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Considerations for Car Design of the Exterior Shape

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Abstract. In the car industry, there is always the pursuit of enhancement in performance and fuel efficiency but underlying all these is one primary challenge and that is the minimization of aerodynamic drag. This drag directly influences fuel consumption and the general driving experience as it directly affects the interaction of this vehicle with the air during motion. Fluid mechanics interaction contributes to the development of the way the car body penetrates the air, and the optimization of the interaction with the air is one of the main concerns in the development of a car body design. Car designers understand that the less rounded the appearance the less resistance their cars have and therefore cars are more efficient. This is more than smooth curves, though; it is the way everything on the vehicle interacts with the air; the wheels and the mirrors and the way the back end is. With the pressure of lighter and fuel-efficient cars being taken by manufacturers, the relationship between weight loss and aero becomes increasingly more close. It is a natural fact that lighter cars experience a lower drag, but the problem is how to decrease the weight without losing aerodynamics and safety. In this paper, the author examines the extent to which the shape and structure of a car can be optimized to reduce the drag by examining the effects that minor adjustments to single components can cause. It also issues about the impact of weight reduction on the aerodynamics and general performance. With the changing technology of vehicles, it is not only the technical challenge of strike the balance between design, weight and air flow, but it has become the issue of progress.

Keywords: Aerodynamic drag, light weight design, fuel efficiency, vehicle performance, material science.

1. Introduction

Constant innovation is driven by the desire to achieve automotive goals of higher performance and lower consumption, but behind these desires is one serious challenge, which is decreasing the aerodynamic drag. It is a direct effect of the vehicle interaction with the air, and the vehicle exhibits such an interaction causing this drag that directly affects the fuel consumption and the overall driving experience. Fluid mechanics is important in determining the interaction of the body of a car in the air and the optimization of the interaction has been a major point of emphasis in car designing.

Automobile designers understand the fact that a smoother exterior is more likely to result in a less resistant car thereby making the car more efficient. But this is not only of smoothness down the lines, but of how all sections of the car could conform with the air, including the wheels, mirrors,

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and the back part of it. With the pressing of light and fuel-saving cars by manufacturers, aerodynamics and mass decrease become increasingly correlated. The lighter cars have an advantage of less drag but this has been discussed as a challenge of how to lower the weight without compromising the aerodynamics and safety.

This paper discusses ways in which the car shape and structure can be optimised to reduce drag, considering how individuals can change a particular component in small ways to yield big effect. It also brushes on the changes with minimised weight on aerodynamics and the entire performance. With the modern technology of cars at fluxus, balancing the aspects of design, weight, and air flow is no longer a technical trick, but a leap forward.

2. Basic facts of aerodynamic drag

The resistance that the vehicle faces during motion through air is the aerodynamic drag. It causes a reversal effect to the car and requires more power to keep the car moving and this consumes more fuel. The power of drag also increases with the velocity of the vehicle and hence, the greater the vehicle speed the greater the drag force [1].

There are two sources of drag, which are central, force of pressure and friction. The front of the car is pushed against by the air and this gives pressure against the car and friction is provoked by the reaction of the surface of the car and the air. Due to the fact that a faster vehicle assumes large degrees of drag force, the car at high velocity must exert greater amounts of power in order to overcome the air force. When the drag is excessive, then the fuel economy falls, and the performance may be impaired.

The drag force which a vehicle experiences is affected by a few elements. They both contribute to the amount of resistance caused by the air.

$$Fd = \rho u2CdA/2 \tag{1}$$

U-Speed: The more the speed of the car, the higher the drag. The relationship is exponential: drag increases in the form of the square of the speed. In less technical terms, the greater the speed of the car is, the more the body force of the drag is increased four times. The effect on consumptions is far-reaching particularly at highway speeds.

Cd-Drag Coefficient: This is a figure that represents the ability of a vehicle to cut through the air through its ability. The smaller the coefficient, the less the resistance to be encountered by the car. Streamlined shape of a car will have lower Cd and hence less energy will be required to push it in motion. The overall shape of the vehicle is what forms the drag coefficient such as its shapes, edges and the interaction of the air with the vehicle.

p-air Density: Air is denser near the ground, and it drags more and it is more watered out as higher, and it is less watered out as lower. Humidity and temperature are also environmental factors that influence the density of air. Although this transformation is at times not dramatic, it may make a difference in the performance of a car under various circumstances.

A-Frontal Area: The larger is the front area of the vehicle, the more it has to clear the air. Having a bigger frontal reduces the drag and a smaller car or one with a less frontal profile has an easier time cutting through the air. This area is determined by the width of the car, its height and also the shape of the nose.

Moreover, the aerodynamic drag directly and probingly affects the performance and efficiency of a car [2]. It has a direct influence on fuel consumption with higher drag consuming more energy to overcome resistance particularly during higher speeds. A vehicle can achieve a much higher fuel

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economy by decreasing the vehicle drag since the engine power necessary to sustain the speed is reduced. This drag reduction is also an improvement in the performance of the vehicle. A car that is less resistant will travel easier, accelerate quicker and have the ability to travel faster with less effort. It also enhances stability, especially during high speed resulting in increased handle and responsiveness, and cornering. Moreover, a lowered drag will alleviate the driving environmental effect. Fewer emissions shall be created because lower drag translates to fewer emissions in vehicles since the vehicles are environmentally friendly. To manufacturers it is not only the lowering of drag to make things more efficient but also the increasing environmental regulations as the automotive industry heads towards the concept of sustainability. The other advantage of reducing drag is that the drag will be less, and noise will also be reduced. Large drag may lead to turbulence, which leads to wind noise and hence interferes with the comfort of passengers. Having a less drag-prone car does not only make it more fuel-efficient, but it is also less noisy and enjoyable to drive. Fuel efficiency is one of the most important selling points in the market today considering that buyers have become more environmentally aware. Car manufacturers who have created higher drag cars have an edge in their designs as they offer cars that match the performance requirement as well as a more fuel-efficient car at the same time maintaining their style and driving experience.

3. Effects of local structures on aerodynamic drag

The vehicle front is the first one to meet with the air, and this is where drag begins. The form of the grille, headlights and air intakes influence the flow of air, and whether it adheres to the car or not [3-5]. As an example, look at Tesla Model S [6], its front is minimal and smooth with a closed grille, which is not characteristic of many vehicles that have a large and open grille. This design ensures that air does not need to struggle to penetrate through it and this contributes to smoothing out over the car and thus lessening resistance. As a matter of fact, the Model S possesses one of the lowest drag ratings in the markets with a drag rating of 0.24, providing it to be among the most efficient production cars. The closed front permits the flow of air without breaking the needless turbulence. Ferrari, on the other hand, uses a different strategy in its LaFerrari [7]. Its aggressive, performance oriented front possesses huge intakes that are designed to cool the car but placed carefully so as to control or manage air circulation as it passes round the car thus minimizing drag. Another active aerodynamic component on the LaFerrari front is the use of flaps that can change according to the speed optimizing airflow and reducing drag at the appropriate time. The two most contrasting strategies include Tesla which aims at being the most efficient with minimalism and Ferrari which has a combination of both performance and aerodynamics. They both work, however, they are both useful but in different ways illustrating how the front-end design can play an important role in controlling the drag

Rear of a vehicle is equally vital in the drag control. Air can either remain smooth on the back or dislodge and create turbulence, and then the increase of drag begins. The rear of Tesla Model 3 [6], is an example that is tapered away. The manner through which the air is directed out of the car minimizes drag, as it prevents separation thus maintaining the airflow continuous, which minimizes the resistance. The tail part of the Model 3 does not generate a wake turbulence which is a significant source of drag on most other cars. Look at Ferrari's 812 Superfast. It is fast, and thus it has an adjustable rear spoiler which will vary depending on the driving conditions. Such design does not allow the turbulence to be excessive and also in the process maintains the car steady at high speeds. The 812 Superfast is able to reduce and maximize downforce when necessary due to varying the angle of the rear spoiler to enable higher grip on the road over the course of different observed speeds. The back is not a passive component of a vehicle, it is a vital element in the airflow. The

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opposite side has a smooth tapered rear as in the Tesla that decreases the drag, whereas performance cars such as Ferrari have to balance the requirements of the drag with faster stability.

Moreover, the use of spoilers and diffusers is dual-fold as it regulates the airflow in the area of the vehicle and it may either alleviate drag, or produce downforce. A good example is again the Ferrari LaFerrari which has an active rear spoiler which varies according to speed [7]. When the car moves faster, it causes the car to have more downforce which helps in giving the car some stability and when it moves slower it minimizes the drag when it must be pulled in. This dynamic characteristic helps the car to work well under both conditions and so it demonstrates how spoilers and diffusers could be utilized wisely to control the drag and the stability. The other case is the 911 Turbo made by Porsche. Higher speeds cause the rear spoiler to deploy automatically giving the vehicle additional downforce where required but when not in use it returns smooth, not in the way, at lower speeds and causes less drag. The rear diffuser of the 911 functions alongside the spoiler to manage airflow beneath the car to decrease turbulence and drag, making the car stable and efficient.

Spoilers and diffusers are not only about the cut of drag. They are also concerning the behavior of the car in the various speeds. All these factors combine to give the vehicle a better ride experience, as well as, an improved performance when needed the most.

It is equally important in fight against drag on the sides and underbody of the car. The airflow moving on the sides and under the vehicle may pose serious resistance unless it is handled effectively. The vehicle called Model S by Tesla has a flat, smooth underbody which eliminates the air turbulence beneath the vehicle. The design assists the air flow to stream evenly underneath the car and prevents the build up of resistance and increases the efficiency particularly when traveling on high speeds.

In like manner, the 720S of McLaren has a finely-tuned side and underbody design [8]. The car has active aerodynamic features and thus it can regulate its flow of air depending on the conditions. The skirts on the side of the McLaren are used to guide the air in the vehicle such that it does not flow in a too chaotic way to provide drag. The underbody has been also designed to reduce turbulence to ensure that the car is efficient even at high speed.

The side design and under body are usually disregarded yet they play a significant role in ensuring the performance of a car. The control and controllability of the car in the air is made possible by smooth underbody and well designed side skirts that enable the car to move smoothly in the air with minimal resistance to enhance fuel efficiency and stability. Lightweighting and Fluid Dynamics of Vehicles.

Design is an important component to enhance the overall efficiency of a vehicle, since lightweight design directly leads to the reduction of fuel consumption without affecting the performance [9]. Reduction in the weight of the vehicle results in the fact that less power is needed to accelerate the vehicle or keep it moving, which serves as a great source of energy conservation as well as carbon emission. Furthermore, the connection between lightweighting and aerodynamics is rather subtle because by decreasing the weight of a car one can improve its aerodynamic performance by decreasing drag. When a vehicle is lighter there is less resistance when in motion and thus the vehicle accelerates more quickly and at a higher speed with less power consumption thereby increasing fuel efficiency greatly. More to the point, lightweighting also adds agility to a vehicle that allows it to accelerate faster and therefore this is capable of reducing aerodynamic drag. Lightweighting however entails not only reducing weight but also stability and handling of the vehicle. An example is that a vehicle with a lower weight could have alterations in its ride height or downforce and hence affect its stability, especially at high velocities. Hence, this is critical in

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balancing the concept of lightweighting versus the aerodynamic optimization of an aircraft whereby the concept of safety and stability may not be affected.

Material selection is important towards the realization of lightweight design. Historically, steel has been preferred due to its strength and cost-effectiveness but with the changes in technology, lightweight materials such as aluminum alloys, carbon fiber composite, and high strength steel are getting to be very popular in the automotive design. An illustration of these is that aluminum alloys are approximately one-third the weight of steel and have a high-strength to weight ratio. This has been applied in such type of vehicles as the Ford F-150, which employs extensively the usage of aluminum, to minimize the weight of the car a total of about 700 pounds to achieve increased fuel efficiency and performance [10]. Carbon fiber is even lighter than aluminum and even stronger and more expensive, but still used in high-performance cars such as the BMW i3 and McLaren P1. The other possible substitute is high-strength steel which has the same strength with normal steel but is less in weight thus it is ideal to be used in components that needs high impact resistance like vehicle frame, and safety structures.

The decision on the use of lightweight material also greatly influences the structure of the vehicle consequently, the aerodynamics. Since the vehicle is lighter, it can be designed in a more streamlined shape of the body, hence will produce a low drag that is more efficient. Besides, lightweight materials allow more progressive aerodynamic elements to be achieved without any unnecessary weight. These materials can be made more flexible regarding aerodynamic designs which directly increases the efficiency of the vehicle. Lightweighting is however not without its problems. Decreased weight may change the ride height or stiffness of the structure of the vehicle, which may have an impact of the air that passes around the vehicle. Higher ground clearance would be an instance where the stress may be more turbulence under the vehicle, and drag will be higher.

However, lightweighting in high-performance cars can be used in conjunction with aerodynamic attributes because, in this case, control of airflow can be finer [9]. This is because lighter cars are more appropriate to exploit the active aerodynamic system which is shaped upon the speed and driving environment of the car. A convenient example is the McLaren 720S that does employ an active aerodynamic system and works to optimize airflow and minimize drag [8]. These systems can be used in light cars such as the McLaren 720S which can be improved to be more effective by changing its form in real-time to ensure that it not only reduces resistance when moving but also makes better use of its energy.

Moreover, light cars are usually faster to accelerate and require less energy to fight air resistance, they thus can be driven faster using less drag, thus more fuel efficiency is achieved. Lightweighting also enables smaller design resulting into a smaller frontal area of the vehicle which lowers the drag further. Its example is the BMW i8 which is a light car powered by not only high-tech materials but also an efficient design to create a high level of aerodynamic efficiency which is then transferred to performance and fuel consumption. Finally, when evaluating the effect that lightweighting is likely to have on the aerodynamics of a vehicle, it could also bring some changes, but they can be corrected and improved with the right choice of materials and some modifications with the structural model. With the lightweighting approach combined with the aerodynamic design, manufacturers have the potential to come up with vehicles which are more efficient besides adding performance and shaping a perfect combination of form and functionality which is in tandem with the current design trends in modern cars of reducing drag and more fuel efficiency.

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4. Conclusion

To sum up, this paper has discussed how the role of aerodynamic drag reduction and strategies involved in lightweight design can play a huge role in changing the performance of vehicles and fuel efficiency. The techniques that reduce the drag, including the improvement of the outlines of the car, the characteristic of airflows, and the implementation of the active aerodynamic elements, including changeable spoilers, are critical in improving a car in terms of performance and efficiency. These methods as can be illustrated with a real-life example of the most successful manufacturers such as Tesla, Ferrari, and McLaren reveal that even minor design changes can make a significant difference in drag and fuel economy changes.

It is also important that lightweight design is considered. It can make massive weight cuts and save on materials such as aluminum alloys, carbon fiber, and high-strength steel without adversely affecting the structural integrity and safety of the vehicle in that regard. The lighter it is, the more fuel efficiency, acceleration, as well as the ability to optimize aerodynamic characteristics. It becomes possible to achieve not only a faster and highly maneuverable vehicle as a result of finding the right balance between lightweighting and aerodynamic optimization, but also an efficient vehicle when it comes to energy consumption, bringing the automotive future to a more sustainable point.

Finally, the external figure of the car should also be designed with in consideration of air drag and weight of the vehicle. Performance, efficiency and even sustainability can be enhanced by the well-constructed exterior that minimizes drag and weight, without compromising safety or handling. This is the holistic design method of the car, which emphasizes on the need to consider the elements of aerodynamics, as well as lightweight materials in the development of the next generation vehicles that are fast and remain eco-friendly.

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