

The Impact of Wheel Design on Aerodynamics

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Abstract: With the popularity of environmentally friendly policy and the development of electric vehicles, many engineers in the vehicle industry are trying to improve cars' fuel efficiency. This study investigates the impact of wheel design on a vehicle's aerodynamic. It uses the information provided by a computer model to analyze the flow around the wheel, such as how these flows form and their distribution around the wheels. According to these analyses, this paper finds that it is necessary to reduce the vortex systems and turbulence within the wheel cavity. Therefore, the author analyzes the fluid dynamic simulation of different rims' designs, including the number of spokes, the opening area of rims, and the shape of rims. It finds that the wheel design can be enhanced by decreasing the opening area around the disc and enlarging the closed area at the top of the spokes. This approach aims to mitigate the impact of airflow and reduce aerodynamic drag.

Keywords: Wheel Design, Vehicles, Aerodynamic, Fuel Efficient

1. Introduction

In recent years, as environmental protection policies become more prevalent and electric vehicles continue to develop rapidly, automakers have increasingly prioritized enhancing fuel efficiency and reducing emissions. For electric cars in particular, extending driving range has become a central design goal. One of the most effective methods to achieve these objectives is optimizing the vehicle's aerodynamic performance. While much attention has traditionally been given to body shape modifications such as spoilers and air dams [1], the aerodynamic role of the wheels is often underestimated. Research has shown that aerodynamic drag accounts for around 20% of a vehicle's overall energy consumption, and roughly a quarter of this drag originates from the wheels themselves. Given the rise of eco-friendly technologies, this proportion is becoming more significant [2]. As a result, a comprehensive aerodynamic analysis must include wheel design as a key factor. This paper explores the aerodynamic behavior of wheels using data derived from Computational Fluid Dynamics (CFD) simulations, aiming to provide deeper insight into how wheel structures affect airflow and how their design can be optimized to reduce resistance.

2. Methodology

All the data gained from the simulation is based on the analysis of CFD.

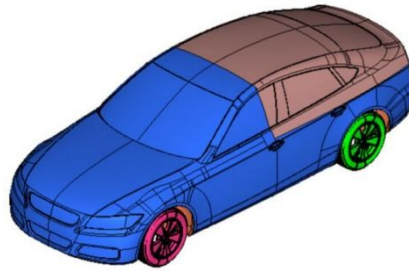


Figure 1: Car model [3]

To diminish other unrelated influencing factors and mainly focus on the impact on wheels, the car model illustrated in Figure 1 gives up the chassis structure, rear view mirrors, and other specific details. The length of the car is 4612mm, the width is 1752mm, and the height is 1418mm, and it is totally symmetric.

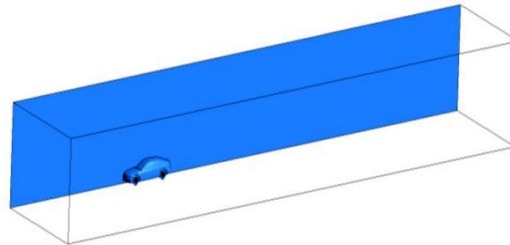


Figure 2: Virtual wind tunnel model [3]

In Figure 2, there is a virtual wind tunnel model with 10 times the length of the car and 5 times the width of the car on each side, and since the car is symmetric, the wind tunnel model domain is half of the car and is also symmetric.

3. Flow field analysis of vehicle wheels

As airflow impacts the vehicle, the highest pressure zones occur at the radiator grille and windshield, where significant turbulent kinetic energy leads to substantial energy dissipation. Additionally, both front and rear wheels play a key role in shaping the vehicle's flow field. Notably, the airflow tends to separate initially at the front wheels, where velocity and energy are greatest, resulting in higher aerodynamic drag compared to the rear wheels.

3.1. Car turbulence

Figure 3 shows that airflow descending from the vehicle roof and rising from beneath the chassis converge behind the car, creating a pair of rear vortices that swirl opposite to the direction of travel. This interaction leads to backflow and substantial energy dissipation. In addition, both the front and rear wheel zones generate numerous vortical structures, contributing to elevated levels of turbulence in these areas.

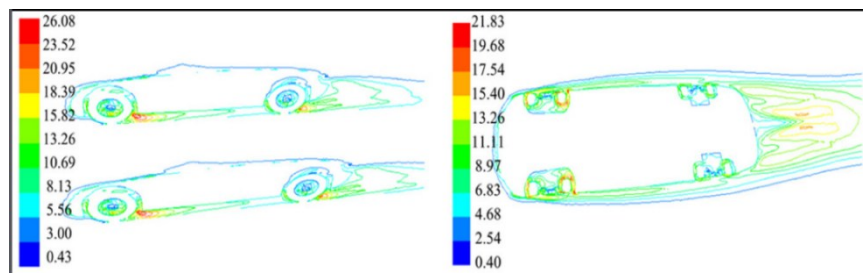


Figure 3: Left: isogram in y-direction; right: isogram in z-direction [3]

3.2. Airflow in the wheel

As depicted in Figure 4, the front wheel experiences a significantly higher flow velocity compared to the rear wheel. The negative pressure causes the airflow to enter the wheel cavity, and the wheel's rotation generates intense turbulence in the lower region of the wheel. Some of this turbulence flows into the bottom of the body, while the rest escapes around the outer side of the wheel. The air that exits the wheel forms a vortex; part of it continues to swirl around the center, while the other part detaches and moves backward [4].

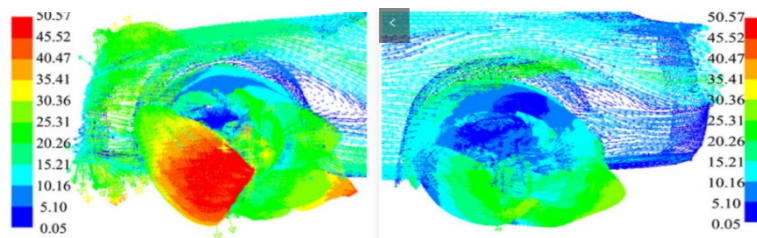


Figure 4: Y-axis is the velocity vector of the wheel [3]

Analysis of vortex patterns suggests that minimizing the aerodynamic drag coefficient requires reducing the strength and extent of vortex structures within the wheel cavity. In addition, it is important to lessen both the turbulence intensity and the interaction between vortices escaping from the cavity and the surrounding external airflow.

4. The effects of rim design

4.1. Influence of spoke number

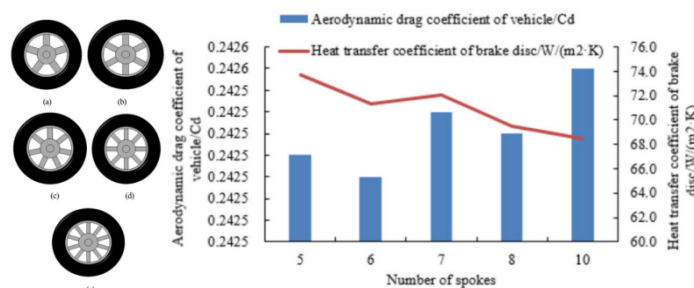


Figure 5: Rim of different number of spokes and its aerodynamic drag coefficient [3]

The number of spokes is one of the greatest characteristics of rims. As illustrated in Figure 5, the aerodynamic drag coefficients for different spoke numbers remain nearly unchanged. This indicates that variations in spoke count have minimal impact on local turbulence levels, kinetic energy dissipation, and overall flow behavior near the wheels. Simulations reveal that wheels with fewer

spokes feature wider gaps, allowing more airflow from the external field to enter the wheel cavity and increasing the velocity near the brake disc — which is advantageous for thermal dissipation. Conversely, adding more spokes creates more but narrower gaps, reducing airflow intensity and speed through the wheel, thereby weakening the brake's cooling performance. Thus, provided the total open area of the wheel remains constant, spoke number has little effect on aerodynamic drag but a more noticeable influence on brake heat management.

4.2. Influence of different spoke types

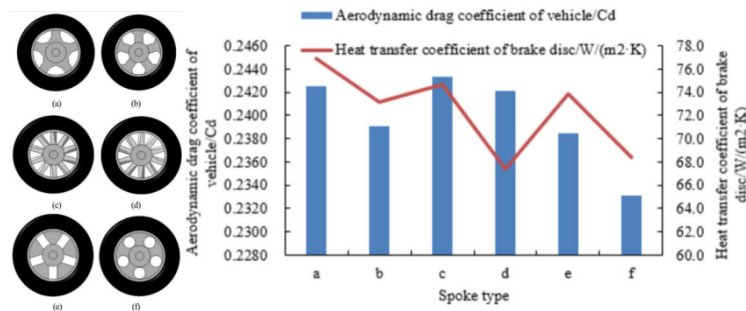


Figure 6: Rim of different spoke type and its aerodynamic drag coefficient [3]

Advances in automotive manufacturing and shifts in consumer design preferences have led to a wide range of rim styles available on the market. Wind tunnel data, along with Figure 6, indicate that rim types a and c retain features close to standard configurations and show minimal differences in aerodynamic drag. In contrast, rim types b, e, and f exhibit spoke designs with significantly larger closed regions at the top (where the spoke meets the rim) and narrower areas at the base (near the axle). These top-heavy designs help limit airflow into the wheel cavity, effectively reducing internal vortex formation and turbulence, which in turn lowers drag. Additionally, these designs promote more efficient heat convection from the brake disc. Notably, rim type D displays the lowest brake heat transfer coefficient. Its spokes slope outward, and as the vehicle moves forward with the wheels rotating counterclockwise, this geometry channels air away from the wheel cavity, suppressing vortex formation but reducing cooling efficiency.

4.3. Influence of spoke width

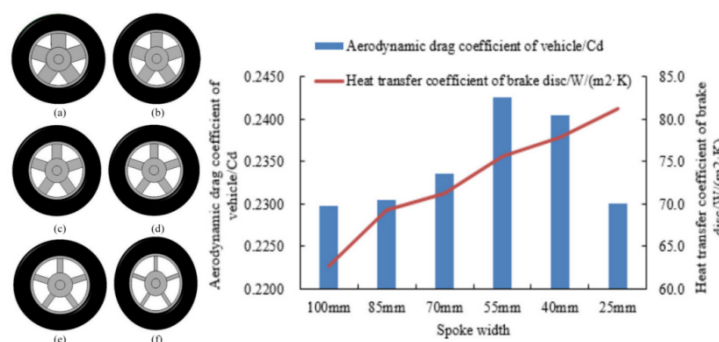


Figure 7: Rim of different width of spokes and its aerodynamic drag coefficient [3]

Variations in spoke thickness result in different disc opening areas, which directly influence aerodynamic characteristics. This section examines how drag coefficients change with varying opening sizes, assuming spoke count and geometry remain fixed. As the disc's open area increases, the aerodynamic drag initially rises, reaching a peak, and then declines. Meanwhile, the heat

transfer capability of the brake disc steadily improves. Greater openings allow more airflow to penetrate the wheel cavity, intensifying vortex formation and turbulence, which leads to higher drag and energy dissipation. However, Figure 7 shows an unexpected drop in drag beyond a 55mm opening. Although the complex nature of the airflow makes it difficult to pinpoint the cause, it is speculated that increased opening may induce a reorganization of flow patterns—potentially streamlining airflow and weakening turbulence—which contributes to the observed reduction in drag.

4.4. Case studies of practical wheel designs



Figure 8: The rim of Tesla Cybertruck [5]

As illustrated in Figure 8, the Tesla Cybertruck employs full wheel covers that eliminate any openings in the rim. This sealed design significantly cuts down on airflow entering the wheel cavity, thereby minimizing aerodynamic drag. However, this approach comes with a trade-off: the enclosed structure also restricts cooling airflow around the brake discs, raising concerns about thermal performance under high-speed or extended driving conditions.



Figure 9: The rim of Kia concept car [5]

In contrast, Figure 9 presents a concept wheel from Kia. This design partially encloses the upper sections of the spokes to lower drag, while deliberately leaving three vertical gaps to allow for brake disc ventilation. Additionally, the surrounding cover surfaces are shaped with gentle curves to help redirect airflow smoothly outward, aiding in both drag reduction and thermal regulation.

5. Conclusion

The paper discusses wheel aerodynamic drag by explaining how pressure zones (positive and negative) affect aerodynamic drag and that front wheels generate more drag than rear wheels, a phenomenon which significantly influences the vehicle's flow field. Secondly, improving wheel design can reduce the impact of side airflow on rotating wheels, lowering vortices and thus reducing aerodynamic drag. Thirdly, it exhibits the influence of wheel design and how to improve it. Changes in spoke count have a minor effect on aerodynamic drag coefficient. Moreover, increasing spoke numbers will decrease the heat transfer performance of brake discs. Wheels with larger closed areas at the spoke tops can significantly reduce drag while improving heat dissipation. An appropriate opening area of the disc can also decrease the aerodynamic drag.

Because of the difficulty of the experiment and the availability of some documents, the study has overlooked a lot of influencing factors while driving. The car model is simplified, and the range of the rim design is limited. Therefore, to make this experiment more comprehensive, various types of vehicle models with more details can be used in the future, such as SUVs, sport cars, trucks, etc. Moreover, the rim design today is more diverse, so some advanced rims from the latest concept car can be used as a research subject, and test them through CFD and compare the data to the regular wheels to find more potential influence of rim design. Future studies should also analyze the flow fields of the wheel in different driving statuses, for example, the flow fields of the wheel during cornering or during reversing. Since it needs to consider the flow from different phases.

From all of the experiments shown above, it demonstrates how the wheel design impacts aerodynamics and how to reduce the vehicle's aerodynamic drag coefficient. The study expects that the design of the wheel will play a larger role in the future car industry because it can effectively reduce the aerodynamic drag coefficient of the car, which can lead to higher fuel efficiency and longer driving ranges for electric vehicles, which can support the increasing popularity of environmentally friendly policies and electric vehicles.

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