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To cite this article: Xuechao Wang *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **242** 032026

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Analysis on aerodynamic performance based on optimization of automobile head shape

Xuechao Wang^{1*}, Qiang Lu¹, Renzheng Li² and Xiaoming Xu²

¹China Automotive Technology & Research Center Co. Ltd, Tianjin, 300300, China

²School of automobile and traffic engineering, Jiangsu University, Zhenjiang, Jiangsu, 212013, China

*Corresponding author's e-mail: xuxiaoming3777@163.com

Abstract. Aerodynamics characteristic parameters are the important parameters that affect the performance of automobile, such as dynamic performance, economic performance and control stability, which play an important role in automobile appearance design. In this paper, FLUENT software was used to simulate the simple models with different head shapes and study the aerodynamic characteristics, so as to optimize the automobile modeling and improve the aerodynamic performance.

1.Introduction

With the development of automobile technology, more and more attention has been paid to the study of aerodynamic characteristics of automobiles. Wind tunnel test is a traditional and effective method for automobile aerodynamics research, but wind tunnel construction investment is large and the test cycle is long, and it is difficult to simulate the complex conditions of automobile surface details, wheel rotation and internal flow [1, 2]. Only using wind tunnel test and road test technology to study automobile aerodynamics cannot meet the needs of rapid development of economy, safety and comfort automobiles. With the development of computing technology, the numerical simulation method has opened up a new way for the research of automobile aerodynamics [3]. The typical Computer Fluid Dynamics software FLUENT can simulate complex conditions, such as body details and inflow, which are difficult to simulate in the wind tunnel test [4-7]. In this paper, FLUENT software was applied to analyse the aerodynamic performance of simple automobile models with different head shapes, so as to provide reference for the design of the automobile head shape.

2.Model Development

2.1Mathematical model

In this paper, the maximum speed of automobile is less than 400km/h which is far less than sound speed. The body surface flow can be considered as incompressible flow which should be treated as turbulence. The control equations are as follows.

Mass conservation equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} = 0 \quad (1)$$

In the formula: ρ means density; t means time; u , v , w means the component of velocity vector in direction of x , y , z .



Momentum conservation equation:

$$\frac{\partial(\rho u)}{\partial t} + \text{div}(\rho u u) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + F_x \quad (2)$$

$$\frac{\partial(\rho v)}{\partial t} + \text{div}(\rho v u) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + F_y \quad (3)$$

$$\frac{\partial(\rho w)}{\partial t} + \text{div}(\rho w u) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + F_z \quad (4)$$

In the formula, p means the pressure on the micro unit; τ means the component of viscous stress in different directions; F means the body force in different directions.

Turbulence transient control equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (5)$$

$$\frac{\partial u}{\partial t} + \text{div}(uu) = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \text{div}(\text{gradu}) \quad (6)$$

$$\frac{\partial v}{\partial t} + \text{div}(vu) = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \text{div}(\text{gradv}) \quad (7)$$

$$\frac{\partial w}{\partial t} + \text{div}(wu) = -\frac{1}{\rho} \frac{\partial p}{\partial z} + \text{div}(\text{gradw}) \quad (8)$$

The energy conservation is not considered because the heat exchange can be ignored in incompressible flow of automotive body outflow field.

2.2Automobile body model

Figure 1 is the automobile body of GAMBIT model with dimensions: length 4800mm, width 1800 mm, height 1500 mm.

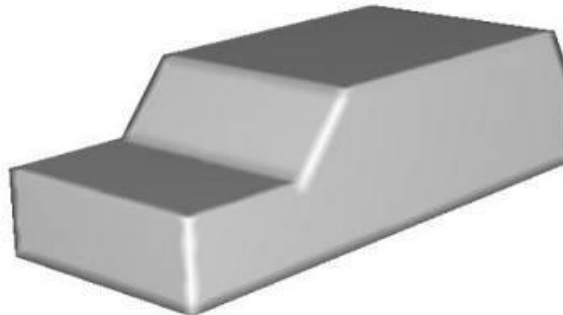


Figure 1. GAMBIT automobile body model.

2.3The body mesh

The flow field near the body is the main research object. In this paper, hybrid grid technology is used for space division of the wind tunnel. A structured grid represents the air around the automobile, an unstructured grid represents the body surface, and a non-structured grid is used for the body. Figure 2 is the schematic diagram of the automobile body distribution grid.

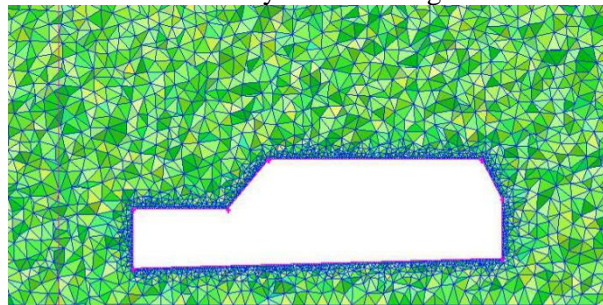


Figure 2. Schematic diagram of body mesh distribution.

2.4 The wind tunnel model

The wind tunnel's dimensions should meet the following specifications: three times the automobile length allotted for space in front of the automobile, five times the length of the automobile allotted for rear space, five times the height of the automobile between the ceiling and automobile roof, five times the automobile width allotted for each side. Only by this way, the blocking effect does not appear. Figure 3 shows a wind tunnel cross sectional shape.

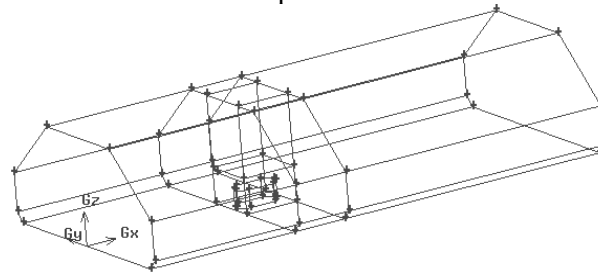


Figure 3. Wind cross-section shape.

2.5 Boundary conditions

The entrance boundary for the velocity boundary condition is the automobile's speed with its surface perpendicular to the direction of import. The export is the pressure outlet boundary condition, equal to the standard atmospheric pressure. Specific boundary conditions are set as follows:

- (1) Simulating the wind tunnel entrance boundary condition, the entrance boundary for the velocity boundary condition speed is the automobile's speed of 100km/h, its surface being perpendicular to the direction of import;
- (2) Simulating a wind tunnel outlet boundary condition, the pressure outlet boundary condition is equal to standard atmospheric pressure;
- (3) The automobile's body wall boundary condition, assuming the surface is under a no slip boundary condition.

3. The basic model of automobile aerodynamic performance

The aerodynamic drag of the basic model is 118.14N, the drag coefficient is 0.7568, the lift force is -28.92N, and the lift coefficient is -0.0545. Drag coefficient and lift coefficient are both large and aerodynamic performance is poor. Figures 4, 5 and 6 are the body surface pressure field, velocity field and vector distribution of basic model respectively. The front part of the automobile is high pressure area, and the pressure at the windshield and rear corner is small, but the wind speed is very large, so it is easy to form vortex. In addition, there is obvious vortex formation behind the hood and rear, and the aerodynamic performance of these parts can be improved by optimizing the body structure.

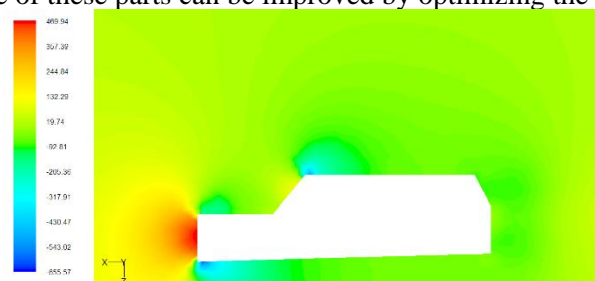


Figure 4. Pressure field distribution.

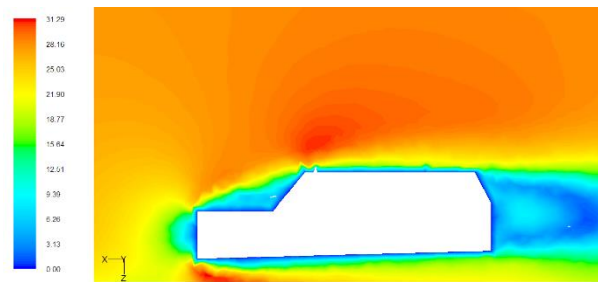


Figure 5. Distribution map of velocity field.

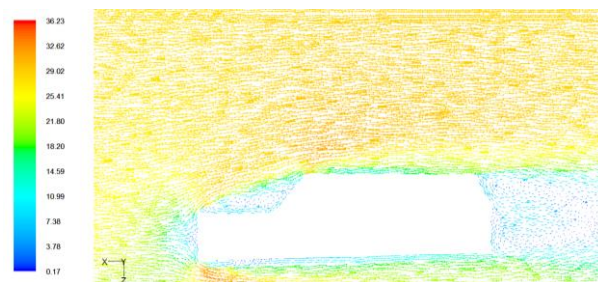


Figure 6. Vector field distribution.

4.The overall optimization of automobile head shape

In automobile design, we must consider both drag coefficient and lift coefficient at the same time, so that the drag coefficient and lift coefficient of automobile can be as small as possible. Figure 7 is automobile model of integrated optimization of automobile head shape. Table 1 is aerodynamic parameters of the overall optimization of automobile head shape. Through the overall optimization of automobile head shape, the drag coefficient is 27.5% lower than that of the basic model and the lift coefficient is 84.5% lower than that of the basic model, which improves aerodynamics performance of automobile.

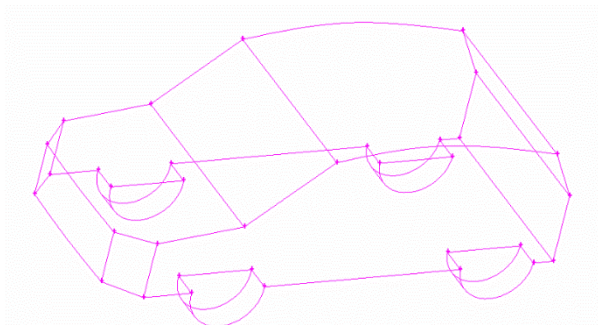


Figure 7. Vector field distribution.

Table 1. Aerodynamic parameters of the overall optimization of automobile head shape.

L (mm)	Drag (N)	Drag coefficient	Lift(N)	Lift coefficient
Basic model	115.71	0.7413	-27.60	-0.0520
Optimal model	94.88	0.5375	-3.51	-0.0066

Figure 8 and 9 are the distributions of pressure field (a), velocity field (b) and vector field (c) on the surface of automobile after optimization respectively. Through the analysis of the distribution of pressure field, the front of the head and windowpane are high pressure. Negative pressure is formed at the top front end, front end, side front end and rear part of the automobile. Through the velocity field distribution, the front end and the rear end of the automobile are low in wind speed, and the velocity at the front end of the automobile and the front side of the automobile body varies greatly. Through the

vector field distribution, flow direction changes at the front end of the automobile, and there is a swirl at the end of the automobile and both sides of the body, the flow tends to be gentle, and the eddy current in the chamfer is smaller;

Compared with the basic model, the chamfering of front side reduces the front side pressure difference of automobile body. The dropping of engine hood and tilting of windowpane reduce the front pressure of windowpane greatly and greatly reduces the eddy current of the combination area of the hood and windowpane to a great extent. The uplift of the roof reduces the pressure difference at the front end of the roof and reduces the eddy current; The transverse front protrusion of the front part of the automobile has a certain guiding effect on the airflow; Overall, aerodynamic performance of the optimized integral automobile head shape is greatly improved compared with the basic model.

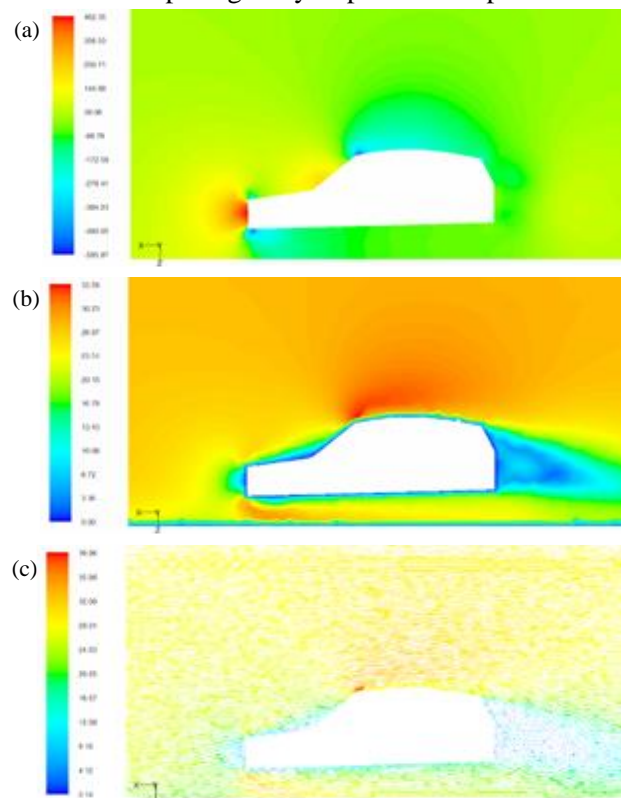
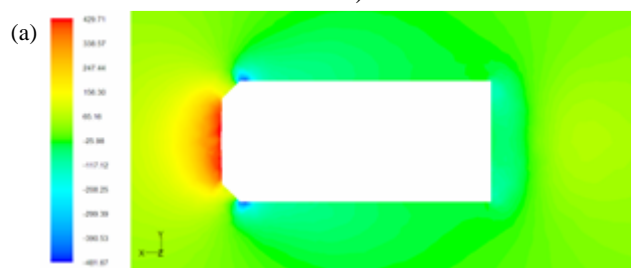


Figure 8. Aerodynamic performance of the optimized integral automobile head shape (main visual direction).



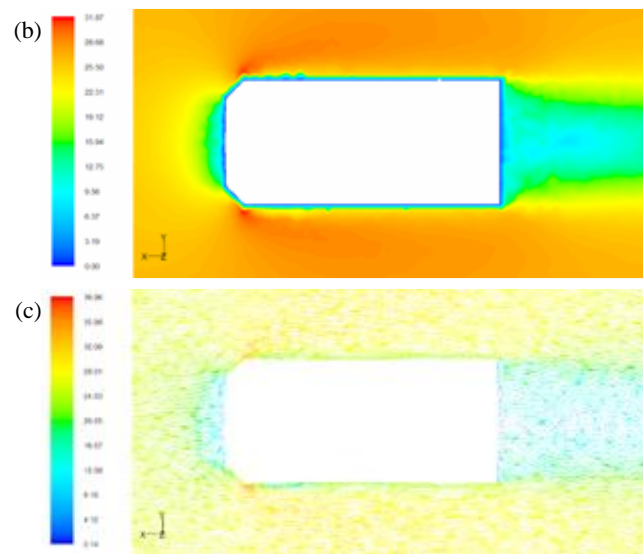


Figure 9. Aerodynamic performance of the optimized integral automobile head shape (down looking direction).

5. Conclusion

FLUNET software was used to analyse the aerodynamic performance of the basic model. From the results after the overall optimization, the aerodynamic performance can be improved by increasing the gradient of the windscreen, changing the juncture between the automotive roof and windscreen into fillet, increasing the tilting angle of the engine cover, changing the right-angle automotive head into fillet. And the aerodynamic performance improves a lot after the optimization, the drag coefficient decreases by 27.5% and the lift coefficient increases by 84.5% which can provide reference for the design of automobile.

Acknowledgments

This project is supported by National Natural Science Foundation of China (Grant No.51505196), National Natural Science Foundation of China (Grant No.51875259), National Natural Science Foundation of China (Grant No.51705208), Science Fund of State Key Laboratory of Automotive Safety and Energy (Grant No.KF1819), Postgraduate Research & Practice Innovation Program of Jiangsu Province (Grant No.SJCX17_0583).

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