Research on Longitudinal Resistance of Vehicle Body Shape

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Abstract

The longitudinal resistance research of body molding is aimed at optimizing vehicle design and reducing air resistance, thereby improving economic efficiency and performance. Starting from the composition of vehicle resistance, the factors affecting the longitudinal resistance of vehicles are discussed, and the methods needed to reduce drag are pointed out. The current research status of spoiler and vehicle appendage is introduced, and the development prospect of future drag reduction technology is proposed. As technology advances, automotive aerodynamic drag reduction research will continue to deepen, contributing to achieving higher aerodynamic performance and energy efficiency. The optimization of vehicle wake field structure is the key to reduce aerodynamic resistance and improve vehicle driving performance.

Keywords

Air Resistance; Reduce Drag; Spoiler; Pillar A; Side-view Light.

1. Introduction

With the global energy crisis and environmental pollution problems becoming increasingly severe, reducing the aerodynamic resistance of cars to reduce energy consumption and emissions is currently a research focus in the field of automotive engineering. As early as the 19th century, Riedfer from Germany [1] introduced the concept of aerodynamic resistance for the first time and applied it in subsequent studies. Subsequent researchers, including Aston et al. [2], conducted in-depth research into the mechanisms of aerodynamic resistance, further revealing the essence of aerodynamic resistance. Research has shown [3-6], when a car reaches a speed of 70-80 km/h, aerodynamic resistance becomes a key factor affecting the car's performance. As the speed increases, the total power consumption of the car increases rapidly, of which the power consumption due to aerodynamic resistance is particularly significant. When the speed exceeds 70 km/h, the power consumption due to aerodynamic resistance even exceeds the power consumption due to rolling resistance. Therefore, by rationally designing the vehicle's body shape to reduce aerodynamic resistance is an important means to achieve energy savings in cars [7, 8]. This paper first explains the principle of vehicle resistance generation, then analyzes the longitudinal resistance of the vehicle body, including the body streamlining and body shape streamlining technologies, summarizes their advantages and disadvantages, and looks forward to the development trend of streamlining technology. Since 1994, Fushi Min from Jilin Jilin University [9-15] successfully added aerodynamic kits to the CA141 truck to achieve the goal of reducing wind resistance. Subsequently, in-depth research was conducted on the aerodynamic feature parameters that affect the aerodynamics of the vehicle. Through numerical simulation and experimental research on the airflow behind the vehicle, it was found that the airflow behind the vehicle plays a crucial role in reducing the longitudinal wind resistance of the vehicle and enhancing the stability of the vehicle during driving. Therefore, vehicle manufacturers have attached unprecedented importance to the design of vehicle spoilers. Although streamlined body design, aerodynamic optimization parts, etc. have been widely used [16-18], further research is needed on the streamlining optimization of different parts of the vehicle to achieve comprehensive improvement of streamlining effect.

2. Aerodynamic Resistance Components of a Vehicle

Aerodynamic resistance of road vehicles accounts for a significant portion of vehicle fuel consumption, accounting for 50% of total vehicle fuel consumption on highways. Reducing aerodynamic drag provides an inexpensive solution for improving energy efficiency, so shape optimization with low drag becomes an important part of the entire vehicle design process [19]. The aerodynamic resistance of a moving vehicle is mainly composed of the following four parts: shape (pressure) resistance, induced resistance, interference resistance and internal resistance

2.1 Form Resistance

2.1.1 Sub-section Headings

Shape resistance is the main component of aerodynamic resistance, which is generated by positive pressure at the front of the car and negative pressure at the rear of the body. The body surface and its turning mode have an important influence on the shape resistance [20]. Therefore, optimizing the body design, especially the shape and turning mode of the front and rear, is of great significance for reducing the shape resistance and improving the energy efficiency of the vehicle. The size of the shape resistance depends on the geometric characteristics of the vehicle shape and the moving speed of the vehicle relative to the air, and at high speeds, the shape resistance can account for a large part of the total resistance of the vehicle [21, 22]. The reduction of vehicle shape resistance is crucial to improve vehicle energy efficiency, reduce wind noise and reduce airflow separation, so shape optimization technology is gradually receiving attention [23]. Mukut et al. [24] discussed the possibility of reducing shape resistance to improve energy saving efficiency from the theoretical level, and introduced a variety of methods to reduce air resistance, including optimizing vehicle shape, using low wind resistance design, using aerodynamic kits, reducing speed, etc. Drag reduction technologies and methods need to be more refined and innovative. In the future, more effective drag reduction measures can be studied through computer technology and numerical simulation methods, such as the use of variable surface materials and the adoption of new manufacturing processes. Tang Wenyuan [25] et al. from Changshu Institute of Technology explained the importance of shape resistance in aerodynamic modeling design and optimization of automobile body and how to reduce shape resistance through numerical simulation and optimization design methods. These methods help improve vehicle energy efficiency, reduce emissions and enhance driving stability. At present, some new materials such as carbon fiber, titanium alloy and metal matrix composite materials have been used in vehicle manufacturing, these materials have the characteristics of lightweight and high strength, which can further reduce the weight of vehicles and improve performance. In the future, with the development of new material technology, there may be more new materials suitable for vehicle manufacturing [26-28].

2.2 Induced Resistance

Induced drag is a part of aerodynamic lift. When the car is driving at high speed, due to the difference in the upper and lower air velocity, the upper and lower pressure is different, and the lower pressure is larger. The component force generated by this pressure difference in the horizontal direction, that is, the induced resistance, accounts for 6%-8% of the entire air resistance. This force will make the car have an upward trend, resulting in the vehicle at high speed is easy to "float". The induced resistance of the car body is mainly affected by the shape of the back. The air resistance coefficient of the car changes with the change of the rear Angle of the car, as shown in Figure 1. This is the influence of back Angle on shape resistance and induced resistance, and also the result of the interaction of these two kinds of resistance.

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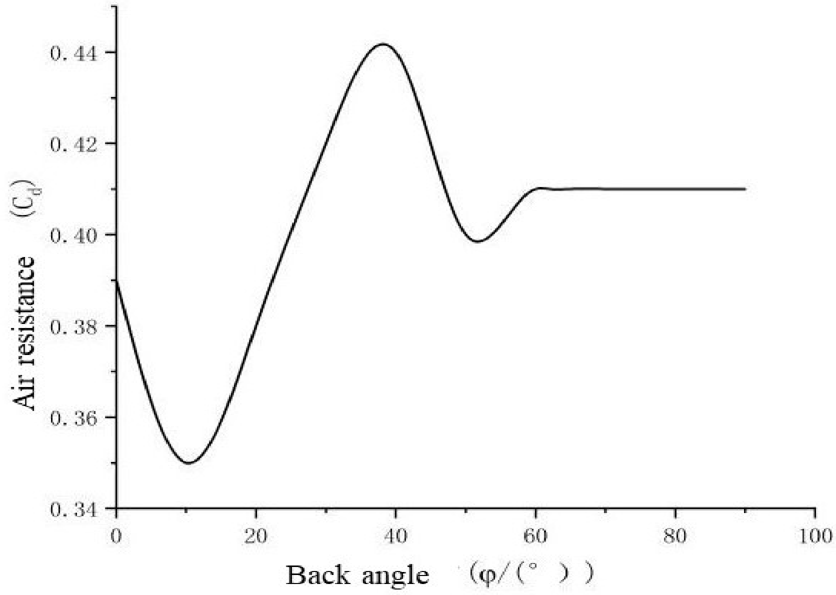

Figure 1. Relationship between rear Angle and air resistance [20]

Therefore, optimizing body design and reducing induced drag are of great significance for improving vehicle energy efficiency and performance [20]. Eller[29] et al. discussed the possibility of reducing induced resistance to improve economic efficiency from the theoretical level. An effective method of induced drag reduction is provided through experimental evaluation, which includes flow display and resistance measurement experiments in low speed wind tunnel and water tunnel. The experimental results show that the proposed passive drag reduction method can effectively reduce the drag, and the drag reduction effect is related to the Reynolds number. Experimental results in low speed wind tunnel and water tunnel also show that the method is effective in reducing drag in different types of flows. The proposed passive drag reduction method can effectively reduce the resistance of the object, thus reducing energy consumption and improving efficiency. This method of drag reduction does not require any power source, so it has the advantages of simple, reliable and practical. This method can be applied to various fields that need to reduce resistance, such as aerospace, transportation, architectural design, etc., and has a wide application prospect. In the future, people may improve the performance of vehicles by improving materials and designing more efficient air drainage mechanisms.

2.3 Interference Resistance

Interference resistance is the air resistance generated by the bumps on the surface of the vehicle during the driving process, such as door handles, mirrors, suspension guide bars, axles, fenders, etc. This resistance accounts for 12%-18% of the total air resistance. Therefore, optimizing vehicle surface design to reduce protrusions and air turbulence is of great significance for reducing interference resistance and improving vehicle energy efficiency. To reduce interference resistance, researchers and engineers have come up with a number of methods, including CFD analysis, wind tunnel experiments, optimizing vehicle shape, and more. Ferraris[30] et al. mainly explained two methods to reduce the resistance of urban vehicles through shape optimization and additional devices, so as to improve energy efficiency and reduce emissions. At the same time, the application, advantages and disadvantages of different shape optimization methods and additional devices are discussed, which provides an important reference for vehicle design and optimization. The use of CFD to analyze the body resistance of hybrid vehicles can provide important help for future vehicle design, including optimizing vehicle design, developing more efficient hybrid power systems, predicting and solving

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fluid dynamics problems, realizing more accurate aerodynamic prediction, and realizing personalized design [31].

2.4 Internal Resistance

Internal resistance refers to the resistance generated when the air required for engine cooling and interior ventilation passes through the interior of the vehicle during operation, accounting for about 5%-12% of the total air resistance. Therefore, optimizing the air flow path in the car and reducing unnecessary air flow barriers are of great significance for reducing internal resistance and improving vehicle energy efficiency. In vehicle design and optimization, the internal resistance directly affects the energy consumption, emissions and driving stability of the vehicle. To reduce internal drag, researchers and engineers have come up with a number of ways, including optimizing the flow path design, improving aerodynamic performance, and reducing component friction. Szodrai et al. [32] explained how to use CFD method to analyze the internal resistance of a wide and flat shape car, and how to reduce the internal resistance by optimizing the vehicle design and adding additional devices. This method can provide an important reference for vehicle design and optimization, and help improve vehicle energy efficiency, reduce emissions and enhance driving stability. Nath[33] et al. mainly explained that the application of aerodynamic equipment in a race car can reduce the internal drag, thereby improving the energy efficiency, speed and stability of the race car. Through the design and optimization of aerodynamic equipment, it is possible to achieve the best drag reduction effect and improve the performance and competitiveness of the car. Mukut et al. [24] summarized the methods and effects of reducing the internal resistance of vehicles. Through optimized vehicle design and the use of aerodynamic equipment, internal drag can be effectively reduced, thereby improving vehicle energy efficiency, reducing emissions and enhancing driving stability. These methods can provide important reference for vehicle design and optimization.

3. Flow Field Study

3.1 Analysis of A-column Flow Field of Automobile

Pillar A is located on the left and right sides of the front wind window, which is the main part of longitudinal air separation. This is the area with serious flow separation, and the vortex formed here will have an adverse impact on the aerodynamic resistance of the car [34]. At the A-pillar position, the drag is usually caused by the separation of the air flow from the front windshield to the side surface of the carriage and the formation of longitudinal eddies (with eddies in the direction of flow). This longitudinal vortex develops backwards to the rear of the car and promotes a reduction in pressure at the trunk end. This will result in an increase in the surrounding airflow from the side of the vehicle and an increase in the longitudinal eddy drag caused by eddy B. Therefore, in order to improve aerodynamic performance, it is important to reduce the longitudinal vortex generation in the A-pillar as much as possible [35]. Cao Shengping et al. [36] from Jiangsu Minan Electric Vehicle Co., Ltd. conducted an in-depth study on the A-pillar modeling of automobiles. They used different A-pillar split structures and different installation methods to make A comparative analysis of the modeling differences, and summarized the changing trend of A-pillar modeling affecting vehicle pneumatics, thus achieving the reduction of wind resistance and noise and improving the aerodynamic performance of the vehicle. Murad et al. [37] conducted investigations at speeds of 60, 100 and 140km/h and at 0 ° yaw Angle. The results of Cp values are compared with available experimental data. A qualitative airflow visualization analysis based on CFD results was also performed to better understand the airflow behavior behind the pillar A region. The results obtained by using CFD modeling provide a reasonable agreement with the existing experimental data, and some suggestions are put forward for future work. Kelkar et al. [38] can effectively improve the performance and safety of A-column by using fiber reinforced materials, while also reducing costs and improving production efficiency. This technology has a wide application prospect in the field of automobile manufacturing.

There are many ways to optimize the A-pillar, such as special treatment of the A-pillar surface to reduce the generation of air resistance. For example, by spraying A coating with epoxy resin [39], the

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friction resistance on the A-pillar surface can be reduced. In addition, nano-technology [40, 41] can also be used to micro-structure the A-column surface to make its surface smoother, thereby reducing air resistance. Alternatively, through the introduction of intelligent sensors and control systems, real-time monitoring and intelligent regulation of the A-pillar are carried out. According to the driving state of the vehicle, road conditions and weather and other factors, the shape, size or surface treatment of the A-pillar can be adjusted to achieve the best drag reduction effect. These methods provide more possibilities for optimal drag reduction of A-column but require experimental verification and further research to realize their practical application in the automotive industry. At the same time, in order to better achieve the effect of A-column optimization drag reduction, it is necessary to further study the laws and characteristics of automotive aerodynamics. With the continuous progress of technology and the continuous in-depth exploration of researchers in this field, it is believed that there will be more innovative methods and technologies to promote A-column optimization drag reduction in the future.

3.2 Automobile Rear Spoiler Research

The rear spoiler, also known as the automobile tail wing, is an aerodynamic device installed at the back of the car, whose main role is to improve the aerodynamic performance of the vehicle, improve stability and reduce wind resistance. The working principle of the automobile tail is to improve the vehicle performance by changing the air flow during the car driving [42]. The installation of tail fins on the rear of passenger cars has gradually become the mainstream, as shown in Figure 2, which can provide the vehicle with greater downforce and increase the grip of the tires, thus improving the safety and handling stability of the vehicle [43].

Figure 2. Passenger car tail fin

When the car is driving, the airflow generated by the tail will create a high-pressure area under the body, which causes the body to produce a lifting force. At the same time, the tail can also reduce the aerodynamic resistance of the vehicle at high speed and improve energy efficiency. Stojanovic et al. [44] proved through practice that the presence of rear spoiler reduced the lift coefficient by 32% and increased the drag coefficient by 3.4%. The result of increasing the spoiler is considered to be beneficial to the vehicle and will improve the safety of the vehicle, so it can be considered that the installation of the spoiler on the vehicle is very important.

The optimization design of the appearance of the tail is mainly based on the principle of aerodynamics. By optimizing the shape, structure, size and other parameters of the tail, the purpose of improving the aerodynamic performance of the vehicle is achieved. Increasing the weight of the chassis can improve the stability of the vehicle, but it will increase the weight of the vehicle and fuel consumption.

Therefore, in order to ensure the stability of the vehicle, installing the tail fin at the back of the vehicle is a very good improvement method. The tail wing device can increase the surface pressure of the car body, increase the adhesion between the tire and the ground, change the flow field of the rear of the car, and reduce the lift caused by the rotation of the rear air [45]. In general, regardless of the shape of the rear spoiler, the resistance of a vehicle equipped with a rear spoiler is always greater than that of a vehicle without one. For vehicles with rear spoilers, the lift is always less. [46] By installing tail fins at the rear of the vehicle, more downward pressure can be provided to high-speed vehicles. Thus, the vehicle can obtain better dynamic performance and improve its aerodynamic performance and handling stability [47].

The passive tail is fixed in the tail of the car, which has poor adaptability and has good effect only under certain working conditions. When the tail is mounted at the end of the body, turbulence generated at the rear of the vehicle is eliminated. Compared with vehicles without tail fins, tail fins reduce the aerodynamic resistance of vehicles and improve the stability of vehicles [48]. Abid[49] et al., through numerical analysis, used ANSYS-Fluent software, which can simulate vehicle air flow, and the results showed that the lengthening of the rear spoiler could not significantly reduce the drag and lift coefficient, but only limited the length. Compared with a plane spoiler, a spoiler with a certain Angle can improve the aerodynamic performance of the spoiler. On the other hand, the Angle introduced to the top of the spoiler provides a significant change in aerodynamic performance. The length of the spoiler has no significant effect on the aerodynamic performance of the pickup truck. The larger the length of the spoiler, the greater the drag and lift coefficient. At the same time, the change in spoiler Angle improves aerodynamic performance and provides lower drag and lift coefficients.

3.3 Wheel Spoiler Optimization for Drag Reduction

The wheel has an important effect on the aerodynamic performance of the vehicle. Some scholars have pointed out that in modern passenger cars, the resistance formed by the car bottom plate, tires and wheel cavities accounts for as much as 50% of the vehicle wind resistance [50]. Further research also found that the tire, rim and wheel cavity areas of the vehicle account for approximately 25% of the total aerodynamic resistance of the vehicle, which means that there is a lot of room for optimization in this part [51]. The study of the Audi A3 also confirmed that the resistance generated by the automobile tire and hub components accounted for almost 30% of the total resistance of the vehicle [52]. Therefore, the research of wheel aerodynamic performance has always been a hot spot in the field of automotive drag reduction. Sebben[53] performed numerical simulations of detailed vehicle geometries fitted with various front wheel baffle designs to assess the effect on drag coefficients. Some designs were found to reduce the overall drag of the vehicle by reducing the drag contribution of the wheels, while other designs did not succeed in leading to a reduction in drag. So it was concluded that while wheel deflectors have the potential to reduce a vehicle's drag by up to 10 drag counts, they must be carefully designed and placed to produce a net positive effect. Since then, the front wheel deflector has been studied in more detail and incorporated into many vehicle designs. For example, the Nissan Qashqai is a crossover SUV with a front wheel deflector that reduces overall drag by about 6%[54]. Wheel width is an important factor that affects the aerodynamic resistance of a vehicle. When the width of the wheel increases, the eddy current at the tail of the wheel will be strengthened, and the aerodynamic resistance will be increased. Therefore, reasonable selection of wheel width is of great significance for reducing vehicle aerodynamic resistance [55, 56]. Due to the existence of a large number of air separation zones under the car, the uncovered underbody structure is directly impacted by the high-speed air flow. Therefore, the key to reduce aerodynamic resistance is to control the airflow under the car reasonably and reduce the airflow separation and impact. Corning et al. [57] found through experiments that the installation of wheel deflectors and lower spoilers does have certain drag reduction effects, but the influence of different positions and widths before and after the addition of air baffle on aerodynamic resistance can be ignored. However, from

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3mm to 10mm, the resistance coefficient of the wind baffle decreases first and then increases, as shown in Figure 3.

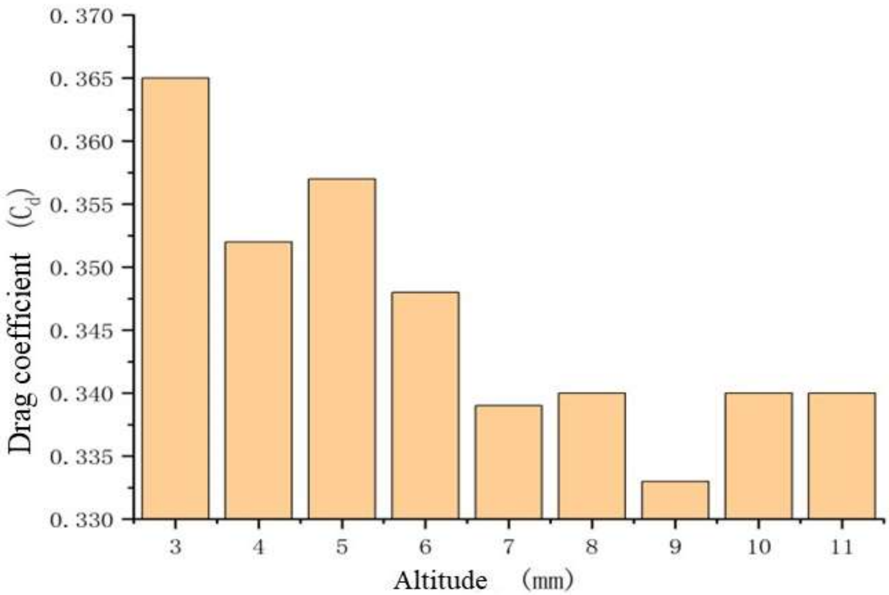

Figure 3. The relationship curve between the model drag coefficient and the height

Yuan[58] et al. studied the influence of different wheel spoiler heights on vehicle aerodynamic resistance based on a three-car model, as shown in Figure 4. The results showed that with the increase of spoiler heights, aerodynamic resistance tended to decrease first and then stabilize. Thus confirming Corning's conclusions.

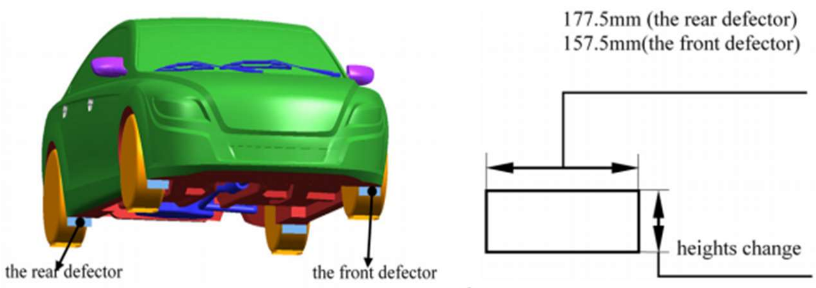

Figure 4. Wheel spoiler assembly drawing of different heights [58]

In recent years, researchers have come up with a number of innovative ways to optimize wheel spoiler design. Among them, the intelligent spoiler [59] is a promising new technology. Through the introduction of intelligent sensors and control systems, the shape and Angle of the spoiler can be adjusted in real time according to the driving state of the vehicle and road conditions. This smart spoiler can achieve the best drag reduction according to the actual situation, thereby improving energy efficiency and reducing emissions. Bionic design [60, 61] also provides a new idea for the optimization of wheel spoilers. Many organisms with excellent aerodynamic properties exist in nature, such as shark gills and bird wings. By drawing on the design elements of these organisms, they can be applied to the design of wheel spoilers to achieve better drag reduction effects. In addition, the rise of 3D printing technology [62, 63] also provides new possibilities for the optimal design of wheel spoilers. The use of 3D printing technology can be made more flexible, lightweight wheel spoilers, and can achieve complex shapes and structures. This technology can not only improve manufacturing efficiency, but also reduce production costs, and further promote the development of wheel spoiler optimization drag reduction.

3.4 Rear View Mirror Optimized for Drag Reduction

The side mirror of a car is one of the important factors of wind resistance. From a performance point of view, the contribution of regular side mirrors to the total drag of a car is about 3-6%[64]. Over time, we can monitor a variety of integrated advanced features such as built-in cameras, dynamic turn signals, blind spot detection lights, heating, tilting and dimming mirrors. However, the basic essence of the rearview mirror has not changed and is to provide the driver with an overview of what is going on around the vehicle. Magazoni et al. [65] used the adjoint method to analyze the sensitivity of the driver's side mirror, and the analysis results showed the potential of modifying the vehicle. This analysis shows that small changes in the surface shape at the position of the sight mirror can have a large effect on the axial force. Then an optimization solver is used to improve the surface of the mirror and reduce its resistance. This work demonstrates the potential of optimization techniques that can be applied in the early stages of a project and extended to the optimization of multiple surfaces of the body. Kim et al. [66] used the four-dimensional robot PTV to measure the four-dimensional flow of the side-view mirror model, and discussed the flow field characteristics around the vehicle side-view mirror model and its impact on the aerodynamic performance of the vehicle. They also discussed the influence of side-view mirror models of different shapes and sizes on the flow field characteristics, and the influence of side view mirror position on the overall aerodynamic performance of the vehicle. Through the experimental measurement and analysis, the relevant conclusions are obtained, which provide a reference for optimizing vehicle design and improving vehicle aerodynamic performance. Alam et al. [67] found that the resistance and the work done to overcome the resistance were proportional to the resistance coefficient. By calculating the fuel consumption reduction of the planar side mirrors and hemispherical side mirrors when the vehicle was driving at a speed of 120km/h, they found that the maximum fuel consumption reduction was 29.3 liters per year when the design of the side mirrors was changed from a plane to a hemispherical one. The new rearview mirror designed by TR[68] et al. improved the blind spot area caused by the B-pillar of the original model, and the comparison between the improved side view mirror and the original side view mirror is shown in Figure 5. This not only minimizes blind spots, but is also more aerodynamic than the original model.

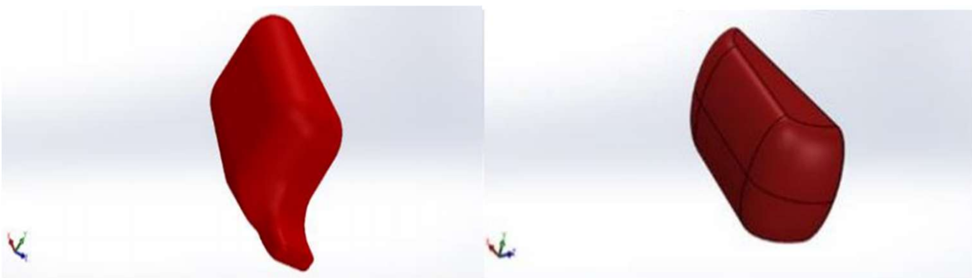

Figure 5. Original side view mirror New side view mirror design [68]

Mirrorless cars are concept cars that completely remove rearview mirrors and use cameras and LCD screens as visual AIDS for safe driving [69]. Camera applications as an alternative to automotive rearview mirrors have advantages and disadvantages. Compared to traditional mirrors, they have the advantage of being combined with automotive active safety components, having less aerodynamic resistance and volume, better acoustic comfort, and eliminating blind spots. But camera applications require high-quality cameras and high-resolution screens, which are expensive. Some automakers believe the technology may not be efficient enough to deliver the desired results in the future. Therefore, at present, this alternative scheme has not achieved a significant position in the market [70].

4. Conclusion

Today, with the development of economic and trade globalization, the volume of vehicles is gradually increasing, energy consumption and exhaust emissions are also increasing, and the application of drag reduction technology has an important role in reducing energy costs and energy conservation and emission reduction. Specifically, we have developed many effective techniques such as simulation, wind tunnel experiments, Computational Fluid Dynamics (CFD) analysis, etc., which allow us to simulate and optimize the aerodynamic performance of the vehicle in a computer, saving a lot of time and resources. However, there are still many problems in the research of vehicle resistance, so the future research on vehicle drag reduction technology is still the focus. This paper analyzes the generation principle of vehicle resistance and the research status of drag reduction technology at home and abroad. The problems to be solved and suggestions are as follows:

1) We need to consider the impact of environmental factors on automotive aerodynamic performance more comprehensively. For example, weather conditions, road conditions, etc., will have an impact on the aerodynamic performance of the vehicle. We need to better understand and predict these impacts through research and experimentation so that we can design vehicles that are more adaptable to a variety of environments and conditions.

2) We can further research and explore the application of smart materials in automotive aerodynamics. The ability of smart materials to automatically adjust their shape and performance in response to environmental changes will dramatically change our understanding and practice of automotive design. For example, we can use smart materials to create adaptive vehicle surfaces that optimally reduce air resistance.

3) Future research will not only focus on drag reduction, but also explore how aerodynamic design can improve vehicle safety, comfort and environmental performance. For example, by optimizing the underside design of the vehicle to reduce vortex generation and reduce noise and vibration; Or improve the safety of electric vehicles by designing efficient cooling systems to prevent batteries from overheating.

In the future, automotive aerodynamic drag reduction research still has a broad space for development. With the popularity of electric vehicles and the development of driverless technology, we will face new challenges and opportunities. Process

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