	-0.049
2	1	2（150）	2（15^o）	2	-0.367
3	1	3（170）	3（30^o）	3	-0.204
4	2（Flat）	1	2	3	-0.445
5	2	2	3	1	-0.441
6	2	3	1	2	-0.263
7	3（Common）	1	3	2	-0.231
8	3	2	1	3	-0.251
9	3	3	2	1	-0.334
K_1	-0.620	-0.725	-0.563	-0.824	/
K_2	-1.149	-1.059	-1.146	-0.861	/
K_3	-0.816	-0.801	-0.876	-0.900	/

According to Table 4, variance value of each factor can be calculated, from the F distribution, we can calculate the F value, and then judge the significant of each factor. Rules are as follows:

When $F_i>F_{0.01}$, the factor is high significant.

When $F_{0.01}>F_i>F_{0.05}$, the factor is significant.
When $F_{0.05}>F_i>F_{0.1}$, the factor is little significant.
When $F_{0.1}>F_i>F_{0.25}$, the factor is no significant.
$F_{0.25}(2, 2)=3$, $F_{0.1}(2, 2)=9$, $F_{0.05}(2, 2)=19$, $F_{0.01}(2, 2)=99$, so significan results are shown in Table 5.

Tab.5 Significant Results

Factors	S	F	F	Significant
A	0.2184	2	7.045	little
B	0.1429	2	4.610	little
C	0.2382	2	7.684	little
Empty	0.0310	2	/	/

3.2 Result Analysis

(1) From Table 4, the change of lift coefficient of case 4 (flat type/chord length 130mm/horizontal angle 15^{o}) is largest, with -0.445. So its lift coefficient is smallest and upward lift is minimum. But the lift coefficient of the case 1 is largest, which is not good for car attachment.

(2) From Table 5, A, B and C, represent for cross-sectional shape, chord length and horizontal angle, are little significant for car lift coefficient. About the impact, the order of three factors is CAB. The best combination case is C2A2B2, which is flat type, 150mm chord length and 15^{o} horizontal angle. This can increase the attachement effect of the car.

IV. CONCLUSION

Based on orthogonal theory, regard lift coefficient as the indicator, explore and analyze the influence of rear spoiler on the dynamic characteristicsof the car. It can provide a theoretical reference for the design of automotive styling. The car is driven at a constant speed of 120km/h with front wind. Choose standard k-ε turbulence model. Make a total of nine cases, and simulate the corresponding lift coefficient one by one. Having a analysis on significant for three factors, to get they all have little significant to rear spoiler and lift coefficient. The result is the best combination is flat type, 150mm chord length and 15^{o} horizontal angle. This is good for reducing the lift force of car, increasing the ground adhesion of car, saving the time of designing, seizing new market easily and quickly.

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