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Improvement of the Airflow Alignment in an Automotive Brake Disc Through a Naca 2411-Il Profile Using Computational Fluid Dynamics (Cfd).

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Abstract

In the present study, we investigate the improvement of airflow alignment in brake discs through the application of NACA profiles. Efficient ventilation is crucial to avoid problems such as overheating and brake fading. Using Computational Fluid Dynamics (CFD) simulation with ANSYS Fluent, we compare the traditional geometry of a brake disc with a proposal that incorporates NACA profiles. Our results demonstrate a clear advantage in terms of airflow alignment with the proposed geometry, suggesting significant potential for improving brake performance. This study sheds light on a promising innovation in the automotive industry and its implications for road safety and vehicle efficiency. The results obtained in this study provide insight into the fluid dynamics in the brake disc, including differences in velocity distribution and a more uniform pressure distribution. The proposed geometry has the potential to offer improvements compared to the original geometry.

Keywords: Brake disc, CFD, NACA profile, ventilated disc, fluid flow.

INTRODUCTION

One of the fundamental systems in an automotive vehicle is its braking system, as its primary responsibility lies in ensuring the safety of the occupants, regardless of prevailing environmental conditions. In this study, a brake disc from a 2008 Nissan Versa Hatchback was used, characterized by its straight ventilation design incorporating 36 thermal dissipation fins. However, to optimize its performance, these fins were replaced with 25 NACA-type profiles. The vehicle in question is equipped with tires of dimensions 185/65/R15 and has a mass of 1251 kg. The disc's construction material is gray cast iron, with a machined surface and a fastening system consisting of four bolts. A drum brake system is used in the rear section. It is worth noting that both discs were replicated in a virtual environment using SolidWorks mechanical design software.

Within the framework of the analysis conducted by [1], regarding the thermodynamic study of an automotive brake disc with NACA 66-209 type ventilation pillars, the effectiveness of the braking system was confirmed in various climatic conditions, considering the employed NACA profile configuration. Conversely, [2] conducted a meticulous analysis of the heat exchange flow between the cooling channels of three brake discs. Under operational conditions of 80 km/h, optimal behavior in terms of temperature, velocity, and heat flow in the ventilation ducts was observed. Relevant research, such as that conducted by [3], involved a dynamic analysis of three ventilated disc brakes through numerical simulations using SolidWorks Simulation software. This study demonstrated that the third brake disc design proposal exhibited superior performance under various working conditions, including speed and displacement during the braking process in the cooling channels. Additionally, [4] explored the velocity field measurement in the suction and discharge of an automotive brake disc with drop-shaped ventilation pillars, using the particle image velocimetry technique. He proposed NACA 4418 and 66-219 profile geometries in this configuration, obtaining optimal results. In another line of research, [5] conducted a thermodynamic analysis of three ventilated disc brakes using finite element analysis (FEM) at a constant vehicle speed of 80 km/h. In this investigation, both heat dissipation velocity and heat extraction temperature were evaluated, taking into account the material properties used in the discs. On the other hand, [6] conducted an exhaustive review of Computational Fluid Dynamics (CFD) applications in the automotive industry and their influence on the design of automotive components. It was concluded that incorporating CFD in the initial design stages is imperative to minimize subsequent modifications and corrections. [7] anticipated the cooling factors of an automotive brake disc and analyzed their impact on the results of thermal numerical simulations. The obtained results revealed a substantial effect on temperature, emphasizing the importance of incorporating accurate heat transfer coefficients in simulations to obtain reliable results.

METHODOLOGY

En Figure 1, the specific brake disc chosen for this research is presented. To provide a more detailed understanding of this brake disc, Figure 2 displays its precise dimensions, carefully annotated in millimeters. These dimensions include the outer diameter, inner diameter, disc thickness, as well as the strategic placement of slots and ventilation holes. Each of these measurements is of critical importance in assessing fluid dynamics.

Figure 1. The disc belongs to a 2008 Nissan Versa hatchback. Source: Authors.

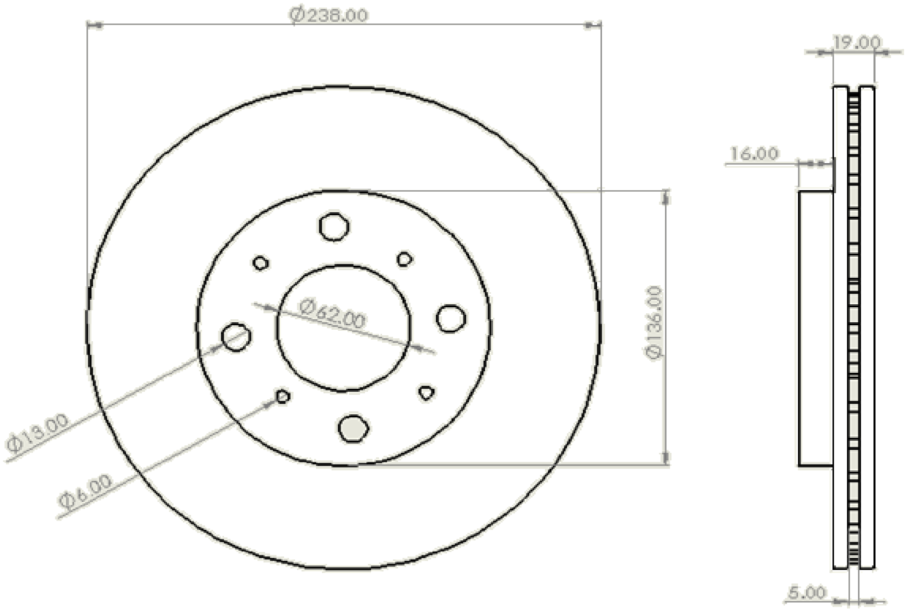


Figure 2. Brake disc dimensions, annotated in mm. Source: Authors.

The purpose of this study is to modify the original design of the brake disc, which incorporates cooling channels characterized by rectangular profiles. The central focus of the research is the evaluation of fluid dynamics in the system after replacing these profiles with an aerodynamic design based on the NACA profile. The geometric description of this new profile is presented below.

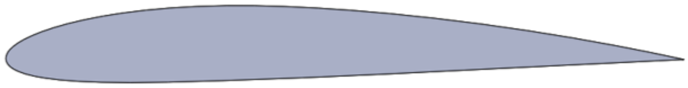


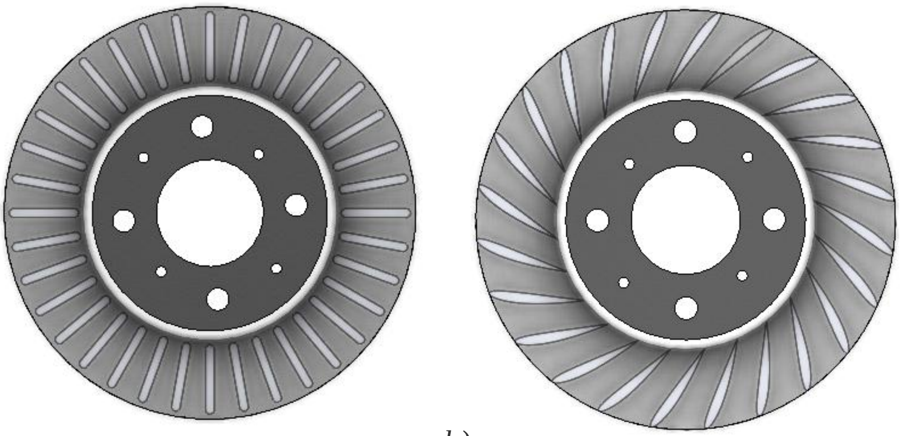
Figure 3. NACA 2411-il Profile. Source: Authors.

Table 1. Profile Characteristics.

NACA 2411 aerodynamic profile
Maximum thickness from 11% to 29.5% of the chord.
Maximum camber from 2.5% to 39.6% of the chord.

Source: http://airfoiltools.com/airfoil/details?airfoil=naca2411-il.

SolidWorks mechanical design software was used to model both the original brake disc and the alternative proposal. The detailed representation of both models is illustrated in Figure 4.



a) *b)*

Figure 4. Brake disc a) original model b) proposal. (Source: Authors).

For the simulation, ANSYS Fluent software was chosen, and the decision was made to use a mosaic mesh. This choice is based on its high flexibility, allowing it to adapt effectively to highly complex geometries. Additionally, this mesh provides the ability to generate a highly accurate discretization, capturing the local details present in the geometry under analysis meticulously. It is worth noting that, compared to other meshing approaches, the mosaic type requires a lower number of elements, resulting in a significant reduction in computational load.

In summary, the selection of a mosaic mesh is justified by its versatility, ability to provide accurate discretization, and efficiency in terms of computational resources. Figure 5 shows the visual representation of the mesh used in this study, offering an illustrative detail of its structure.

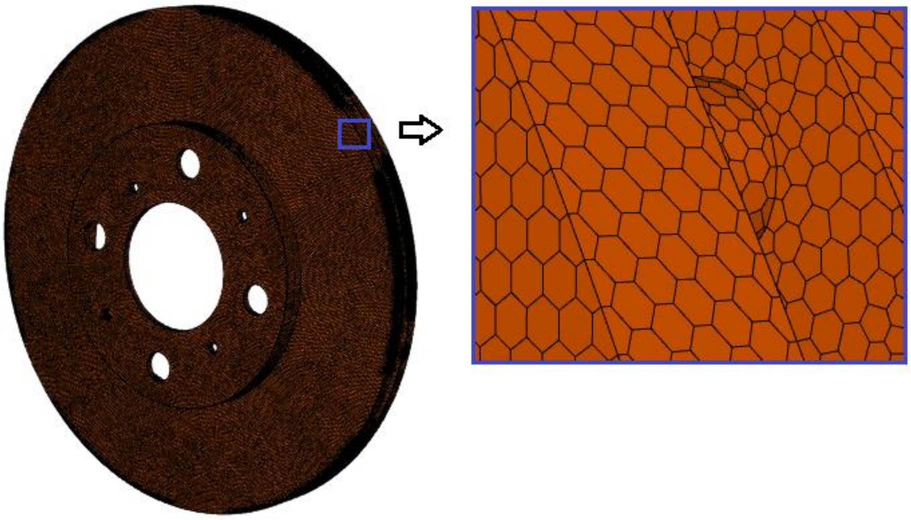


Figure 5. Meshing of the brake disc. (Source: Authors).

In our analysis, we conducted a mesh convergence study to validate the choice of the mesh used. This process is crucial in numerical simulation as it ensures that the selected mesh is most suitable for accurately representing the behavior of the brake disc. The convergence of results, confirmed as we refined the mesh, conclusively supports that we have chosen the most suitable mesh to achieve highly accurate and reliable results in our engineering analysis of the brake disc. Figure 6 illustrates the computational domain used in this study. In the context of simulating the brake disc, a wall boundary condition has been implemented to represent the disc's surface. Additionally, air inlet and outlet conditions have been incorporated to model and analyze the flow through the system.

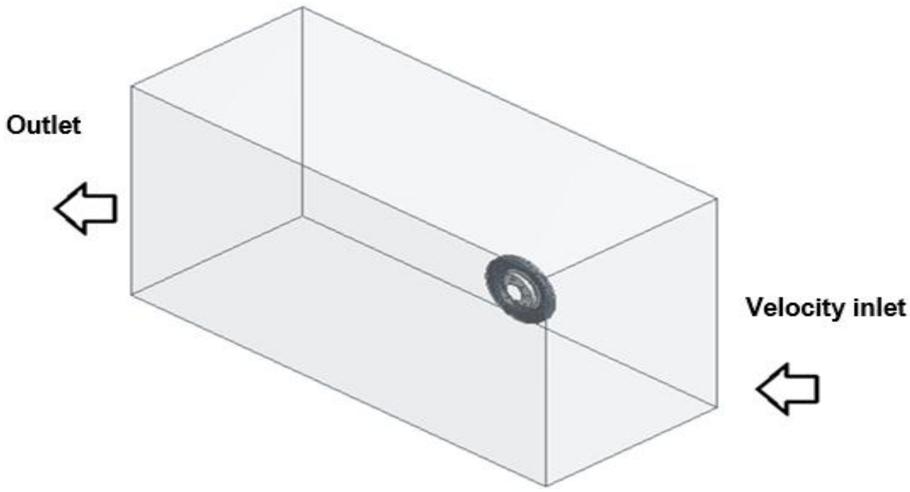


Figure 6. Computational domain. (Source: Authors).

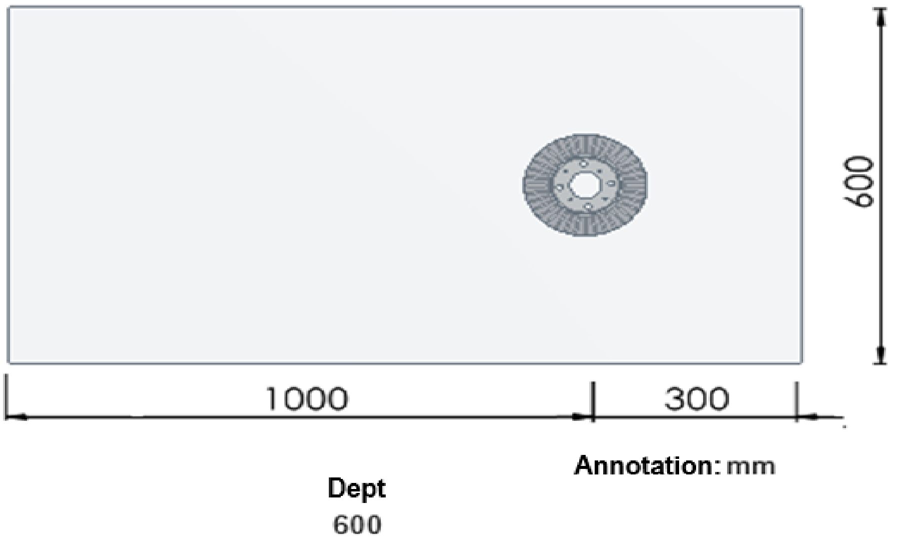


Figure 7. Domain dimensions. (Source: Authors).

Figure 7 depicts the dimensions used for the study. Three-dimensional (3D) simulations were chosen for their ability to capture critical three-dimensional phenomena and provide an accurate representation of the interaction between the brake disc geometry and the airflow. Since brake discs are 3D objects with non-uniform temperature and airflow distributions across their thickness and surface, 3D simulations allow for a precise assessment of heat transfer and aerodynamic resistance. In automotive and aerospace applications, where safety and performance are paramount, these simulations offer results closer to reality, supporting informed decision-making to enhance efficiency and safety in vehicles.

The choice of the k-epsilon turbulence model for this study is based on an extensive review of scientific literature, consistently highlighting its effectiveness in predicting turbulent flows in various contexts. Numerous authors have reported that the k-epsilon model provides more accurate and representative results compared to other turbulence models in situations similar to those addressed in this study. The inlet velocity conditions in this study have been determined based on typical driving speeds in different environments. To represent driving in urban settings, an average speed of 60 km/h has been considered. Additionally, to simulate driving on highways, two additional scenarios have been evaluated, namely speeds of 90 km/h and 120 km/h. These speed selections are based on common driving patterns and reflect usage conditions encountered on highways and in urban areas.

Considering that:

$$1\ \frac{\mathrm{km}}{\mathrm{hr}} = \frac{1000\mathrm{m}}{3600\ \mathrm{s}} = 0.27778\ \frac{\mathrm{m}}{\mathrm{s}} \qquad (1)$$

Based on equation 1, it is possible to determine the inlet velocity boundary condition for each of the proposed speeds. In the case of tire rolling, a 80% adherence to the road surface is assumed, allowing the slip to be determined as:

$$x = \frac{(v_i - v_p)}{v_p} * 100 \qquad (2)$$

Where:

$$v_i = \text{Vehicle velocity.}$$

$$v_p = \text{Peripheral velocity.}$$

Once the peripheral speed is obtained, the angular velocity of the brake disc will be determined, taking into account its radius.

$$\omega = \frac{v_p}{r} \qquad (3)$$

Where:

$$\omega = \text{Angular velocity.} \frac{\text{Rad}}{\text{Seg}}$$

$$v_p = \text{Linear velocity.} \frac{\text{m}}{\text{s}}$$

$$r = \text{Brake disc radius. m}$$

Ultimately, the rotation speed of the disc was established, expressed in revolutions per minute (RPM), using Equation 4:

$$\text{RPM} = \frac{\omega}{2\pi} \qquad (4)$$

Table 2. Speeds.

Velocity			
Vehicle velocity (Km/h)	60	90	120
Air velocity inlet (m/s)	16.66	25	33.33
"Peripheral velocity of the disc." (m/s)	9.25	13.88	18.51
Rotational velocity of the disc (ω rad/seg)	69.97	104.96	139.95
Disc rotation velocity (RPM)	667.61	1004.92	1337.23

Source: Authors.

Table 2 presents the results derived from equations 1, 2, 3, and 4. These data will be used to establish boundary conditions for both the inlet velocity and the rotational speed of the brake disc. In the context of this research, the parameters used as references are the air inlet velocity and the rotational speed of the disc, measured in revolutions per minute (RPM).

RESULTS

A cutting plane was chosen to intersect the computational domain and pass through the disc, allowing for the visualization of its internal region.

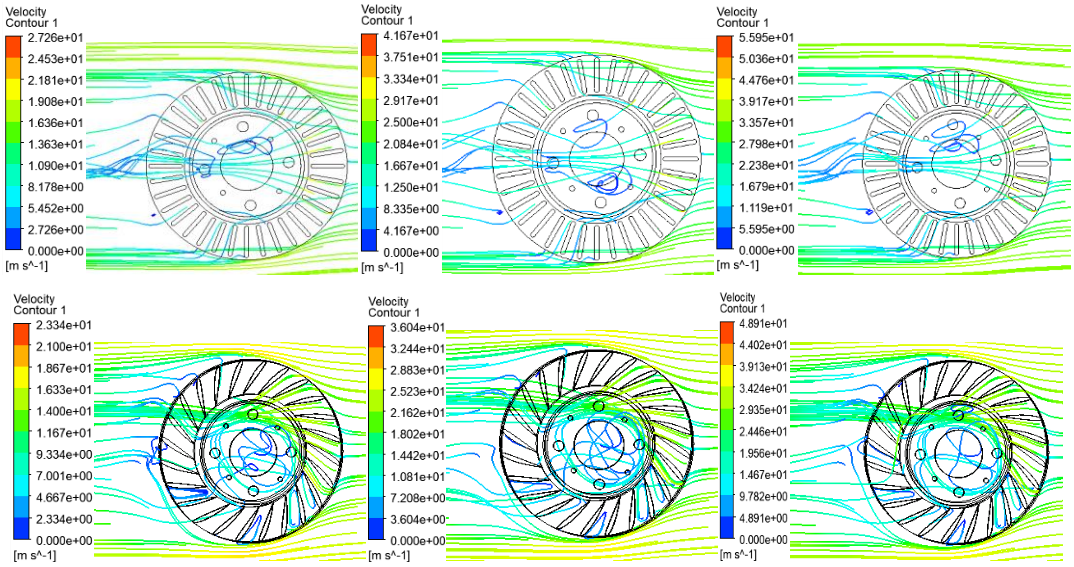


Figure 8. Streamlines of the original and modified disc, for speeds of 60, 90, and 120 km/h. Source: Authors.

Figure 8 presents the streamlines generated for both the original and the proposed configurations. It can be observed that in the proposed design, the NACA profile facilitates the flow entering into the circulation channels, whereas in the original geometry, although it passes through the disc, it does not distribute adequately within that geometry.

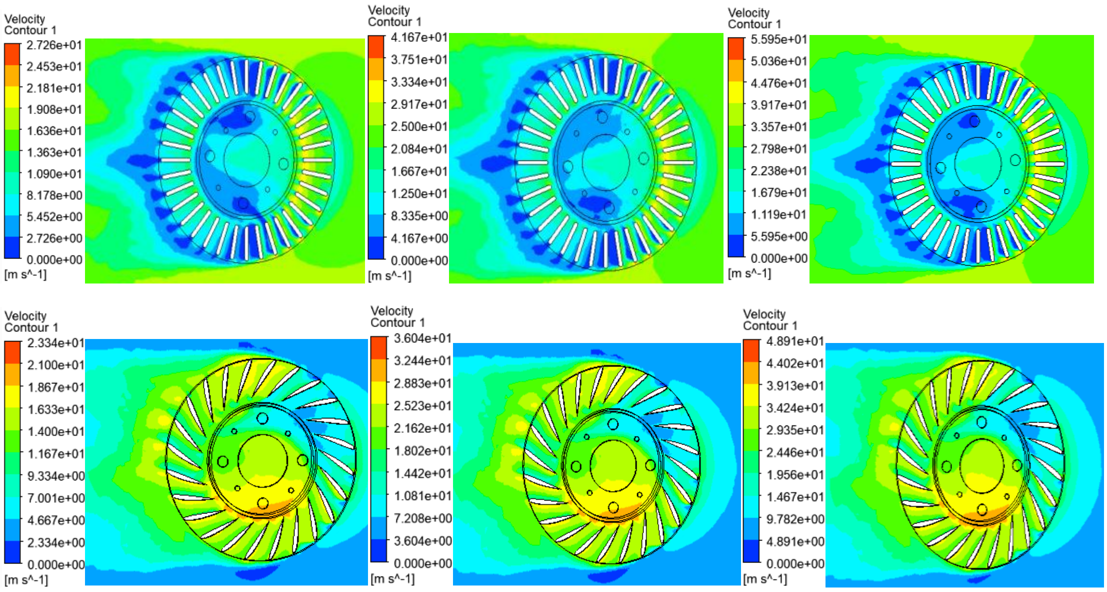


Figure 9. Velocity contours of the original and modified disc, for speeds of 60, 90, and 120 km/h. Source: Authors.

Figure 9 illustrates the behavior already evident in the streamlines. The velocity contours reveal a notable difference in speeds between the original geometry (downstream) and the proposed one. In the original geometry, a significantly lower speed is recorded compared to the proposal, where a more uniform velocity distribution is observed, albeit with a lower magnitude.

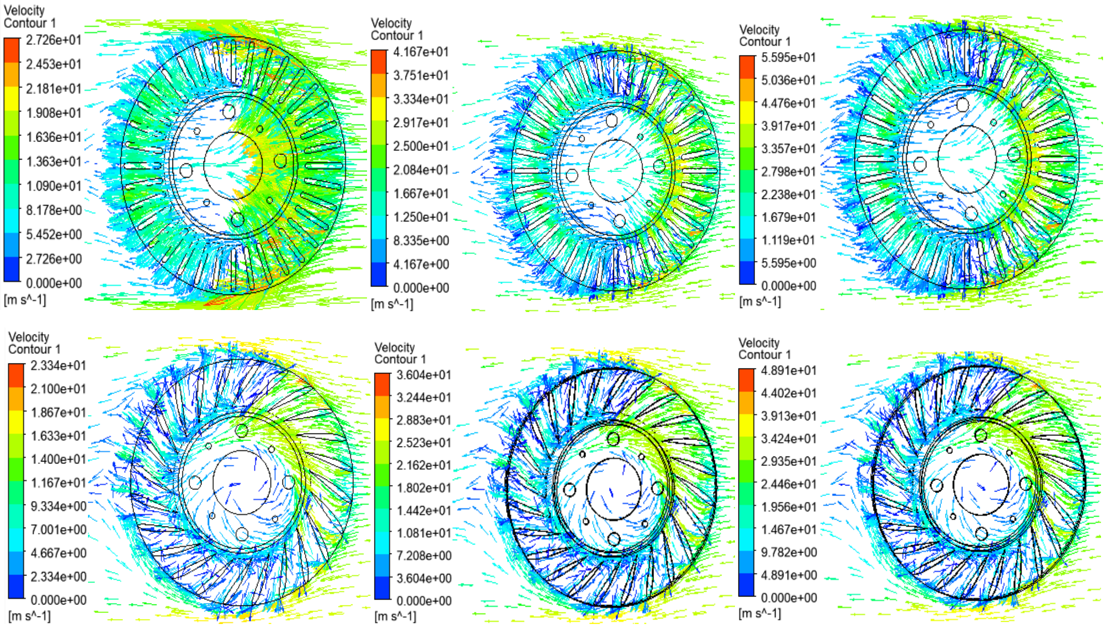


Figure 10. Velocity vectors of the original and modified disc, for speeds of 60, 90, and 120 km/h. Source: Authors.

The velocity vectors represented in Figure 10 show that, in the original geometry, these vectors follow a linear trajectory, while in the proposed design, they tend to adopt a rotational direction due to the influence of the NACA profile. This configuration facilitates the flow circulation along the cooling channel. It is important to note that, although a decrease in velocity magnitude is observed compared to the original geometry, this could be attributed to the circular nature of the path that the flow takes in the proposed design.

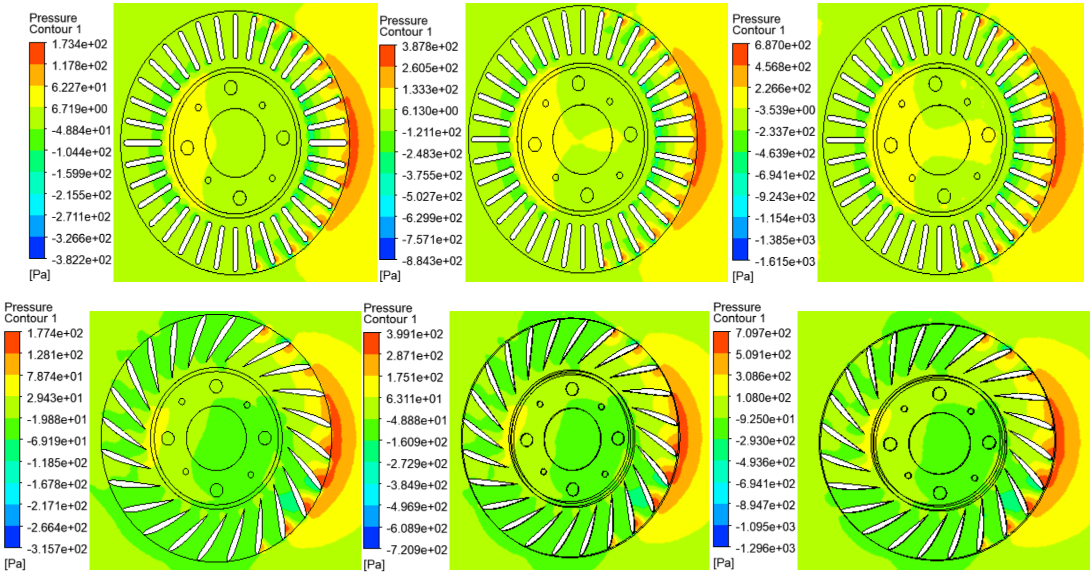


Figure 11. Pressure contours of the original and modified disc, for speeds of 60, 90, and 120 km/h. Source: Authors.

The pressure contours depicted in Figure 11 reflect that the proposed configuration exhibits a pressure distribution in contrast to the original geometry. This observation indicates a potential improvement in heat dissipation capability. Additionally, a uniform pressure distribution may correlate with increased stability during the braking process, a decrease in the risk of unwanted vibrations or noise, and a reduction in fluid flow resistance.

CONCLUSIONS

Following the research and analysis process, the results obtained in this study provide insights into the fluid dynamics of the brake disc. Below, we will present the conclusions derived from the findings.

Differences in velocity distribution: Clear differences in velocity distribution are observed between the original and proposed geometries. The proposed geometry exhibits a more uniform velocity distribution across the area of interest compared to the original geometry, which shows less uniform velocity. This improvement in velocity uniformity in the proposed geometry suggests potential advantages in terms of flow and heat dissipation.

Effect of the NACA profile: In the proposed geometry, the influence of the NACA profile is reflected in the rotational direction of velocity vectors. This feature can be beneficial as it facilitates flow circulation along the cooling channel. The rotation of velocity vectors is an adaptation that implies a more efficient design for fluid circulation.

More uniform pressure distribution: Pressure contours in the proposed geometry show a more uniform distribution compared to the original geometry. This uniformity in pressure distribution is a positive indication as it may enhance heat dissipation capability and stability during braking. Additionally, it reduces the risk of unwanted vibrations and fluid flow resistance.

The results indicate that the proposed geometry has the potential to offer improvements in terms of velocity distribution, flow circulation, and pressure distribution compared to the original geometry. These improvements suggest a design that could be more efficient in heat dissipation and brake system performance, potentially positively impacting vehicle safety and efficiency.

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