Aerodynamics and Drag of a Car

Yingjie Fu*

Wuhan University of Technology, Wuhan 430000, China

* Corresponding Author Email: Fu17362984739@whut.edu.cn

Abstract. According to Chinese economic development and human life improvement, the vehicle, as the most important transportation, goes into common people's life gradually. The following problems of energy are highlighted day by day. In Chinese Manufacturing 2025, the idea of energy-saving and new energy vehicle was pointed out as an important development area, and energy-saving and emission reduction had already been the core work content for Original Equipment Manufacturers. Aerodynamic performance has great influence to vehicle handling performance, power performance, fuel and economy. The external flow filed character better or not will all impact vehicle comfort performance directly. Therefore, OEMs paid more and more attention to vehicle aerodynamic simulation analysis. Reasonable aerodynamic performance plays an important role in improving the performance of vehicle dynamics, economy and so on. Therefore, how to meet the requirements of modeling, engineering at the same time, but also to improve aerodynamic characteristics is particularly important for design a car. This paper discusses the factors that affect the air resistance of the car.

Keywords: Aerodynamics; Drag; Gas Resistance Coefficient; Wind Tunnel Test; CFD.

1. Introduction

With the improvement of people's living standards, the number of cars has increased year by year, which has caused great pressure to create an ideal living environment with blue sky and white clouds. Exhaust emissions [1] are one of the main directions of development and research in the automotive industry. Air resistance, as one of the main harmful resistances in the process of car driving, reduces the energy utilization rate of the car, and the higher the vehicle speed, the more significant the impact of air resistance on the vehicle [2]. Therefore, for automobile enterprises and related researchers, it is of great practical significance to improve the design of vehicles according to the air resistance coefficient of automobiles in the design stage. As an important means to test the fuel economy [3] of the vehicle, the vehicle sliding test can not only measure the vehicle exhaust emission, but also monitor the rolling friction resistance between the tire and the road surface [4], acceleration resistance, and air resistance [5] to provide improvement ideas for improving vehicle fuel economy, reducing vehicle resistance and energy waste caused by driving [6].

The air force on the vehicle can be decomposed into six components: resistance, lift, lateral force, yaw aerodynamic moment, pitch aerodynamic moment, and roll aerodynamic moment [7]. Among these six components, the power consumed by the air resistance of the car and the power consumed by the rolling friction are equivalent, so the aerodynamic drag coefficient has become the most basic parameter to measure the aerodynamic performance of the car, that is, how to reduce the The drag coefficient of automobiles has become the most important research content of automobile aerodynamics. The most commonly used method to reduce the air resistance of the car when driving includes reducing the windward area of the car and the drag coefficient of the air. Generally speaking, the size of the car determines the size of the windward area of the car, and the exterior shape of the body determines the size of the air resistance. Therefore, compacting and streamlining the car body are the two most important ways to improve the aerodynamic performance of the car.

The development of the world's car styling is basically synchronized with the technical research on reducing the wind and sun coefficient. From box, streamline, boat, fish and wedge shapes, every change in styling style has brought about a significant reduction in the wind resistance coefficient [8]. Automobile companies in various countries have invested a lot of manpower, material resources and financial resources to test and study the aerodynamic characteristics of automobiles. The traditional research on automobile aerodynamics is mainly based on wind tunnel tests [9], but wind tunnel tests require a lot of investment, take a long time, and have limited resources. In recent years, with the high development of computers, the theory of turbulence. Continuously updated and improved, computational fluid dynamics (CFD) [10] methods have been widely used in the study of vehicle aerodynamic performance. Advanced numerical simulation methods [11] are used to more effectively analyze and study the characteristics of the external flow field of the vehicle. At the same time, the method combined with traditional research methods is also used to greatly improve the aerodynamic performance of the vehicle, improve R&D efficiency, save R&D costs.

By analyzing the physical model for resistance, the author provides some practical methods that often used by car companies in the development stage, theoretically deduces the relationship between the air resistance coefficient and the shape of a car.

2. Mechanism

2.1. The sources of air resistance

According to the result of previous research, the air resistance received by the car is roughly divided into pressure resistance and friction resistance. The pressure resistance is related to the form, the protrusions on the body surface, the internal circulation resistance and the aerodynamic lift.

The aerodynamic force acting on the vehicle can be divided into aerodynamic drag, aerodynamic lift, and aerodynamic lateral force. The direction of aerodynamic resistance is parallel to the direction of the car and points to the rear of the car (x-axis direction); aerodynamic lateral force is the force in the y-axis direction of the car; aerodynamic lift is the upward force perpendicular to the ground (z-axis direction sentence), of course, Downforce is the force in the -z-axis direction. When the car is running in strong crosswind conditions, the aerodynamic lateral force cannot be ignored, but in order to simplify the research, it is generally believed that the speed of the car is much greater than the crosswind speed, so the influence of the aerodynamic lateral force can be ignored.

2.2. The physical model for resistance

The reason for air flow resistance

A simplified model is used to analyze the causes of air flow resistance. Assuming that the flat plate with cross-sectional area A in Figure 1 moves at a relative speed v in the air flow, the fluid with Av△t volume in front of the flat plate is expelled from these fluids in time.

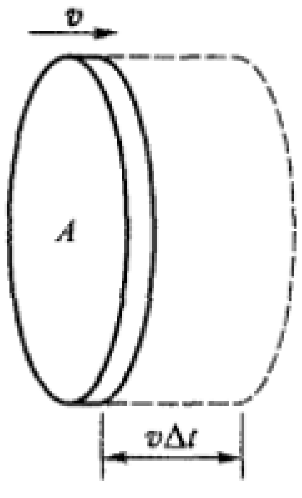

Figure 1. Tablet movement resistance

Kinetic energy is

$$E_k = \frac{1}{2}(\Delta m)v^2 \tag{1}$$

Then, $\Delta m = \rho A v \Delta t$ ρ is the density of the fluid. According to the kinetic energy theorem, the kinetic energy of the displaced fluid can be thought of as the result of the force exerted by the plate on the fluid doing work on the fluid. The work is

$$w = Fv\Delta t \tag{2}$$

With $w = \Delta E$, we can get

$$F = \frac{1}{2}\rho A v^2 \tag{3}$$

Generally speaking, the flow resistance of the air is related to the shape of the object and the degree of surface smoothness, the flow resistance can be written as

$$F = kv^2 = \frac{1}{2}C\rho A v^2 \tag{4}$$

In the formula, we could conclude that aerodynamic force is proportional to the square of vehicle speed. In the meantime, C is called the air resistance coefficient, which is a value whose dimension is 1. For objects of different shapes, the air resistance coefficient c is different due to the different conditions when the fluid is expelled, as shown in Figure 2. Taking three kinds of objects with the same cross-sectional area facing the wind but different shapes as examples, Figure 2(a) is a circular plate, and Figure 2(b) is a cylinder. When they face the airflow, they will not only be pressurized by the airflow in front of them, but also the rear of the circular plate and the cylinder is a plane.

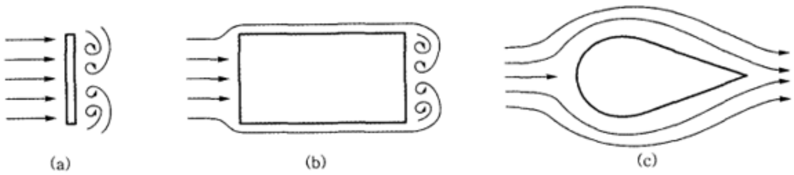

Figure 2. Flow resistance of objects of different shapes

Due to the partial vacuum of the airflow, a vortex will also be generated. A "Kalman vortex street" is formed, which produces a pulling force behind the flat plate and the cylinder, so the flat plate and the cylinder are subjected to greater resistance in the airflow.

Figure 2(c) is a streamlined body. It can be seen from the figure that the eddy current in the first two cases is basically eliminated due to the existence of the tail cone behind the streamlined body. But the flow resistance of the streamlined object in the airflow is small. And the following Figure 3 is a rough result of experimental data.

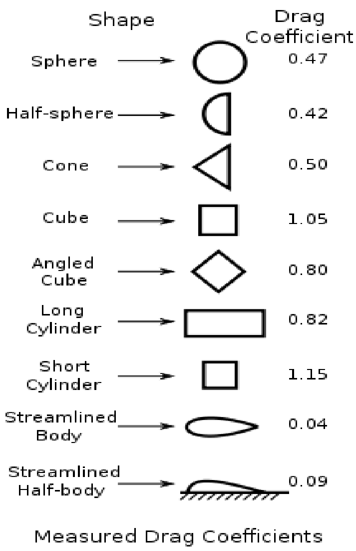

Figure 3. Drag coefficient of different shape.

Drag coefficient

After analyzing the resources of air drag, we use a drag coefficient to present the key to the design of the aerodynamic shape of the vehicle. It is a mathematical parameter determined by wind tunnel experiments and sliding experiments. It can be used to calculate the air resistance of the vehicle when driving.

The effect of lift reduces the load on the axle, thereby reducing the contact between the tire and the ground, and the air trapped in the tire and wheel house will also act on the spring like an air cushion, so to study the aerodynamic characteristics of the vehicle, the Automotive wind tunnel test in Figure 4 is essential.

Figure 4. Automotive wind tunnel test.

The most significant function of the wind tunnel laboratory is to measure the wind resistance of the car while driving. The wind resistance is represented by the wind resistance coefficient. The smaller the wind resistance coefficient, the less the car is affected by the air resistance. Of course, in addition to measuring wind resistance, the wind tunnel test chamber can also be used to study various effects of airflow around the body, such as lift and downforce, and can also simulate different climatic environments, such as hot, cold, conditions such as rain or snow. In this way, engineers can know how the car works in different environments, especially the heat dissipation of the engine radiator and the heat dissipation of the brakes.

In the design stage of the new car, the car must be made into a wind tunnel test model for wind tunnel testing in order to improve the shape design of the car and improve the aerodynamic performance. Therefore, the wind tunnel test has become the most effective means to study the aerodynamic performance of automobiles.

Mercedes-Benz released a set of photos of their newly built climate wind tunnel laboratory. The new climate wind tunnel was built in Sindelfingen, Germany, including two workshops of low temperature and high temperature, which can simulate Heavy rain, hurricane, blizzard, desert and other climate conditions for better testing. Experimental vehicle. The temperature control ranges of the high and low temperature workshops are -10°C~60°C and -40°C~40°C respectively, and each is equipped with a fan with a maximum power of 600kW, which can simulate a wind speed of up to 265km/h. The temperature controllable range of Mercedes-Benz's original wind tunnel laboratory is up to 40°C and the lowest is 20°C, while the performance level of the new climate wind tunnel laboratory has reached the highest level in the industry.

Generally, wind tunnel tests are only used for the development of aviation products. Later, with the rapid development of the automobile industry, people have new requirements for wind tunnel tests. According to the size, wind tunnels can be divided into two types: small wind tunnels for reduced-scale model tests and large wind tunnels for complete vehicle tests. Due to the extremely high cost of wind tunnels, only some major automobile manufacturers have their own large-scale wind tunnel laboratories.

However, the wind tunnel test is very expensive and is known as the highest test in the automotive industry. There are about 50 wind tunnel laboratories around the world, mainly in Europe, America and Japan, and even fewer in China. The price of the wind tunnel of Tongji University in Shanghai is slightly more affordable, and it has reached 27,500 yuan per hour, and the test cost is 900,000 yuan a day. It takes at least 100 hours for a model to go from model to real car, and it is normal to spend millions to tens of millions in wind tunnel tests. On the other hand, the willingness of car companies to spend money on wind tunnel testing is one of the differences between luxury and ordinary brands in research and development. In addition to wind tunnels, a lower-cost technology is emerging: Computer Fluid Dynamics (CFD) [10] simulations incorporating turbulence theory. The numerical simulation of the external flow field of the automobile is to use the numerical simulation method to analyze the aerodynamic characteristics of the automobile during driving, so as to improve the aerodynamic performance, save the cost, and improve the efficiency of design optimization. However, because the computer simulation has high requirements for modeling and is different from the actual environmental parameters, there are certain errors. Therefore, it is still based on wind tunnel test data.

3. Result

The CFD method uses computational mathematics to discretize the governing equation of the flow field into a series of grid nodes to obtain its discrete numerical solution. The fundamental laws that govern the flow of all fluids are: the law of conservation of mass, the law of conservation of momentum, and the law of conservation of energy. From them, the continuity equation, momentum equation (N-S equation) and energy equation are derived respectively. When applying the CFD method to simulate and calculate the air flow field inside the platform, it is first necessary to select or establish the basic equations and theoretical models of the process, based on the basic principles of fluid mechanics, thermodynamics, heat and mass transfer and other equilibrium or conservation laws.

Starting from the basic principle, the conservation equations of mass, momentum, energy, and turbulence characteristics can be established, such as continuity equation and diffusion equation. These equations constitute a connected system of nonlinear partial differential equations, which cannot be solved by classical analytical methods, but by numerical methods.

After several steps including preparing vehicle geometry data, converting 3D vehicle model to finite element mesh model, generating Volume Mesh Set Boundary Conditions with simulation analysis calculation and post-processing of external flow field, we could get Figure 5.

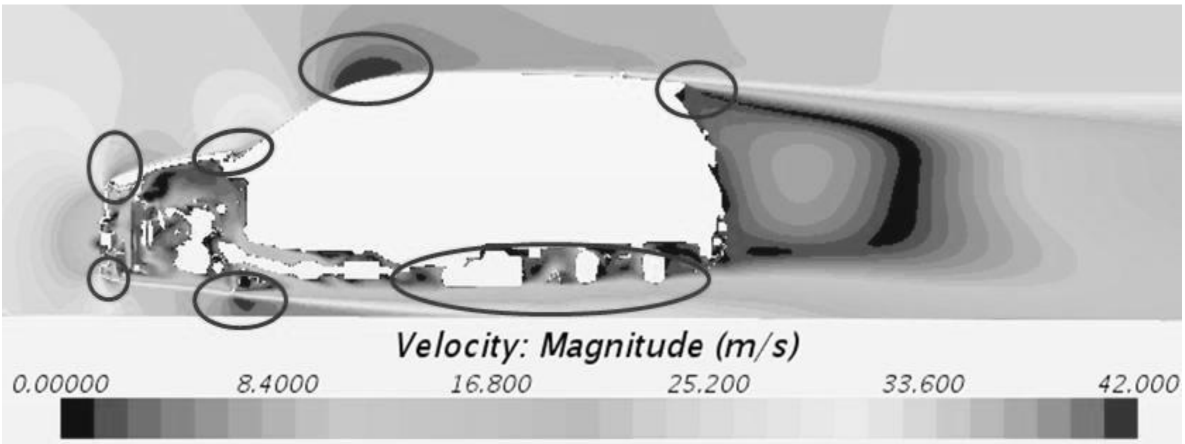

Figure 5. The speed cloud diagram.

It can be seen from the speed cloud diagram of the whole vehicle section in the figure below that the areas marked by the red circles have large changes in the speed gradient, which leads to the phenomenon of airflow separation in these areas, which increases the resistance of the vehicle.

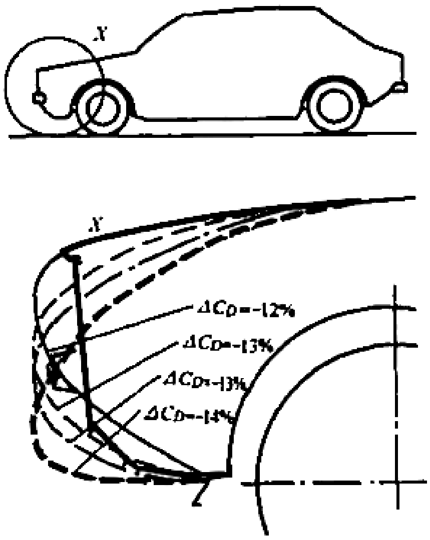

Figure 6. The influence of the change of the
head height on the drag coefficient of the whole vehicle.

Figure 6 shows the comparison chart of the height change of the front of the car. Without changing the overall shape of the hood and affecting the internal spatial structure of the hood, the original front of the car has been lowered by a certain height.

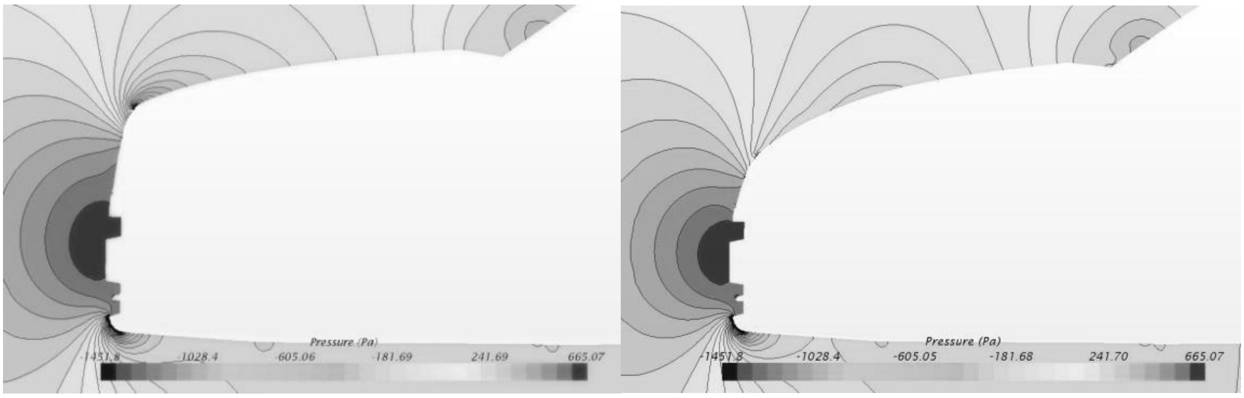

Figure 7. The comparison of the pneumatic pressure.

Figure 7 shows the comparison of the pneumatic pressure before and after the change (the left side is the modified state, the right side is the original state). It is not difficult to see from the figure below that an appropriate reduction in the height of the front of the car can effectively reduce the pressure concentration at the front end of the hood, prevent the airflow from being separated from the body prematurely at the front of the car body, and the airflow flows backward through the front of the car more smoothly. Of course, this change in shape is more intuitive when reflected in the drag coefficient. After the improvement of the front height, the wind resistance coefficient is reduced by 6%, and the aerodynamic performance has been improved to a certain extent.

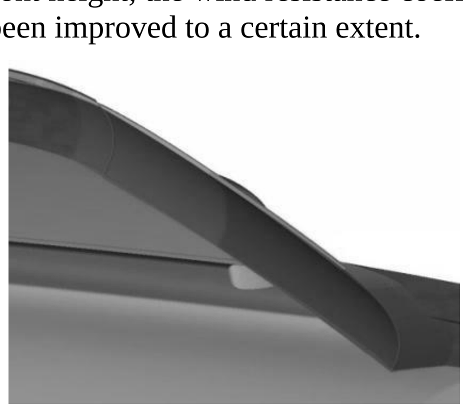

Figure 8. The angle between the front windshield and the cover and top cover.

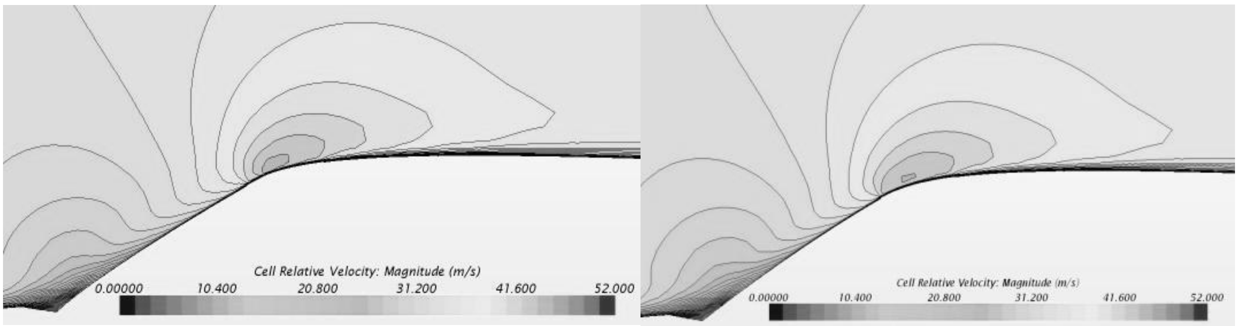

Figure 9. The distribution of the speed cloud map before and after the front windshield modification.

The velocity gradient near the two angles between the front windshield and the hood and the top cover is relatively large, so this section is mainly optimized for this problem. On the basis of not affecting the arrangement of the mechanism under the hood and the head space of the occupants in the cab, the front windshield is rotated 3 degrees, thereby changing the angle between the front windshield and the hood and the top cover. Figure 8 shows the front windshield and the hood. The change of the front windshield angle affects the layout, field of view, and styling style, and the amount of change is small. Therefore, the comparison results of the speed cloud map distribution are similar in Figure 9, but even the slight change of the front windshield angle reduces the wind resistance coefficient of the vehicle by 3%.

4. Discussion

As showing in the graph, It is recommended to reduce the height of the vehicle head and increase the front wind The angle between the window and the hood, reducing the angle between the front windshield and the top cover, reducing the height of the rear edge of the roof, changing the inclination of the rear window, optimizing the structure of the rear spoiler, increasing the rounding of the lower edge of the front bumper, and The exposed parts of the bottom of the car are hidden.

5. Conclusion

Overall, the form drag occupies the main part of total drag and the best way to minimize the drag force is to adopt the body of streamlined shape. And for the induced Friction we could make the bottom of the car smoother to reduce this part. Combined with the domestic and foreign research on the aerodynamic characteristics of automobiles, the important influence of aerodynamics on the automobile industry is expounded, and the significance of improving the aerodynamics performance on the performance indicators such as power and economy of automobiles is introduced in detail.

The basic concepts of automobile aerodynamics and the factors that mainly affect the aerodynamic performance of automobiles are presented roughly in this article, including the basic theory of CFD, a rough introduction to the solution process of CFD, the basic method of wind tunnel test, the structure of wind tunnel and the basic measurement technology of wind tunnel. The simulation analysis results are evaluated, and the reasons for the unsatisfactory aerodynamic performance and the improvement methods are proposed. Authors and Affiliations.

References

[1] Wu Ming, AnD Huang Yaquan. "Analysis and Discussion on Vehicle Energy Utilization." China Highway Society Automobile Transport Society Automobile Use - Energy Saving and Environmental Technology Seminar China Highway Society, 1998.

[2] Automobile Parts, HAO Xufei; YANG Yong; LI Jing; LIU Songgao (GAC Automotive Research & Development Center, Guangzhou Guangdong 511434, China), (2021) 12:108-111.

[3] Automobile Technology, FU Limin, (2000) Vehicle Design and Aerodynamics [M]. China Machine Press, 10:1-4.

[4] Hubei Automobile, Feng Ying, (1998) Research on low-speed wind tunnel test of automobile model [J], 000(004):12-14.

[5] World Auto, Liu Yakun, Ding Jianjun (2013) Aerodynamics world champion in almost all vehicle classes 4:42-45

[6] Dong Jinsong, Xu Hongguo, Research on the calculation of automobile rolling resistance and air resistance coefficient based on road trial [J]. Traffic Information and Security, 2009, 27 (1): 4.

[7] Huang Wei, Luo Hong. Computer-aided analysis of vehicle aerodynamic characteristics, Chongqing University

[8] Huang Wei, Luo Hong. Computer-aided analysis of vehicle aerodynamic characteristics, Chongqing University

[9] Liu Yangzhengl, "Determine the experiment of air resistance coefficient of different shapes." University Physics 36.3 (2017): 5.

[10] Dong Jinsong. "Research on the calculation method of automobile rolling resistance and air resistance coefficient based on road trials." "Traffic Information and Safety 27.1 (2009): 4.

[11] Xing Zhou, Jilin University (2016) Research on Low Aero-drag Design and Aerodynamic Optimization of a Certain Passenger Car http://cdmd.cnki.com.cn/article/cdmd-10183-1016083801.htm