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The influence of the gap on the air intake grille on the downforce of a car

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Abstract. This study investigates the impact of varying air intake grille intervals on the downforce of vehicles. The analysis is conducted using fluid finite element analysis with ANSYS Fluent software. Various grille intervals are tested to determine their influence on airflow and downforce. Results indicate that grille intervals significantly affect downforce, with the optimal interval identified for achieving maximum aerodynamic efficiency. The findings provide insights for optimizing grille design to enhance vehicle performance.

Keywords: Air intake grille, Downforce, Aerodynamics, Computational fluid dynamics (CFD), ANSYS Fluent.

1. Introduction

Air intake grille is an important part of the automobile front face, which not only has the functions of air intake, ventilation and heat dissipation, but also is one of the visual symbols of the automobile brand. With the development of the automobile industry, the design of the air intake grille is also constantly innovated and optimized, from the traditional fixed air intake grille to the intelligent active air intake grille, from the simple geometric shape to the complex spindle, inverted triangle and other shapes, the air intake grille demonstrates the diversity and personalization of automobile design [1].

The development of air intake grille can be divided into the following stages:

Stage 1: early automobile air intake grille is mainly to protect the engine and water tank from road gravel splash, so the design is relatively simple and rough, mostly horizontal or vertical bar form, without much aesthetic consideration.

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Stage 2: With the development of the automobile industry, automobile designers began to pay attention to the aesthetics and brand recognition of the air intake grille, so there are some representative and characteristic air intake grille designs, such as BMW's double kidney shape, Audi's big mouth shape, Alfa Romeo's inverted triangle and so on. These grilles not only enhance the charm of the car's appearance, but also become the iconic elements of each brand.

Stage 3: With the rise of new energy vehicles and intelligent vehicles, traditional internal combustion engine vehicles are faced with the challenges of energy saving, environmental protection and efficiency improvement, so the functionality and intelligence of the air intake grille began to be emphasized. Active air intake grille came into being, which can automatically adjust the opening and closing state of the blades on the air intake grille according to the external environment and automobile working conditions, thus reducing the wind resistance coefficient, improving the engine efficiency, saving fuel consumption and so on. Active air intake grille has been adopted by many models, such as the Fox, Cadillac ATS-L, Buick Enclave and so on.

The development trend of air intake grille can be predicted from the following aspects:

Functionality: With the continuous innovation of automotive technology, the air intake grille may take on more functions, such as the integration of sensors, cameras, radar and other equipment, to achieve a higher level of intelligent driver assistance functions; or the use of aerodynamic principles, to achieve a better control of air flow, improve the stability and handling of the car.

Aesthetics: As consumer demand for personalization and differentiation increases, the air intake grille may see more creativity and changes, such as decorating with different materials, colors, textures, etc.; or using lighting, liquid crystal and other technologies to make dynamic changes and achieve more emotional expression and interaction.

Branding: With the intensification of competition from new energy vehicles and intelligent vehicles, traditional internal combustion engine vehicles may face the risk of declining brand recognition, so the air intake grille may become an important carrier for inheriting the brand genes and shaping the brand image, and the brand recognition and loyalty will be enhanced by maintaining or innovating the design style of the air intake grille.

The spacing of the bulkheads in an air intake grille has an effect on downforce because the size of the bulkhead spacing affects the opening area of the air intake grille, which in turn affects the differential pressure that is created when air flows through the air intake grille. Generally speaking, the smaller the spacer, the smaller the opening area, the larger the differential pressure, the larger the downforce; and vice versa. Therefore, when designing the air intake grille, the size of the partition spacing needs to be reasonably selected according to the performance requirements and working conditions of the vehicle, in order to achieve the best aerodynamic effect.

2. Fluid finite element analysis of air intake grilles based on Ansys

2.1. Ansys introduction

ANSYS is a versatile finite element computer program designed for tackling engineering analyses in the realms of structural and heat transfer. ANSYS boasts a wide range of solution capabilities, encompassing static analysis, elasticity, plasticity, thermal stress, stress stiffening, substantial deflections, and bi-linear elements. It also encompasses dynamic analysis, including modal analysis (for natural frequencies and mode shapes), harmonic response, linear time history, and nonlinear time history.

Furthermore, ANSYS facilitates heat transfer analysis, covering conduction, convection, radiation, coupled fluid flow, and coupled electric flow. The program accommodates analyses across one, two, or three dimensions, including options for axisymmetric and harmonic elements. Additionally, ANSYS features an integrated graphics package and robust pre- and post-processing capabilities [2].

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2.2. Ansys Fluent basic introduction and advantages

2.2.1. Ansys Fluentintroduction

Ansys Fluent is a computational fluid dynamics software package written in the C language. Fluent boasts a wide range of simulation capabilities [3].

Fluent is a computational fluid dynamics (CFD) software designed specifically for the analysis of fluid flow and heat transfer problems. Its robust features enable engineers and scientists to simulate a variety of fluid systems with precision through numerical simulations.

The software offers a plethora of functionalities, including simulating fluid flow, heat transfer, mass transport, chemical reactions, and more complex fluid-related phenomena. It can be applied to study the behavior of liquids, gases, and multiphase fluids, addressing challenges in various fields, from aerospace to the energy industry.

2.2.2. Ansys Fluent advantages

Ansys Fluent allows you to have more time for innovation and optimizing product performance. With a software that has been extensively validated and widely used, you can have complete confidence in your simulation results. With Ansys Fluent, you can create advanced physical models and analyze various fluid phenomena - all within the same customizable and intuitive environment.

Ansys Fluent features a superior interactive graphical interface, a seamless single-window workflow, and parallel grid generation and solving capabilities [4].

2.3. Parameter setting

2.3.1. Geometric size

As shown in Figure 2.3.1, for the sake of simulation convenience, we have abstracted and simplified the longitudinal cross-section of the intake grille. The data is based on measurements taken from a specific vehicle model. In the upcoming simulation process, we will achieve the maximum downforce and as uniform a distribution as possible by adjusting the grille opening (i.e., the width between the grille horizontal bars, indicated by the 47.5mm section in the figure 1).

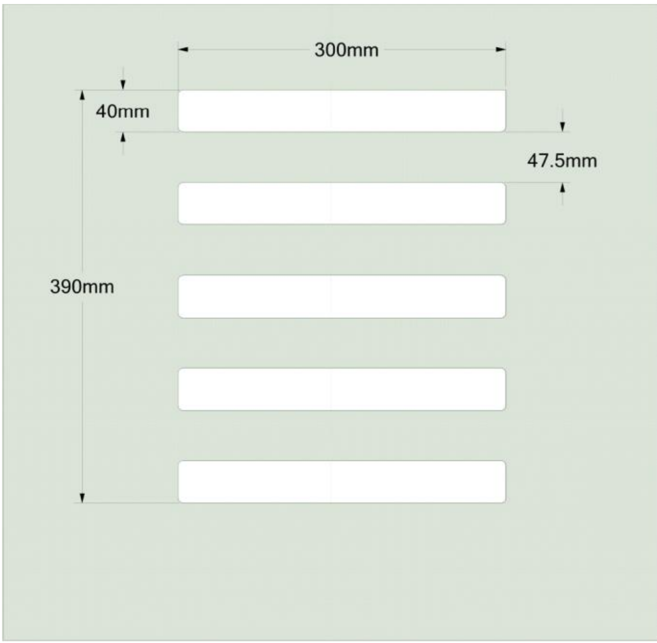

Figure 1. Geometric model establishment

Since flying stones and other debris are easy to enter the car body through the air intake grille during actual driving, the general opening in the industry will not exceed 50mm, so the experimental group shown in Table 1 below is listed

Table 1. Air intake grille opening

Experimental group	1	2	3	4	5
Interval (mm)	12.5	25	32.5	40	47.5

2.3.2. Meshing

Currently, grid generation falls into two major categories: structured grids and unstructured grids. Different engineering problems correspond to various numerical simulation approaches, and each corresponds to a different grid generation method, playing a crucial role in the process. The form and density of the grid have a significant impact on the results of numerical calculations [5].

2.3.3. Experiment conditions

(1) Setting of speed

In the daily driving process, because the vehicle speed is too low, the flow rate through the grille is low, according to Formula (1) the lift coefficient is small, resulting in small downforce, and it is impossible to clearly compare the downforce generated by the air through the grille under each gap, so we set the vehicle speed to 110KPH

$$Cl = \frac{Lift}{0.5 * \rho * V^2 * A} \tag{1}$$

Thereinto:

- Cl is the lift coefficient
- Lift is the amount of lift
- ρ is the density of the air
- V is the speed at which the car advances
- A is the reference area (e.g. wing area, grille surface area)

(2) Parameter setting

In order to simplify the simulation process and time, according to the characteristics of fluid flow, the flow state of Reynolds number distributed along the surface $Re < 5 \times 10\text{^}5$ position is laminar flow, and the flow field enters turbulent flow state at Reynolds number $Re > 5 \times 10\text{^}5$ [6].

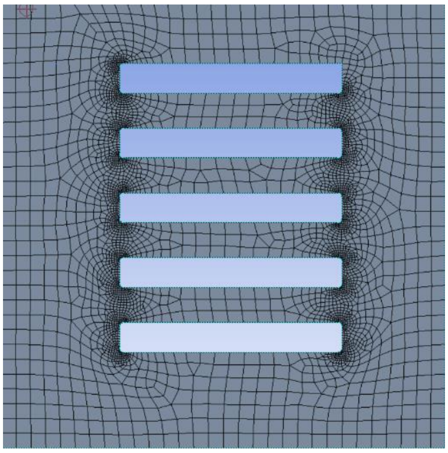

Figure 2. Computational domain meshing

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In an ideal case, we consider the air to be in a laminar flow state, and the laminar flow model has the characteristics of fluid layered flow, non-mixing [7], simple calculation, and fast calculation.

In the meshing, the grid accuracy is 20mm, and the entire computing domain has 4047 nodes and 3790 units, as shown in Figure 2.

3. Emulation Result and Analyzing

3.1. Fluid trace analysis

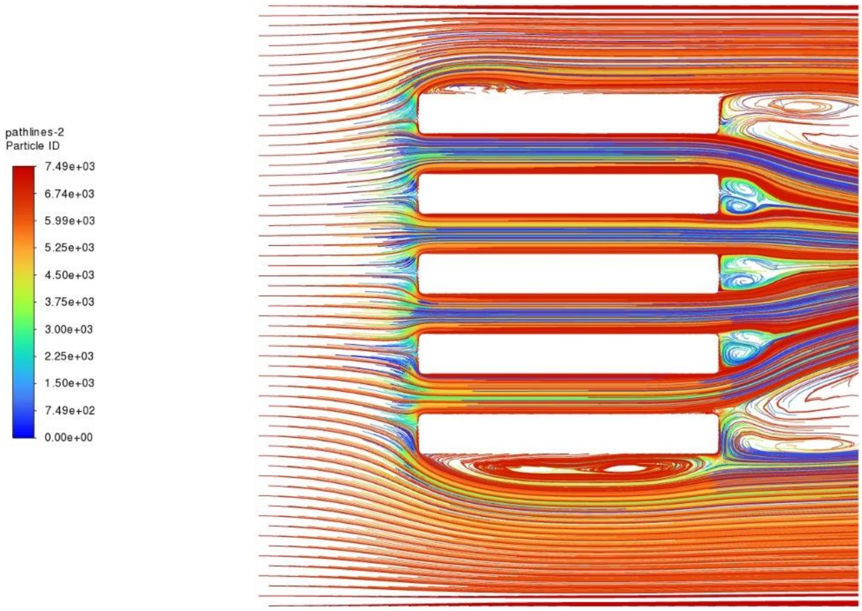

Figure 3. 12.5mm open trace

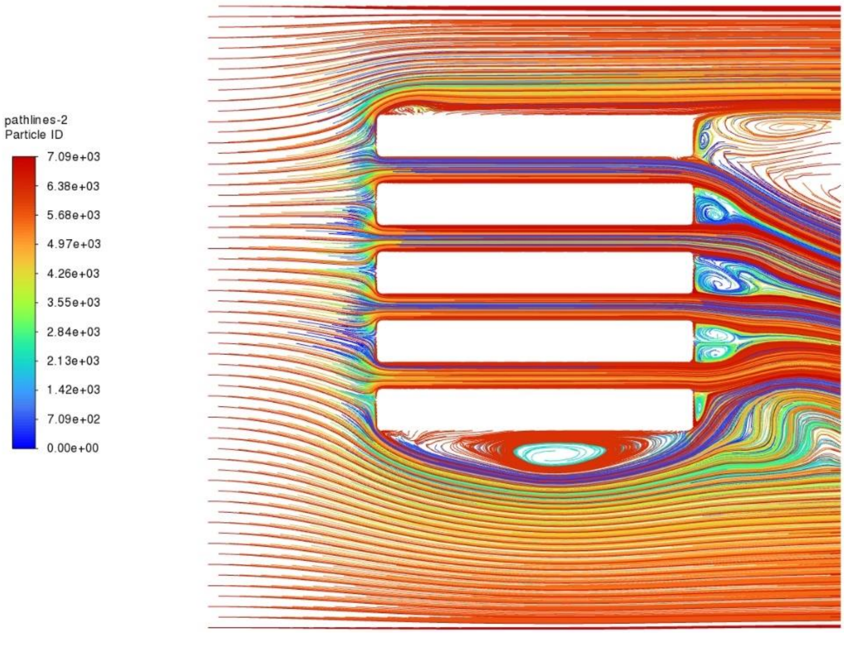

Figure 4. 25mm open trace

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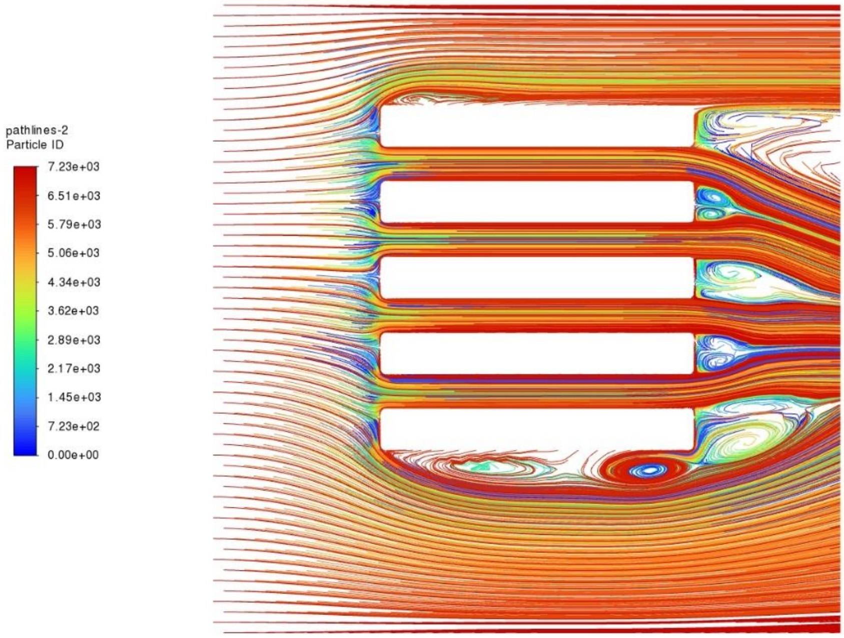

Figure 5. 32.5mm open trace

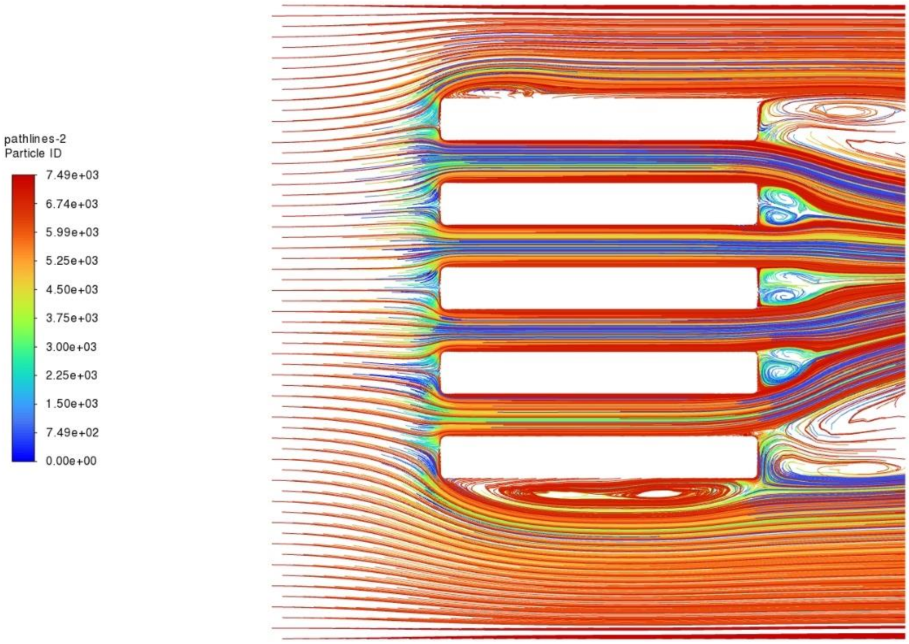

Figure 6. 40mm open trace

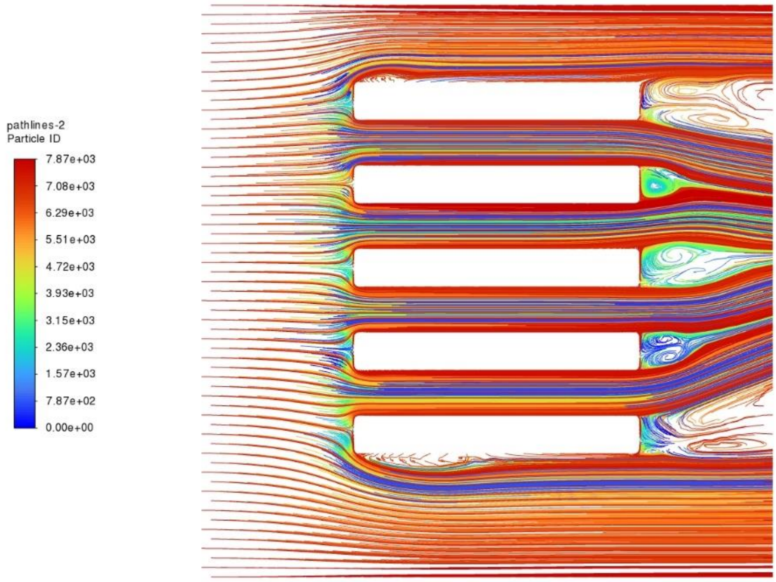

Figure 7. 47.5mm open trace

It can be seen from Figure 3-7 that the flow rate of the inlet fluid is basically the same, and when the grille is encountered, the flow velocity decreases significantly, but there is a large difference in the flow velocity in the gap of the air intake grille, and there is a vortex-like fluid at the outlet of the grille, which has little effect on the downforce and is not discussed. All fluids converge after outflow.

It is worth noting that the fluid flow rate in the intake grille is also different as the opening changes, and the internal fluid flow rate is fastest at the grille opening of 32.5mm, according to the Bernoulli equation [8]:

$$p_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

It can be known that the pressure is small where the flow rate is large, so it can be inferred that the downforce is the least at the place with an opening of 32.5mm.

3.2. Diagram of pressure and its seperation

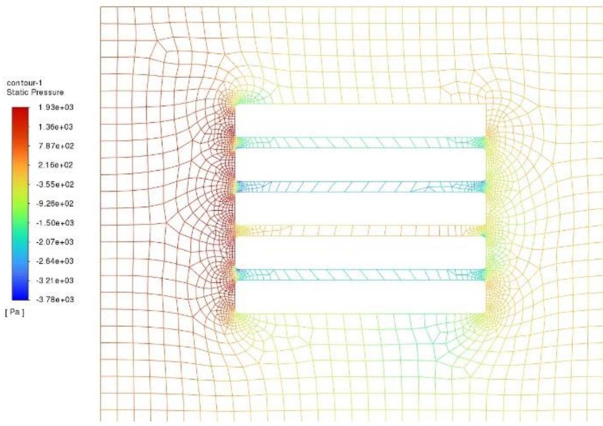

Figure 8. has an opening of Pressure cloud at 12.5mm

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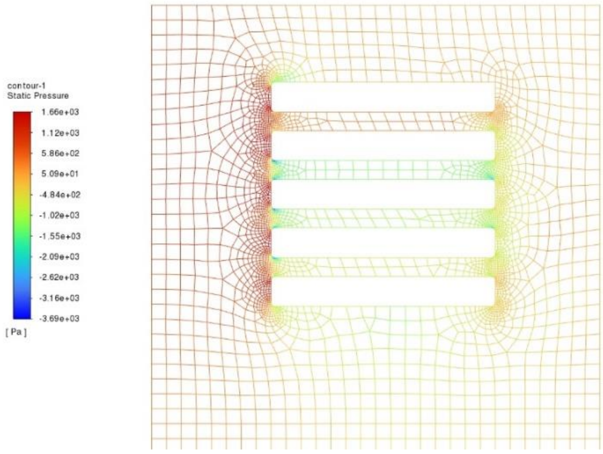

Figure 9. Pressure cloud diagram with an opening of 25mm

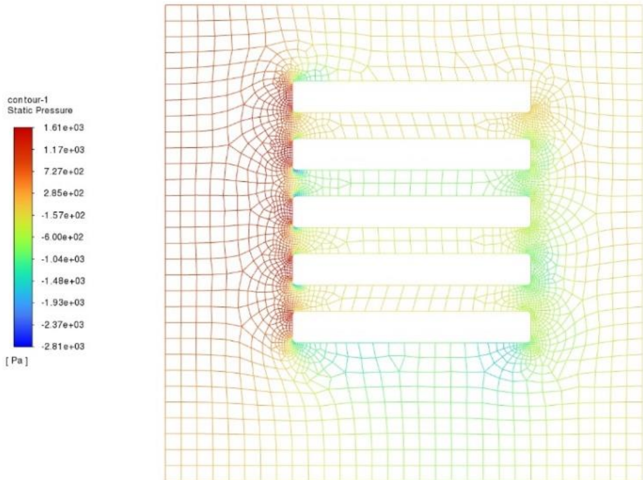

Figure 10. Pressure cloud diagram with an opening of 32.5mm

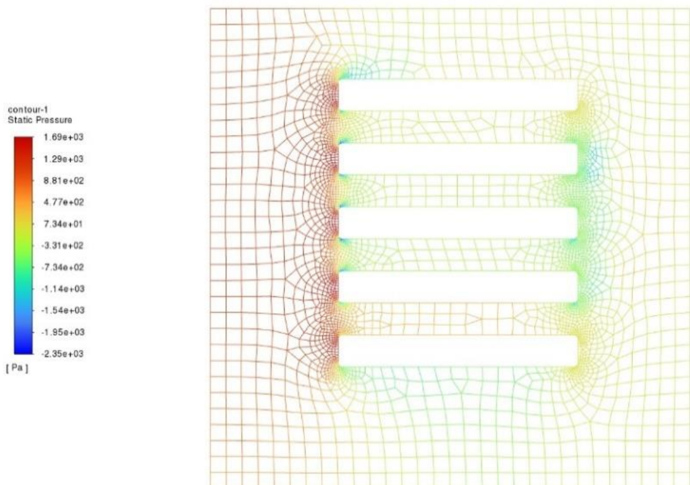

Figure 11. Pressure cloud diagram with an opening of 40mm

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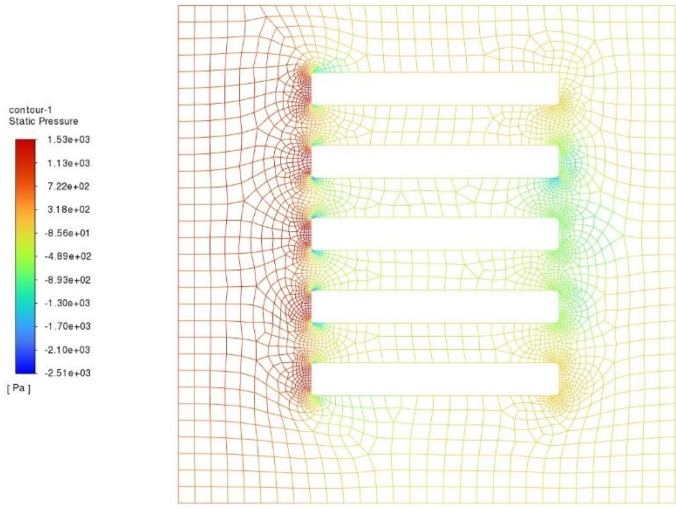

Figure 12. has an opening of Pressure cloud at 47.5mm

From Figure 8-12, it is clear that as the opening increases, the lower the downforce generated by the grille, according to the calculation in Ansys, the maximum downforce occurs at an opening of 12.5mm,$P = 3694.622Pa$, the downforce is, and the minimum downforce occurs at an opening of 40mm, and the downforce is at 40mm, $P = 2350.145Pa$. At 47.5mm, the downforce does not increase but falls due to fluid backflow, but because the opening of 47.5mm is too large for the car grille, it does not have value for further discussion.

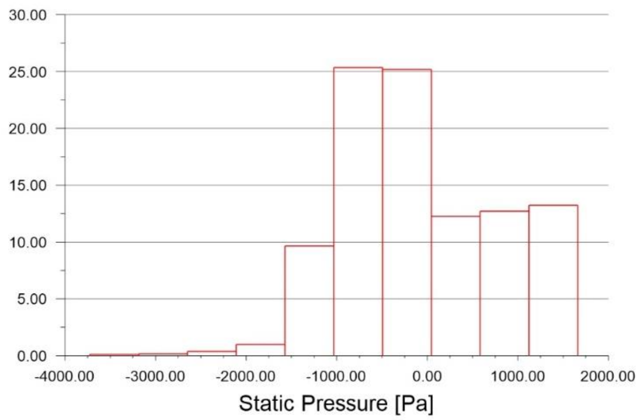

Figure 13. 12.5mm open pressure distribution

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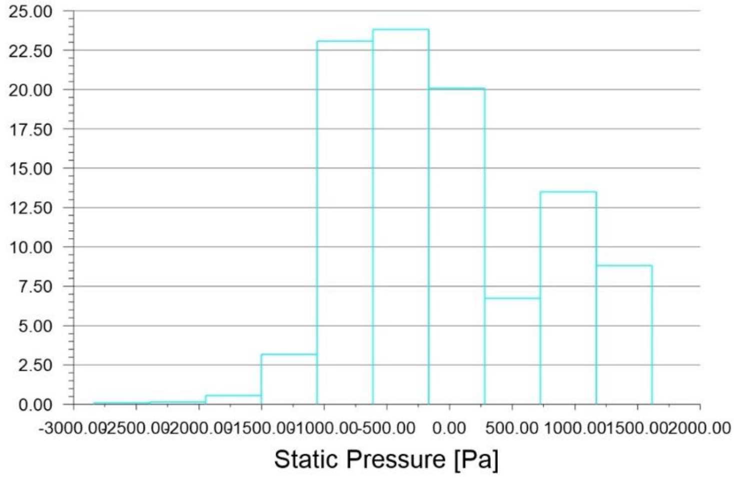

Figure 14. 25mm opening pressure distribution

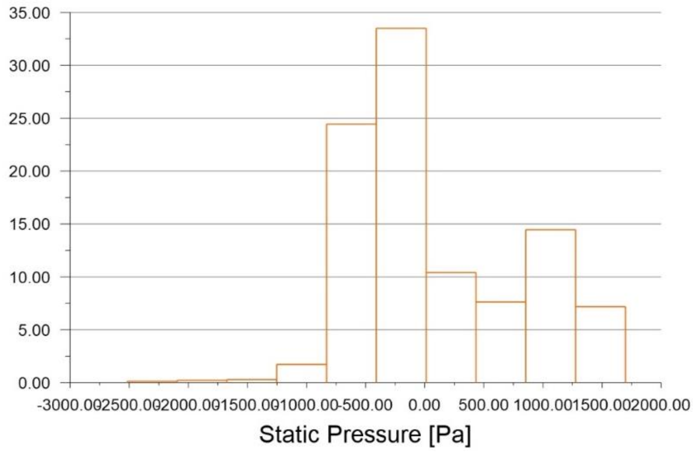

Figure 15. 32.5mm open pressure distribution

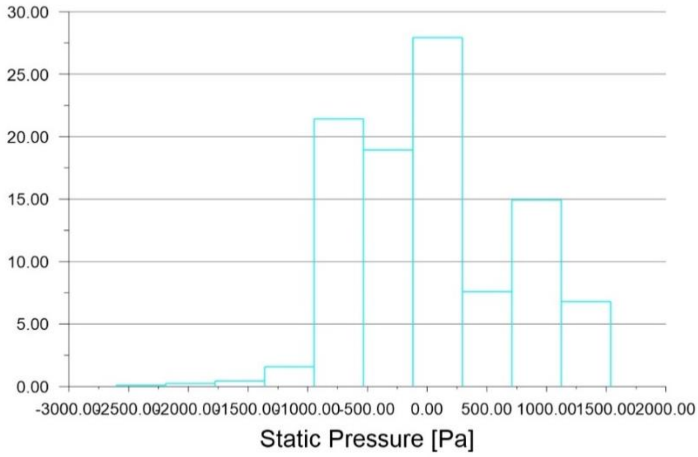

Figure 16. 40mm opening pressure distribution

From the pressure distribution diagram, we can see that when the opening is 12.5mm, the negative pressure distribution is the most, and as the opening increases, the overall peak of the image will move closer to 0, proving that in order to get more downforce, the air intake grille with a small opening should be selected

4. Conclusion

In the grille design described above, in order to obtain more downforce, the following conclusions can be drawn through simulation analysis:

In the case of ensuring that the airway is unobstructed and the air intake and outlet are not obstructed, we should choose a small opening air intake grille as much as possible

When selecting the air intake grille, the grille opening should not be too large to prevent debris from entering the engine

The air intake grille is opened too wide, which will cause the negative pressure to decrease, and all pressures tend to 0Pa

References

[1] Kohnke PC. ANSYS. In: Brebbia CA, editor. Finite Element Systems: A Handbook. Berlin, Heidelberg: Springer Berlin Heidelberg; 1982. p. 19-25.
[2] Joseph. Low-Speed Aerodynamics2001.
[3] Kim JM, Kim KM, Ha SJ, Kim MS. Grille design for passenger car to improve aerodynamic and cooling performance using CFD technique. International Journal of Automotive Technology. 2016;17(6):967-76.
[4] L. Aerodynamics of Road Vehicles: From Fluid Mechanics to Vehicle Engineering. Edited by W-H. Hucho. Butterworth & Company, (Publishers) Limited, London. 1987. 566 pp. Illustrated. £45.00. %J The Aeronautical Journal. 2016;91(906).
[5] Lindsay GA. Pressure Energy and Bernoulli's Principle. American Journal of Physics. 1952;20(2):86-8.
[6] Matsson JE. An Introduction to Ansys Fluent 2023: SDC Publications; 2023.
[7] Patil CA, Vali K, Azeez MR, Srinivasa Reddy N, Srinivasa Rao P. Characteristics simulation on opening of active grille shutters of automobile using computational fluid dynamics (CFD). AIP Conference Proceedings. 2022;2648(1).
[8] Li J., University Physics the Bernoulli equation for compressible fluids 2008; 27 (8): 5