The Application of Fluid Mechanics in The Research of Classic Car Design In BMW

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Abstract. Since Thomas Newcomen invented the world's first steam engine in 1712 and applied it to automobiles for the first time in 1769. For the next 100 years or so, efforts were made to increase the horsepower of automobiles until 1889 when people realized the importance of aerodynamics and began to take it forward. This article will study the design and interpretation of the shapes of some devices that help to reduce the air drag coefficient of an automobile and the principles behind them, based on the principles of hydrodynamics, Bernoulli's principle, the vortex principle, and the boundary layer principle. This paper follows the logic of juxtaposition. From the design used by BMW on its classic models, it presents the effect of different accessories on the wind resistance of the vehicle. The improvement of the aerodynamics of the car with designs such as the rear wing as well as air intakes on the aerodynamics of the whole car is identified. It is hoped that the arguments derived in this paper will help automotive practitioners in their designs.

Keywords: Fluid mechanics; Automotive Design; hydrodynamic principle; Bernoulli's principle; vortex principle and boundary layer principle.

1. Introduction

In 1712, Thomas Newcoemen invented the world's first steam engine, modified by James Watt in 1757, and a condenser was added in 1769, making the steam engine capable of continuous operation. In the same year, N. J. Günew built the world's first steam car. Although it traveled only 3.5 to 3.9 kilometers per hour and had to stop for 15 minutes every 12 to 15 minutes to heat up, it was a major advance in the history of the automobile. In 1825, the Englishman Swadie Garnet built an 18-seat steam bus with a 19 km/h speed and started the world's first bus service. Later, the development of the steam engine became the main power source for use in railroad cars and ships, and people sought lightweight power units with high power to volume and power to weight ratios for their vehicles. As the internal combustion engine's technology evolved, the engine's power became more powerful, but the problems associated with that power, namely pollution, became more intense. In 1889, Camille Jenatzy built the world's first aerodynamic car, which broke the 100 km/h world record with 62 hp. This was the beginning of the dynamic era in human automotive history [1, 2].

Nowadays, the use of aerodynamics in cars is no longer limited to how to reduce the car's wind resistance to make the car go faster at the limit, but how to use aerodynamics to improve the car's performance. For example, BMW has enlarged the front grille in the new 3/4 series to increase the air intake to the engine and speed up engine cooling; for example, by improving the shape of the rear wing and adding an algorithm to add an electric motor to lift the rear wing to help the car get stable downforce when cornering at high speeds without affecting the car's handling; Or the Corvette, a supercar company owned by Chevrolet, has sought a balance between horsepower and aerodynamics by adding a spoiler to the rear of the car to help the gas flow quickly through the chassis and reduce the impact of the wake on the car's speed. Also in the design of some domestic cars, they try to set the lines of the car into a kind of special curve, when the car is in motion, the wind will pass along the curve of the vehicle will blow all the rain beads off the rear window glass, thus eliminating the need for rear wipers. This article will discuss some of BMW's designs for starting effects on classic models. It is also hoped to help some of the newer brands when they are optimizing their cars for aerodynamics [3].

This article will analyze the aerodynamic design used by BMW in different cars on the market based on aerodynamics, Bernoulli principle, vortex principle and boundary layer principle.

2. Theoretical Analysis of Automotive Aerodynamics

When designing a car, this study must consider its air resistance so that the car can let the air pass quickly when facing the wind. Based on the above points, this study have listed the following 4 principles related to this topic.

2.1. Principles of fluid mechanics

Fluid mechanics is the study of the mechanical laws of motion of fluids (liquids and gases) and their applications. The branch of mechanics mainly studies the state of the fluid itself under the action of various forces, and the interaction between the fluid and the solid wall, between the fluid and the fluid, and between the fluid and other moving forms. Fluid mechanics is an important branch of mechanics, it mainly studies the fluid itself at rest and in motion, as well as the interaction between the fluid and the solid boundary wall when there is relative motion and the law of flow. It has important applications in life, environmental protection, science and technology and engineering. In modern automobile design, in addition to technical innovation, fluid dynamics principles are also being applied to automobile design. One important role is optimizing the car styling to achieve better aerodynamic effects. When a car is moving, it encounters air currents from the surrounding environment, so it is necessary to use fluid dynamics principles to describe and calculate the properties and characteristics of air movement, such as pressure, velocity, density, etc [4].

2.2. Bernoulli's Principle

Bernoulli's Principle is one of the most important theorems in fluid dynamics. It reveals some basic laws of fluid dynamics: Bernoulli's Principle of a non-pressurizable, ideal fluid along the flow pipe for constant flow knows that as the flow rate increases, the static pressure of the fluid will decrease; conversely, as the flow rate decreases, the static pressure of the fluid will increase [5]. But the sum of the static and dynamic pressures of the fluid, called the total pressure, always remains the same. In other words, the fluid in the flow, its density and pressure is extremely sensitive to changes in speed, that is, at the same speed, different densities, different pressures of the fluid flow is not the same. In the design of the car, also take into account the impact of Bernoulli's Law. For example, when the car is moving, air resistance greatly impacts the car's driving speed and fuel consumption. In order to improve the driving speed of the car, people consider many factors in the car's design, such as using a streamlined body, reducing the resistance of the body surface and air resistance, and so on.

2.3. Vortex principle

Vortex is a very small cylinder radius in the stationary fluid rotation caused by the surrounding fluid for circular motion of the flow phenomenon. General vortex within a dense area of vortex volume, called the vortex nucleus, whose motion is similar to the rigid body rotation. The above cylinder is similar to the vortex of the vortex nucleus. On its outside, the fluid's circumferential velocity is inversely proportional to the radius; on its inside, it is proportional to the radius, and the circumferential velocity is zero at the vortex center. Vortices affect the airflow around the car and can cause unstable vibrations and cause the car to be dragged by the airflow, thus increasing the car's fuel consumption. Therefore, it is important to investigate how to reduce vortices and allow air to pass quickly through the car for control and stability [6].

2.4. Boundary layer principle

When a very viscous fluid (such as water, air, etc.) in contact with the object at large Reynolds number and have relative motion, the thin fluid layer near the surface of the object due to viscous shear stress and reduce the velocity; immediately adjacent to the surface of the fluid adhered to the surface of the object, the relative velocity with the surface of the object is equal to zero; from the object side up, the velocity of each layer gradually increased until equal to the free flow velocity. This thin layer of fluid deceleration from the object surface is called the boundary layer. In automotive aerodynamics, the boundary layer is important for understanding how the airflow flows along the surface of the car and forms the pressure distribution [7].

3. Theoretical Analysis of Automotive Aerodynamics

3.1. Tailpiece

Aerodynamics is an important consideration in the design and performance of modern automobiles. The shape and position of various components can have a significant impact on drag, and therefore fuel efficiency, handling and stability. One component that plays a key role in aerodynamics is the rear fascia, also known as a spoiler or wing. In this essay, we will explore how a spoiler helps improve the aerodynamics of a car and discuss some of the underlying principles involved.

The primary purpose of a rear spoiler is to reduce drag and improve downforce. As a car moves through the air, it creates a pressure differential between the front and rear of the vehicle. This can cause turbulence and drag, which can reduce fuel efficiency and make the car less stable at high speeds. A rear spoiler is designed to break up this pressure differential and create a smoother flow of air over the rear of the car as Fig.1.

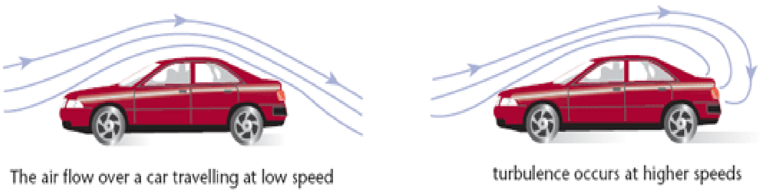

Fig. 1 Air flow at different speed

In addition to reducing drag, a tailpipe can also improve downforce. Downforce is the force that pushes a car down onto the road and is essential for maintaining traction and stability at high speeds and when cornering. A tailpiece can generate downforce by creating a high-pressure area under the wing and a low-pressure area above the wing. This pressure difference can create a downward force that helps keep the car on the road as Fig.2 [8].

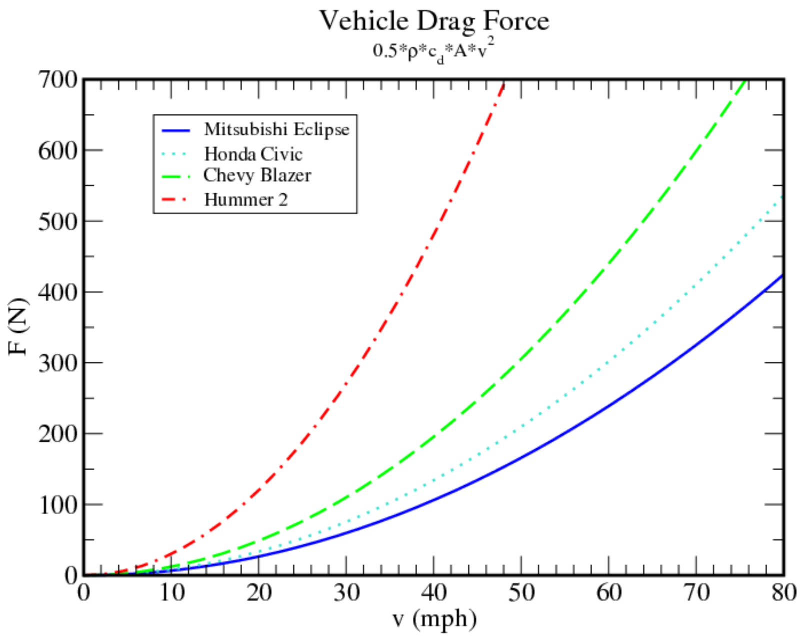

Fig. 2 Drag Force diagram of different cars at different speed.

A tailpiece works by disrupting the airflow over the rear of the car. By creating a high-pressure area under the wing and a low-pressure area above it, a tailpiece can create a downward force that helps keep the car on the road. Additionally, a tailpiece can reduce turbulence and air resistance, which can improve fuel efficiency and stability at high speeds. The exact design and function of a tailpiece can vary depending on the specific type and application. For example, a lip spoiler may simply reduce lift and improve stability, while a wing spoiler may generate significant downforce for improved traction during cornering in Fig.3.

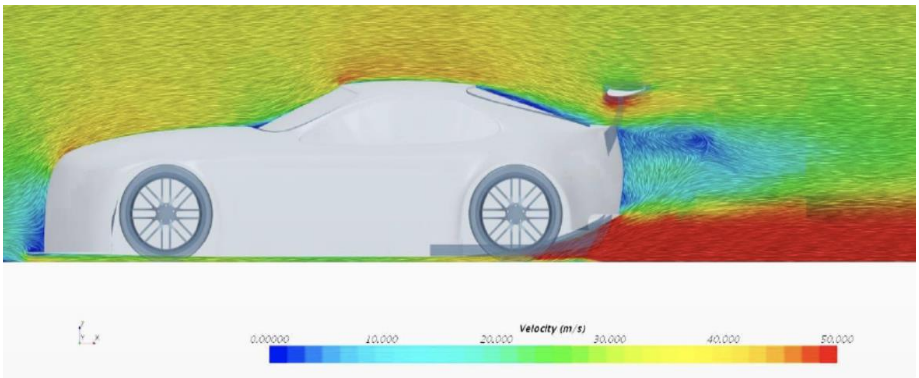

Fig. 3 Vector Scene Showing the Velocity with the Rear Wing Addition

But when designing a car, it is not better to make the downforce generated by the rear wing, because the downforce will only be generated when a certain speed is reached. And if the rear wing is too extreme, it will also generate a lot of drag at low speeds. So how to assemble the rear wing for different kinds of cars is particularly important [9]. Vehicle Type: The design and function of a valance may vary depending on the type of vehicle. For example, a sports car may require a different type of spoiler than a pickup truck. Speed: The speed at which a vehicle travels can affect the design and function of a rear spoiler. For example, a spoiler designed for high-speed racing may not be as effective at lower speeds. Driving Conditions: Driving conditions, such as weather and road surface, can also affect the design and function of a tailpiece. A tailpiece designed for smooth, dry roads may not be as effective in wet or icy conditions.

The rear wing is a double-edged sword, it can provide downforce when the car is moving fast. At low speeds, however, the rear wing increases air resistance. Therefore, BMW's regular models will be equipped with a very simple rear wing, which features a small bulge at the rear of the car. Because it usually drives in the city, the speed rarely exceeds 100km/h. Then it does not need a strong downforce when starting. The main purpose of this rear wing is to integrate the airflow and improve the economic fuel ratio.

The second type of rear wing is prepared to help those who are usually willing to experience the passion or use the private car to go down the track. The characteristic of this type of rear wing is that the rear wing will have a gap from the vehicle, which can make its flow pass quickly. Compared to the first type of rear wing, it will slightly increase some air resistance, but at speeds above 100km/h, it can produce the corresponding downforce as Fig.4.

Fig. 4 Diagram of air flow through the tail

In Fig.5, if the previous two tail fins are for private users on the basis of fuel consumption. The next one is the rear wing prepared for speeds over 200km/h. Its main feature is that it is quite large and angled compared to other rear wings. The driver often wants the rear wing to generate enough downforce for his car (like the M2CS) to maintain body stability during high-speed cornering. According to previous interviews with the BMW design team, the current BMW M2CS can generate 150N front and 150N rear axle downforce at 140kph, 300N front and 300N rear axle downforce at 200kph, and 620N front and 620N rear axle downforce at 290kph. The rear axle can get 620N of downforce. The reason why the data is not made very extreme is because M2CS is a streetcar, so its maximum speed is not very fast, so as long as the downforce is enough.

Fig. 5 The M2CS Adjustable rear wing

This rear wing as Fig.6 is often assembled in the highest category of car racing (The speed is more than 300km/h), its characteristics are added to the bottom of the rear wing can control the angle and height of the rear engine, when the car in the corner, the onboard computer will automatically control the lift of the tail and change its angle, so that the car can get enough downforce but not too much. According to BMW's previous tests, this rear wing's extreme state can provide the vehicle with about 1000N of downforce.

Fig. 6 The M4 GT3 Adjustable rear wing

3.2. Car Design

For a long time in the past, it was thought that if the car design was round enough, it would go faster, but in subsequent experiments it was found that it is not so simple. The first and most important indicator of the aerodynamic effect of the body is the frontal projection area of the body. In short, drag grows linearly with frontal area and non-linearly with speed. The higher the speed, the higher the order, that is, as the speed increases, the drag increases faster and faster. Therefore, if this study cannot control the relationship between wind speed and wind resistance, reducing the orthogonal area will immediately affect the wind resistance. This study used to think that if this study made the front end of the car as sharp as a knife and the connection with the body relatively streamlined, it would be easy to cut off the air and pass it quickly, but this is not the case. Before proceeding to the specific analysis, this study needs to introduce a variable, namely the ratio of the front corner circle's radius to the body's width in Fig.7 [10].

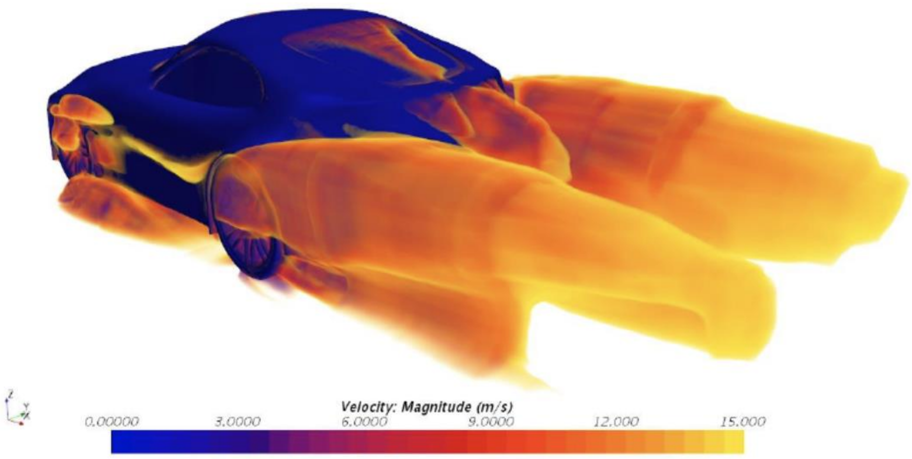

Fig. 7 Initial Testing Resampled Volume Scene

First, this study needs to introduce two concepts of airflow, laminar flow and turbulence. When the front of the car is in contact with the air, the air is transferred from all directions of the body. From the experimental results, this study can see that when the front corner radius is small, the airflow passing through the front of the car to the side of the car will separate from the body and create turbulence. So, the body will produce more resistance; when the radius is larger, the airflow through the front flow to the body is laminar, that is, less resistance, so it seems that the rounder and smooth the front, should not have a better aerodynamic effect? In fact, another factor limits the design of the front, because whether it is laminar or turbulent, the air in contact with the body will create a boundary layer.

In the boundary layer, the wind speed decreases until it can be considered zero at infinite distance [11]. The thicker the boundary layer, the less effect it has on the vehicle's speed, i.e., the less friction on the sides of the body. From this point of view, turbulence and friction are the two factors that increase drag. If the radius is too small, the drag caused by turbulence is higher, while if the radius is too large, the friction on the sides of the vehicle is higher. Therefore, the optimal equilibrium point can be reached when the radius to vehicle width ratio is 0.05. Therefore, from this point of view, it is not difficult to explain that the new car design in the past two years has favored a sharper front-end design, not only for a more youthful design style, but also for aerodynamic requirements.

Compared with the front of the car, the design of the rear of the car is easier to understand, just like aircraft and ships, the design of minimum air resistance is like the stern of the ship, the design of convergence, but for the car, for aesthetic volume length and many other restrictions, it is basically impossible to do, so only the rear of the body area will be formed into a thin area of air, in order to minimize this area, most of the vehicle design will be inward Generate a certain angle of inclination to guide the airflow as early as possible to merge. But the location of the corner is sharper than most people think of the rounded design, because too rounded design, the direction of airflow will be directed to the horizontal, and thus the airflow longitudinal speed reduction, the same will produce the effect of energy dissipation and increased drag. Usually, a certain curvature of the side of the body, can bring less wind resistance, but here this study should pay attention to two problems: First, if the curvature is too large, the airflow is likely to be out of contact with the body, which is the turbulence this study mentioned earlier, but will increase the drag; the second problem is that when increasing the curvature of the side of the body, the area of positive projection will also increase, which also means that the drag So now the models on the market, basically can be considered a flat body side curve, only a very small curvature. For the rear of the car, as this study mentioned earlier, the best way is like a boat or an airplane to close inward, but this angle must also be balanced and should not be too large, for the same reason as the side of the car, too large an angle not only cannot guide the gas to close inward, and will produce turbulence or even vortex, so usually the angle to close inward is 7.5 best [6,12].

3.3. The car's air intake holes and cooling holes

If this study compares modern cars with past cars, this study in Fig. 8 will find that the holes in modern cars are getting bigger and bigger, for example, in the new generation of BMW 3/4 series, the center grille area is much bigger than the previous generation, and a control switch has been added inside.

Fig. 8 The new M4's forward vents and cooling fins

When the temperature returns to normal, it closes automatically to improve aerodynamics. Or BMW came up with the concept of an air curtain, which BMW believes can be responsible for controlling the airflow when controlling the vehicle. This is because it can easily and efficiently reduce air resistance in the body. Its narrow air channels increase the flow of air and direct it over the wheels. This reduces air turbulence at the wheel arches and reduces wind resistance, which in turn reduces fuel consumption and emissions. At the rear of the car, BMW has added two types of holes, called air guides and shark gill side vents. Both of these holes serve to make us feel less air resistance as the car speeds up. This is because the air intakes and shark gill side vents can direct the air to the front wheels and around the vehicle, reducing turbulence at the wheel arches and breaking up the air swirl. This reduces fuel consumption and emissions. In BMW's i8 sports car, the LED taillights also use a layered design concept that creates multiple air channels for airflow [13].

3.4. Summary

In summary, this study has given examples of the various methods of aerodynamic reduction used by BMW in its branded cars and how aerodynamics can be used to improve vehicle performance. This can be summarized in the following points as Table 1:

Table 1. Four tailpieces comparing

Tailpiece Level	Performance
The basic version	Reduces vehicle wake to improve stability and provides a small amount of downforce at high speeds
The advanced version	Reduces vehicle wake and thus improves stability, providing a small amount of downforce.
The professional version	Reduces wake to improve stability and provides at least 300N of downforce to help stabilize the car through corners.
The competition version	[1] Reduces wake to improve stability and provides variable downforce to help the car get enough downforce when cornering but not too much.

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4. Conclusion

This study lists the specific use of aerodynamics in BMW's cars and why these accessories are used. This includes whether rear wings are necessary for our city cars, the idea of modern body design, and how different holes in the body can improve the performance of the vehicle. The use of aerodynamics in cars will remain a hot topic for many years to come, whether it is because the combustion efficiency of internal combustion engines is reaching its limits and therefore people need to improve the aerodynamics of cars to help them become more fuel efficient. Or the development of the tram is also inseparable from the study of aerodynamics, after all, the current battery cannot completely replace the oil car, then how to reduce air resistance has become extremely important. And this study can see that the major car manufacturers have also begun to wind tunnel experiments, the purpose is to improve the performance of their own products. So, this study think aerodynamics in the future of the automotive industry still has a future.

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