Current Situation and Prospect of Computational Fluid Dynamics in Automotive Design

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Abstract. With the continuous innovation and progress of automobile technology, people have put forward higher and stricter requirements on the safety and environmental protection of automobiles. Therefore, the air resistance, surface pressure, aerodynamic lift, aerodynamic side force and other mechanical problems must be considered comprehensively in the design of automobiles. Fluid mechanics is the study of the motion of gases and liquids under the action of various forces and the application of the discipline. All objects moving in the earth's atmosphere are affected by fluid mechanics, so fluid mechanics has a very important guiding significance to the design of vehicle. This paper is mainly aimed at the influence of air resistance on the performance of the car, the fluid mechanics Angle analysis of the role of the car streamlined design, the principle of the car streamlined body, the shape of the streamline several aspects of the comprehensive introduction of fluid mechanics in the car body design application.

Keywords: Hydromechanics, Automobile design, Air friction, Lift force, Surface pressure.

1. Introduction

Fluid mechanics is a discipline gradually formed in the process of using fluids. It originated from Archimedes' research on buoyancy, and developed because of the mutual promotion between mathematical and fluid engineering disciplines [1]. Now it has become one of the foundations of aerospace, vehicle, machinery, environmental biology and other engineering disciplines. Through the study of the basic theory of fluid mechanics, combined with automobile working conditions, it is found that fluid mechanics has an important application in automobile design [2].

Therefore, based on the basic theory of fluid mechanics, the key issues to be considered in automobile design: air resistance, wind resistance coefficient, pressure on the surface of the car, aerodynamic lift, aerodynamic side force and other key factors that can not be ignored are analyzed theoretically, and the application of fluid mechanics in automobile research is discussed.

2. The effect of air resistance on vehicle performance

Air resistance F_w is a kind of reverse force formed by air on a moving car, and its calculation formula is:

$$F_w = \frac{1}{2}\rho \cdot C_w \cdot S \cdot V^2 \tag{1}$$

In the formula:
V: The driving speed, m/s;
S: Area of windward side of the vehicle, m^2;
C_w: Wind resistance coefficient;
ρ: Air density [2].

2.1. The relationship between speed and air resistance

With the continuous increase of engine power, the performance of cars is getting better and better, and the speed is getting faster and faster. Today's car driving speed record has exceeded 400km/h. At such high speeds, the effect of air on a vehicle's ability to move is already significant. Studies have

shown that when the vehicle speed is lower than 90km/h, the main resistance of the vehicle is mechanical resistance, including friction inside the engine, friction between tires and the ground, etc. When the vehicle speed exceeds 90km/h, air resistance becomes the main resistance that the vehicle needs to overcome. When the speed rises to 200km/h, air resistance accounts for almost 85% of all driving resistance [3]. It can also be said that the car at low speed is like jogging in a breeze, while at high speed it is like walking in a gale.

With the continuous progress of science and technology and the acceleration of the pace of work and life, as well as the establishment of expressway network, people's pursuit of driving speed will be higher and higher.

2.2. Wind resistance coefficient and air resistance

According to the calculation formula of air resistance, we know that the size of air resistance depends on the speed of the car, but also related to the car's wind resistance coefficient C_w, the greater the wind resistance coefficient C_w, the greater the air resistance.

The wind resistance coefficient mainly affects the car's fuel consumption, high-speed stability, driving noise and other aspects of the performance, since the wind resistance coefficient is so important, then what is the wind resistance coefficient?

The wind resistance coefficient C_w is a dimensionless value. The wind drag coefficient is a mathematical parameter determined by the wind tunnel experiment and sliding experiment. The research shows that the wind drag coefficient has no relationship with the weight of the vehicle, but is closely related to the appearance of the vehicle. The biggest impact on the coefficient of wind resistance is the vehicle body styling.

Theoretically, the coefficient of wind resistance for a vertical plane is about 1.0, while the smallest coefficient detected so far is around 0.05 for raindrops [4]. This also explains why the wind drag coefficient of SUV models is high, while the wind drag coefficient of some new energy concept vehicles is low.

Since the coefficient of wind resistance depends on the shape of the car, how is it caused? The resistance caused by the appearance of the car comes from the vacuum area behind the car, the larger the vacuum area, the greater the resistance. In theory, a smaller coefficient of wind resistance is certainly more energy efficient. In the early stage of automobile invention, automobile appearance was not particular about, and the wind resistance coefficient was very high, reaching about 0.8. It used to be thought that the main source of a car's wind resistance was the "head-on drag" caused by air hitting the car head-on. Through the research, it is found that the wind resistance of the car mainly depends on the flow pattern at the rear of the car.

2.3. Windward area and air resistance

Windward area refers to the car driving in the direction of the projection area, and the wind area depends largely on the size of the car, limited to the use of space is not suitable to further reduce, such as high-speed bus although the wind has a very large area, but it's hard to make it completely streamline type, can only as far as possible to optimize the wind resistance coefficient, at the same time reduce the front positive projection area.

To sum up, the shape of the car body has a great influence on the car body performance.

3. Fluid mechanics of vehicles

3.1. Analysis of vehicle air resistance based on fluid mechanics

The component force of the air force in the driving direction of the car is called air resistance. Air resistance is mainly divided into friction resistance and pressure resistance, the middle pressure resistance accounts for about 91% of air resistance, become the main role of automobile resistance. As a fluid, air is viscous. According to Newton's law, there is interaction between the middle layer and the layer of viscous fluid in the flow process. The tangential force generated by air on the body

surface is friction resistance, which is the component force of the resultant force in the driving direction. The resultant force of normal pressure acting on the surface of the automobile body is called pressure resistance, which can be divided into shape resistance, interference resistance, internal circulation resistance and induced resistance.

Among them, shape resistance is the main part of pressure resistance, and has a direct relationship with the shape of the body, is the main factor affecting air resistance; The interference resistance is the resistance caused by the airflow interference caused by the bumps on the body surface, which only accounts for 14% of the pressure resistance. Internal circulation resistance (12%) is the resistance of air flowing through the interior of the car body; The induced resistance (7%), also called differential pressure force, is caused by the fact that the airflow velocity passing through the roof is greater than that flowing through the bottom of the car, so that the air pressure under the car is greater than that on the roof. As a result, the vertical pressure of the air acting on the body of the car forms a pressure difference, as shown in Figure 1.

Air resistance is an important factor affecting fuel consumption. Reducing the vehicle air resistance to the maximum is an effective way to reduce fuel consumption, reducing fuel consumption can also reduce emissions and reduce the cost of use. Tests have shown that the air resistance coefficient reduced by 10%, fuel savings of about 7%. Therefore, the reduction of air resistance mainly depends on the reduction of air resistance coefficient [5].

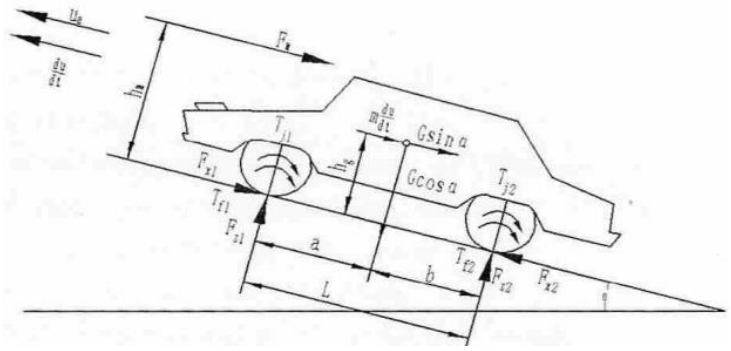

Figure 1. The force diagram of the car when it accelerates

3.2. Analysis of vehicle surface pressure based on fluid mechanics

When the car is driving, the front air flow first acts with the front of the car to block the air flow and reduce the speed. Under the action of air pressure, a positive pressure area is formed in the front of the car. The pressure distribution around the car is shown in Figure 2 [6]. This part of the air flow is divided into two streams, one through the hood, the front windshield, the cab roof back flow; The other part flows to the tail through the lower part of the body. When the air flow upward flows through the upper edge of the front, due to the relatively small radius of the edge Angle, the air flow has no time to turn, leading to local separation, so there is a large suction peak near the upper edge Angle. The airflow then reattaches to the hood.

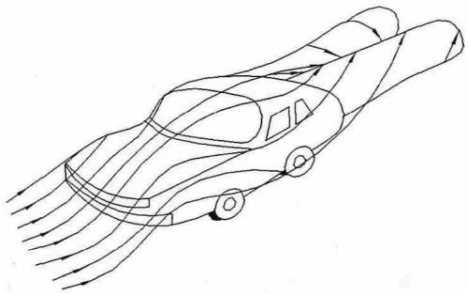

Figure 2. Turbulent vortex at the rear of an automobile

3.3. Based on the application of hydrodynamics in aerodynamic lift analysis

The source of aerodynamic lift of a car is similar to that of a wing. Since the car is running on the ground, the ground effect is an important factor affecting the aerodynamic lift of a car. Pneumatic lift of automobile includes differential lift and viscous lift, of which differential lift is the main part. On the one hand, the lift of differential pressure is caused by the different curvature of the upper and lower surfaces of the car. On the other hand, due to the ground effect, an air flow channel similar to the shrinking nozzle is formed between the bottom of the car and the ground, so that the negative lift force is formed at the bottom of the car.

The research shows that when the vehicle speed exceeds 70km/h, the aerodynamic force of the body becomes one of the main factors affecting the vehicle performance. When a vehicle is running, the aerodynamic lift increases with the speed of the vehicle, which has a certain impact on the stability and economy of the vehicle. The aerodynamic lift reduces the pressure on the ground and affects the dynamic and braking performance of the vehicle [7].

At the same time, the aerodynamic lift force reduces the lateral adhesion and lateral stiffness of the tire, thus affecting the handling stability of the vehicle. The influence of aerodynamic force on vehicle performance at high speed take the lead. With the increase of vehicle speed, the rolling resistance of the vehicle decreases gradually under the influence of aerodynamic lift force. However, the aerodynamic resistance of a car increases rapidly with the increase of vehicle speed. The research shows that when the vehicle speed is about 70km/h, the aerodynamic resistance and rolling resistance of the vehicle are almost the same. When the vehicle speed is greater than 150km/h, the aerodynamic resistance is 2-3 times of the rolling resistance. Obviously, the influence of aerodynamic lift is more significant when the car is running at high speed. Therefore, in order to ensure safety, higher requirements are put forward for aerodynamic lift at high speed.

As the main fluid in automotive force analysis, air is dominated by fluid dynamics such as conservation of mass, momentum and energy during the whole process of flowing through the vehicle body. Computational fluid dynamics is to analyze the motion of the air in the flow field around the car through these basic governing equations. In theory, the study of aerodynamic drag and aerodynamic lift is based on the “path theory” proposed by Bernoulli. This theory is based on fluid dynamics, in which the fundamental elements of fluid dynamics such as Reynolds number and flow state should be fully considered [8].

In today’s society, the design speed of vehicles and the speed allowed by highways are getting faster and faster, so it is very necessary to solve the problem of flying at high speed and it is an important measure to ensure driving safety.

3.4. The role of hydrodynamics in aerodynamic lateral force analysis

Danger doesn’t have to come from behind, danger can also come from the side. In addition to the effect of aerodynamic lift force, a considerable part of traffic accidents occurring at high speeds are due to the effect of aerodynamic side force [9]. When the airflow is parallel to the longitudinal plane of symmetry of the vehicle, there is no aerodynamic lateral force. However, in the actual driving of the vehicle, the airflow will not always be parallel to the longitudinal plane of symmetry of the vehicle. When the airflow and the vehicle have a transverse Angle, the vehicle will generate aerodynamic lateral force. In other words, the source of the lateral force is due to the lateral flow. In the actual environment, the source of lateral flow is more complex, such as natural wind gusts, cars passing over Bridges, vehicles overtaking and so on [10]. The research on the influence of aerodynamic side force on vehicle performance is a wide field, and it has a non-negligible influence on the main vehicle performance [11]. When the car is subjected to lateral wind, strong airflow will be generated at the side panels of the body [12]. The existence of this airflow not only destroys the normal small vortex state between the cab and the body, but also forms a vortex dense airflow area, which increases the resistance right in front of the body, and makes the car shift from the original straight driving direction, causing potential danger. Therefore, aerodynamic side force is also one of the important factors that must be analyzed in automobile design [9].

The lateral wind changes in nature are very complex. The direction of the crosswind, the change of wavelength has an important effect on the flow field, so the analysis of aerodynamic side force is relatively more complicated.

4. Prospects and discussion

It is foreseeable that in the future automobile design, people will pay more attention to safety and vehicle performance, which indicates the need for more in-depth research in fluid mechanics.

The intersection of fluid mechanics and automobile design knowledge will have a great impact on automobile modeling and analysis and evaluation, and gradually become the main theoretical knowledge of automobile product development and design [10].

5. Conclusion

In modern automobile design, the design speed of the vehicle and the speed allowed by the highway are getting faster and faster. Air resistance is an important factor affecting the performance of the vehicle, such as power performance and fuel economy. Cars have become an important part of people's lives. The safety performance of the vehicle is the premise that people's high quality of life can be guaranteed. Make full use of the application of fluid dynamics in automobile air resistance, pressure, aerodynamic force and so on to improve the performance of all aspects of the vehicle. It is a problem that designers in the new era must face and discuss deeply.

References

[1] Xie X. Application of Fluid Mechanics in Automobile Body Design. Sichuan Vocational Technology Journal of Surgery, 2015, 25(6): 1672-2094.

[2] Fu L. Automotive Aerodynamics. Beijing: Automotive Industry Press, 1998.

[3] Liu G. Principle and Analysis Method of Fluid Mechanics. Beijing: Higher Education Press, 1992.

[4] Yang Z. Automobile Body Design. Beijing: China Machine Press, 2016.

[5] Huang X. Vehicle Aerodynamics and Body Styling. Beijing: People's Communications Press, 2009.

[6] Yang X. New Energy Vehicle Styling and Interior and Exterior Decoration Design. Southeast University, 2016.

[7] Zhang H. Conceptual Design and Development of New Energy Vehicle Body Structure. South China University of Technology, 2013.

[8] Chen Q., Zhu J., Tian G. Advanced Electric Vehicle Technology. Beijing: Chemical Industry Press, 2007.

[9] Yu Z. Automobile Theory. Beijing: China Machine Press, 2014.

[10] Tong T., Jun L I., Wei-Cheng L I. Computational Fluid Dynamics (CFD) Analysis of Cooling Water Jacket in Diesel Engine. Modern Vehicle Power, 2005, 78: 120-127.

[11] Zhou D S., Zhou C Y. Numerical simulation of automotive configuration based on computational fluid dynamics. Journal of Hunan University of Arts and Science (Natural Science Edition), 2010, 34(5) 56-63.

[12] Sankar H R., Dinesh K J., Raja R. Design Optimization of Automotive Emission System using Computational Fluid Dynamics. Esrsa Publications, 2014(11): 37-43.