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Design and Optimization of Wheels for Better Aerodynamics and Cooling of Brakes

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Abstract: ***In the world of automotive, lots of research has been done yet on overall vehicle. Researchers improved every single part of vehicle but wheel is one of the part that hasn't changed much in automotive history. In case researchers got their desired results, they stopped working on wheel and most of the research has been done on grip of the tire. That's why there is no innovative research done on wheels. And it is one the biggest part who contribute in vehicles performance and other aspects like comfort and ride quality. Most of the manufacturers never consider and work on aerodynamic part of wheel. So, Different aerodynamics concept vehicles have been studied in the report. The flow around wheels are manage and smoothen in proposed design also it is designed in such a way that air flowing around wheel can easily take inside through Rim design and throw on brake pads as well as on wheel hub for consistently cooling them. They key for success is to manage the flow and keep the wheel functional and attractive. In this paper new wheel is designed and compared with convectional wheel designs.***
Keywords: Wheel Aerodynamics, Design and Optimization of Wheel, Cooling of Brakes, 3D Wheel design, Aerodynamics of Wheel.

I. AIM OF THE PROJECT

Aim of project is to design and optimization of wheels for better aerodynamics and cooling of brakes using air. So this will eventually work of vehicle performance and efficiency.

II. OBJECTIVE OF PROJECT

The objective of the project which is needs to seek in the further process is as per the following:

1) Creating Design for wheel to reduce drag of vehicle during ride.
2) Improvement in vehicle stability and control on top speed.
3) Creating design of wheel which can Intake air from wheels and send it to the brake pads for cooling them.
4) Creating 3D model for Wheel to test CFD Analysis.
5) To analyze the design which is been created using the CAD software which will ANSYS in the FEA software to analyzing the design which is been created.
6) To select material which is sustain and sustainable for the wheel.
7) Reduce vibration of car and sound during high speed.
8) Testing wheel in ANSYS as per requirement to improve design according to results and choose design which has less drag.
9) Retest whole car with tire again in CFD analysis to get all data related to aerodynamics and make sure which is not going to affect other aspect of aerodynamics of car.

A. *Existing Problems*

1) Bad Aerodynamics of wheel can create more vibrations due to more drag
2) It makes car unstable on high speed
3) Brake pad heating issue occur because of wheel design which stop air flowing around brake pads.

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III. INTRODUCTION

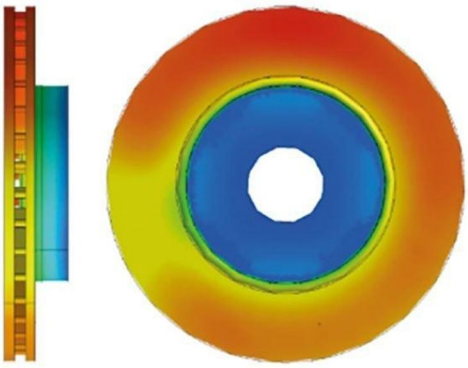
In today's world, there are lots of companies working on vehicle aerodynamics to improvise their performance and make the vehicle more stable at high speed using less drag design of the vehicle.

The aim of our project is to design and optimization of wheels for better aerodynamics and cooling of brakes

[1]

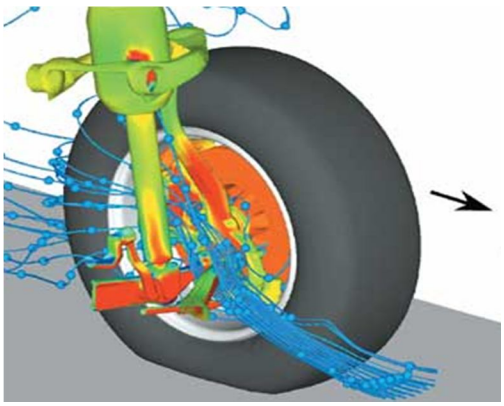
BMW Motorsport wheel concept

Wheels may look like a simple component of a vehicle but it is very important when we talk about vehicle performance it will affect vehicle overall performance and even it can have a huge impact on a car's overall aerodynamic performance, In the F1 race vehicle developers majorly focus on wheel design and aerodynamics.


[1]

Thermal analysis in Disc Brakes

Which can help them to boost their car performance in the race. Developers have developed wheel design in such a way that air flow around the wheel has to be in perfect flow which will reduce drag and make disc brakes cool. *The brake cooling ducts affect airflow through the wheels.*



The airflow around the frontal area of car also plays a key role.

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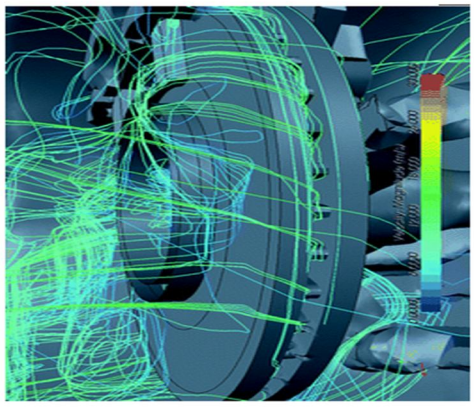
2006-2007 In this season developers developed in Car great lengths to optimize the aerodynamic of this area of a vehicle. *Manufacturers like Ferrari, have tested disc-shaped devices that covered the outside of the wheel, which was independent of wheel rotation, and just sculpted the wheel.*

However, as Pascal Vasselon, of the then Toyota F1 team, explained in 2007, making these devices work effectively was not an easy job. "The effect of the front wheel blanking is not something you can capture very simply," "We now have some experience with it, and it can have a different effect according to the rest of the flow structure over the rest of the car. It's a powerful item, and you can use it in different ways. It's not only a drag reduction item; it really can change a lot of things in terms of front-wheel wake – you are of course playing with the font wheel wake. It requires careful tuning according to the rest of the car." Said him.

Airflow Around Normal Wheel Design

Over the next four years, these systems developed into some extreme experiments, some of which were stretched to the back of the tire. Despite sweeping regulatory amendments enacted in 2009 to 'clean up' automotive aerodynamics to reduce the impact of a vehicle's wake on the cars behind it, wheel covers have survived. However, in 2010, the FIA felt they had to go and amend the rules to make them illegal.



Streamlines around Break pads and wheel hub

Ferrari was able to agree to the new regulations by integrating the air conditioning system into the cockpit. This was a ruse since the rims were to be worn during the season, making it impossible for their rivals to copy the pattern. Needless to say, the FIA thought these went against the spirit of the regulations, and regulations strictly regulating the shape of the wheels were implemented for 2011. However, this has not stopped teams from pushing their growth, and many have made me new.

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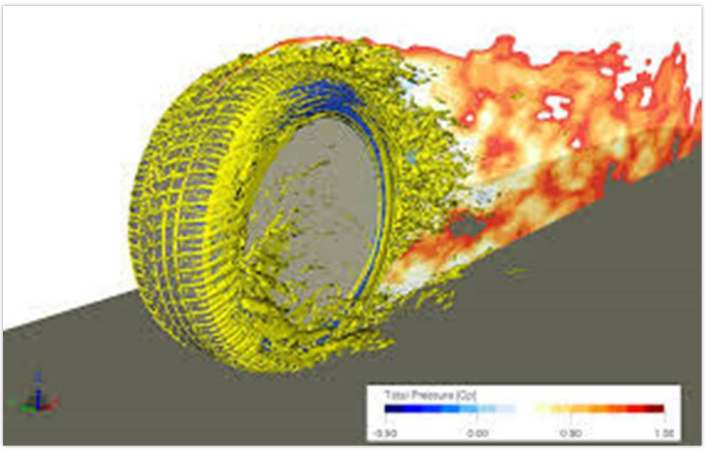
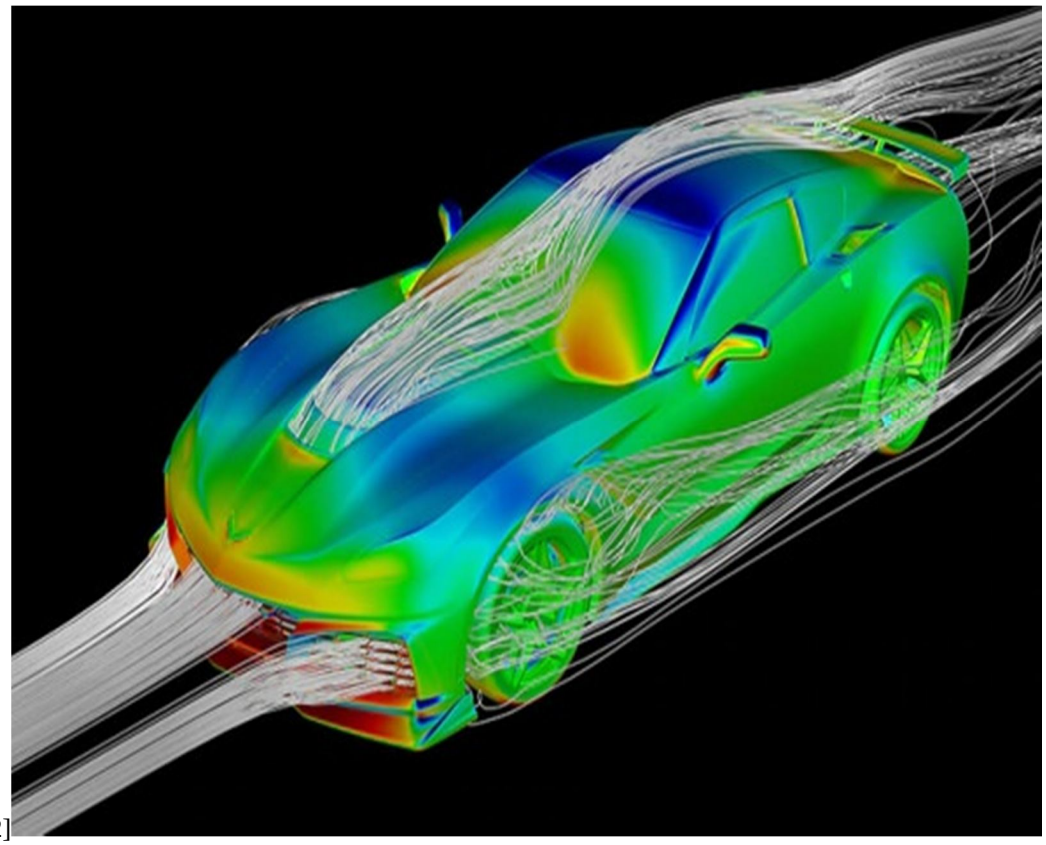
In 2012 Williams created a scoopless brake duct for FW34 in an attempt to better monitor the airflow in between the wheel, the brakes, and body frame.

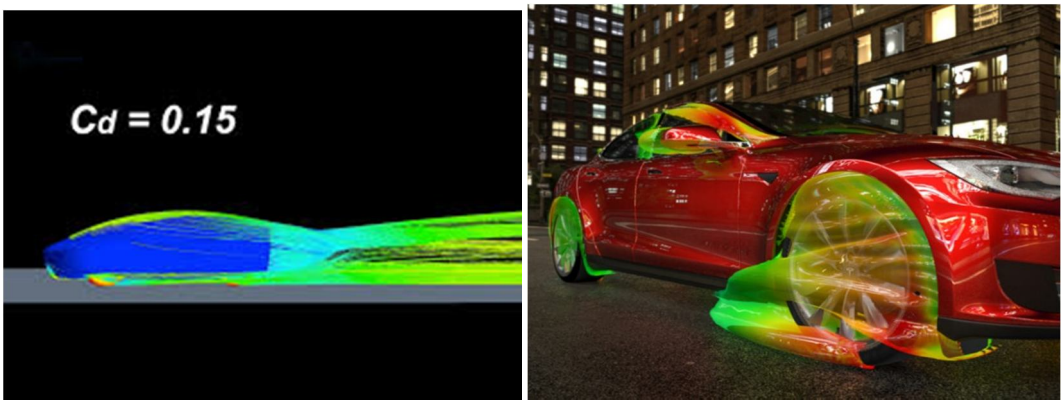


By using a hollow axel that terminates before the wheel nut and is thus within regulations, the design achieved this. He designed this by using a hollow axel that ends before the wheel nut and hence it is within the regulations.
The air flows through the axle and reaches out over the wheel rim from the brake vent.
As well as further advances to channel air out of the front axle, several other teams adopted similar solutions in 2013. In 2012, Red Bull attempted a similar approach with the RB8, but the design vented outboard air from the wheel nut and was therefore considered illegal.
Despite the design changes of the overall body of the car, such small aspects matter when talking about aerodynamics. These aspects highlight the degree of optimization of design achieved by cars.

 # What is aerodynamics?



[2]

[2] 

Basic Aerodynamics of Vehicle

Solids and liquids are much denser than gases. The best suitable example is a swimmer swimming in a pool. If the swimmer tries to walk in the swimming pool that will create a lot of efforts to be given by the swimmer. Otherwise, while swimming the efforts are very less comparatively as the swimmer transforms his body into a long thin form which effectively creates less resistance.
Similarly, while moving through air a long and thin vehicle body or a body having specific geometric shape will effectively gain speed as it will cut the air while other type will show more impact of air on the bodies. This study of dynamics of car moving in air as a medium is called as aerodynamics.

IV. LITERATURE REVIEW OF EXISTING TECHNOLOGIES

There is tremendous technology based on vehicle aerodynamics. But very few research papers I found were based on wheel aerodynamics.

A. Leśniewicz, Kulak, Karczewski

In this paper, researchers told that Manufacturers are focusing on the aerodynamics of cars in order to minimize their drag because of increasing prices of fuel. To reduce the drag R&D teams of the manufacturer are majorly working on including tires and rims of vehicles. Precise study of an isolated wheel should be conducted in advance in order to better demonstrate the effect of rotating wheel aerodynamics on the vehicle body. For performing software-based analysis we have to focus on Moving wall, boundary conditions and multiple reference frames should perform to get the perfect simulation results. Results of the investigation illustrate dependency between the type of simulation and coefficients (drag and lift). MRF approach proved to be a better solution giving results closer to the experiment.[1]

B. Hobeika

In this paper researcher share some information which is based on how automotive industry is focusing on Computer simulations instead of testing physically which was so hectic, time consuming and costly. Even though physical test will give you most accurate results but now computer software's also give you most precise results and they share some design tips about How to improve aerodynamics of your vehicle. So this paper would be useful to design wheel for project. [2]

C. Wäschle, Alexander

Investigations are discussed on the aerodynamic effect of rotating wheels on both the simplified vehicle model and the series production car. CFD simulations are used for this research in combination with wind tunnel measurements such as LDV and aerodynamic forces. Several geometries of the wheel rim are analyzed. [3]

D. Ilea, Iozsa

This paper focused on CFD analysis of vehicle body shape around the wheel in order to minimize Drag coefficient of vehicle, aerodynamic of the wheel is one of the important aspects of the vehicle which was neglected for several decades. Aerodynamically, and not just for visual reasons, careful design of the wheel area can lead to a significant reduction in drag and improvements in the vehicle drag coefficient. Now in the digital world software are there to perform CFD analysis so all automobile now diverting towards software-based analysis this process is giving results accurate so all body parts are now tested separately that's why companies are shifting their focus in order to reduce the drag of wheel. [4]

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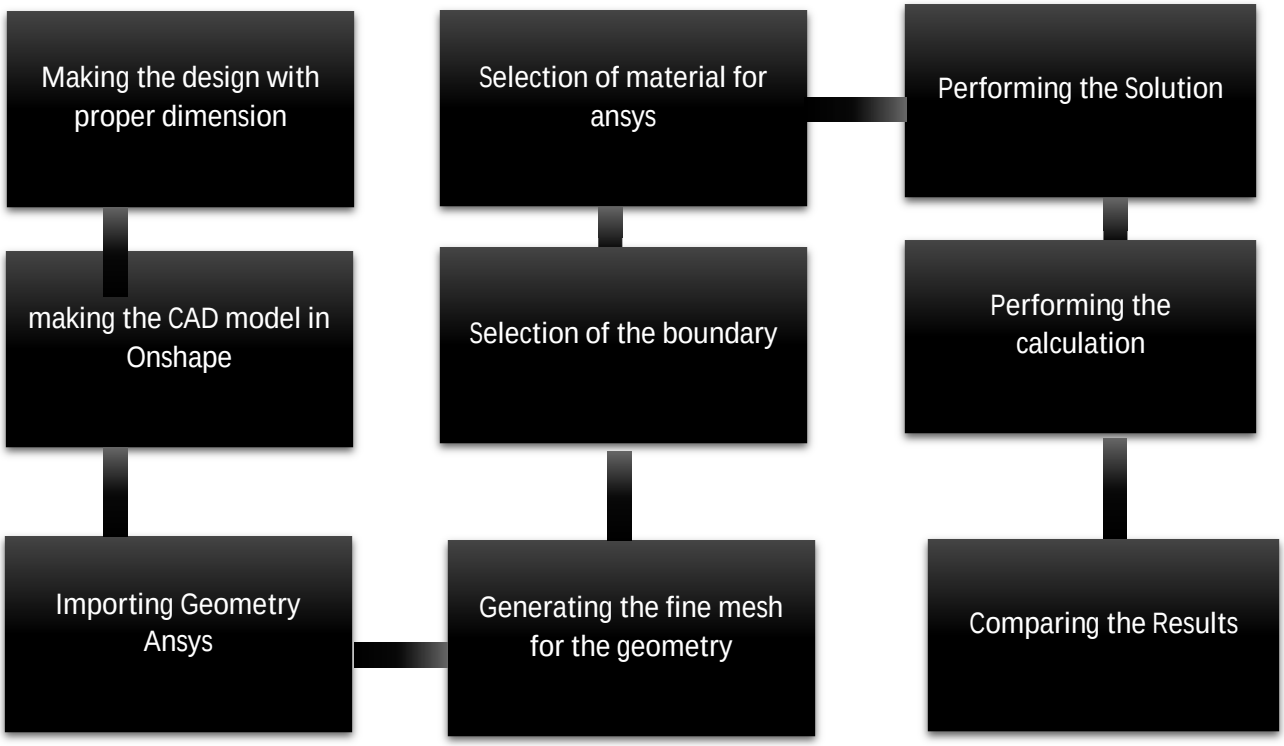
V. METHODOLOGY PROCESS



VI. METHODOLOGY

The first task was to select a suitable topic of research that not only was in my field of interest but also was something completely new. I was always fond of sports and supercars. Their stance and especially the aerodynamic devices like spoilers, diffusers, wide-body kits attracted me a lot. As a result, I was very sure that I had to do some research on a vehicle aerodynamic device. With that lead, I started basic research by reading about different aerodynamic devices and their technologies which were the latest and are used in today's automobile industry. By doing so I have noticed that research had been done to develop Wheel aerodynamics. On the contrary, other mechanical and electrical parts of vehicles are more developed like Active Aerodynamics. Some major problems occur like over-heating of disc brakes, losing the stability of vehicle also it generates some amount of sound and vibration on chassis and Its directly exert influence on vehicle Overall performance and fuel economy as well. After collecting all data and history of the wheel I had decided to design a wheel that is aerodynamically and Aesthetically better than existing designs. It can also reduce the temperature of Disc brakes and make the vehicle more stable.

A. Creating Geometries

A CAD designing software "Onshape" was used to make the design of the wheels. 3D modeling not only assists planners and end-users in **visualizing** space needs but also increases drawing performance and precision. When drawing in 2D, the artist is unable to see what they would not be able to see in 3D.

Visualization is a term that refers to the process of It goes without saying that a 3D model would aid you in visualizing a concept much better than a 2D design, due to the increased realism it provides. The ability to create a realistic rendering and save your time also enhance product proposal and it will give you accuracy while simulation.

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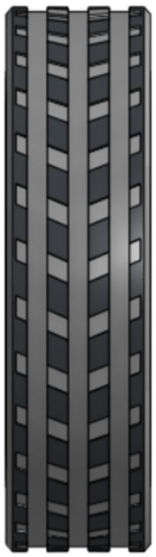
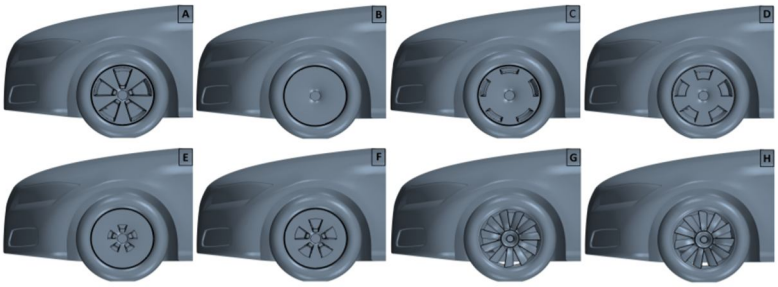
B. About Existing Design of Wheels And Problems

Normal wheel design for comparison

	
Front View	Rear View
	
Side View	Isometric View

Most of the Alloy wheels that I know of are designed Aesthetically. You'll find them having no connection with the Aerodynamics whatsoever. The body of the Car does 80% of the Aerodynamics on itself leaving the rest to the rear Spoiler and the car's hydraulic mechanisms. But, in certain cases, the Alloys give you Stability. Also, they are designed in such a way so as to provide the Airflow to the Brake calipers, when they get heated up. otherwise, it's pretty much Show. Very few cars, especially the Hypercars that have speeds in excess of 240 mph, have specially designed aerodynamic rims. Such as the Bugatti Supersport. everything about that car is well thought out to work with the conditions.



Existing Rim Designs

C. Aggressively Styled Wheel Designs

Most of the wheel manufacturers nowadays are working on the esthetics of the wheel so it looks more attractive to the consumer. But it's not aerodynamically tested or designed instead working on them. Those are one of the most important aspects while designing a wheel.

[3]

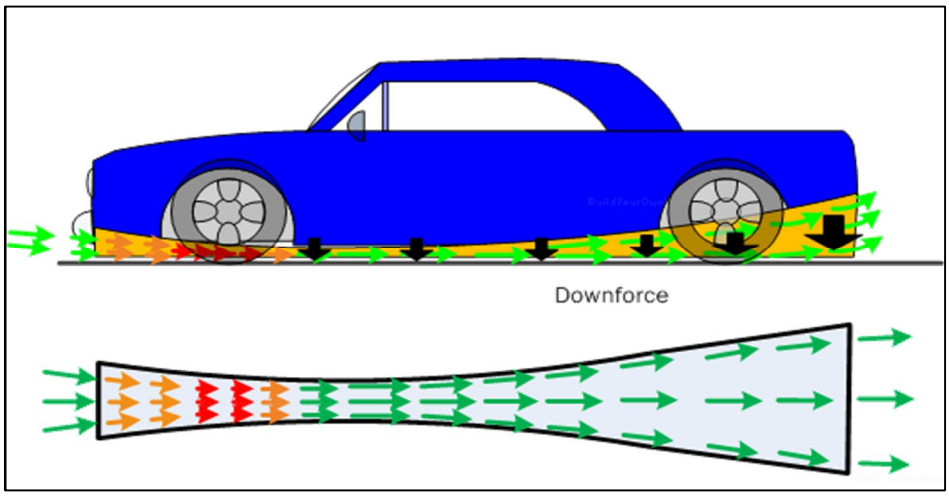
D. Fake Aerodynamics

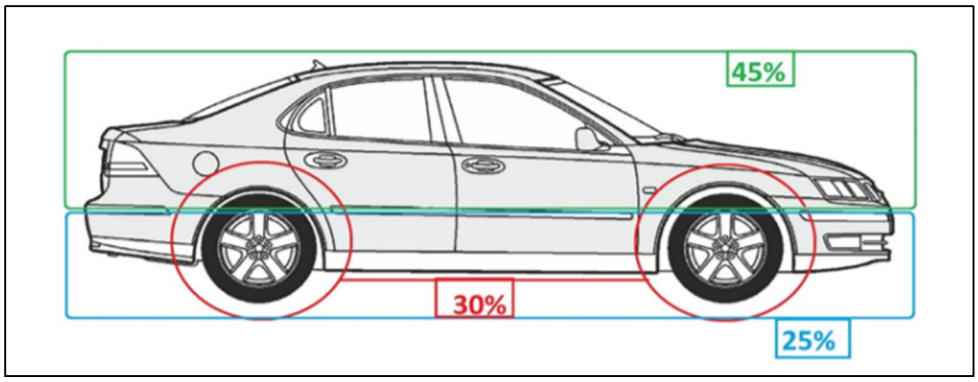
Side reflectors are commonly used to decrease the high-pressure region on the side of the car from the side of the road. Where an air splitter is used, low pressure is applied to the air below the car and the higher pressure on the outside and at the side of the vehicle is caused by the decreasing ground and downstream impact.

The efficiency of the skirts mostly depends on the level of proximity to the floor of the low edge. That edge should be less than 2 cm from the ground, otherwise, the efficiency of the skirts will decline quickly as the space increases.

[4]

In most cases, Side Skirts are made fake to maintain ergonomics and esthetics. Some of the manufacturers are making open skirts to flow air around the wheel hub and underbody. But those are not aerodynamically tested that's why it created turbulence after passing through Air skirts and it was affected vehicle stability and body vibrations at High speed.

[5] 



Relative contributions of vehicle sections to the overall drag coefficients for passenger vehicles

Another major problem we facing is alloy wheels broke when they face sudden impacts like potholes at high speed. The sudden impact can easily break down Alloys. That's why I have distributed pressure equally in the proposed design so while impact pressure with distributing all over the wheel and save alloy from breaking down.

[6] 

YouTube videos for reference: https://www.youtube.com/watch?v=t9mQfhCH6LI

Most Manufacturers are never working on the wheel's design especially on its aerodynamics. That's why sometimes it led to vibration in the chassis also creates sound at high speed or problems like Disc brake heating. They are only working on the aesthetics of the wheel.

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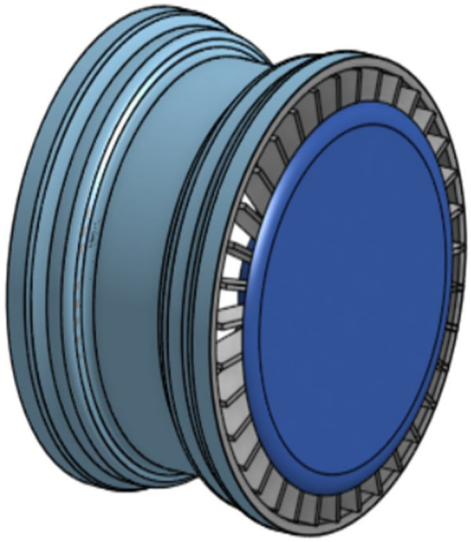
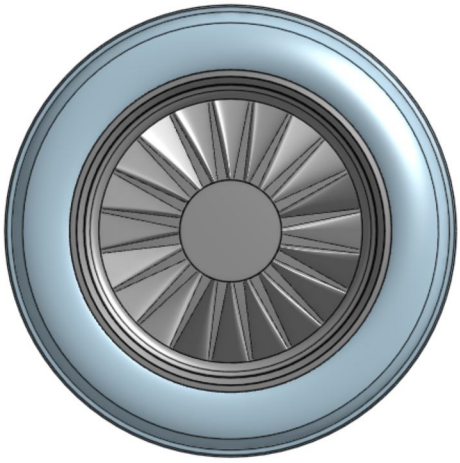
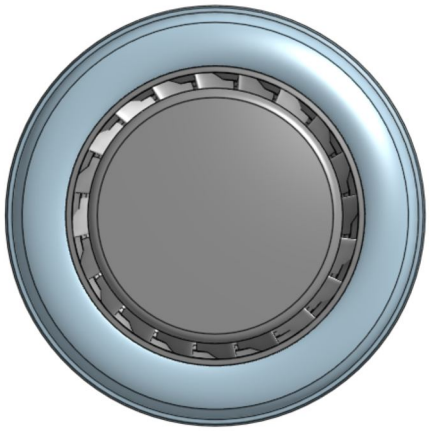
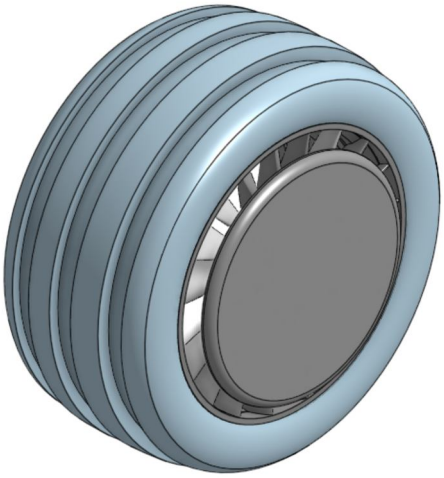
The above design is one of the existing design wheels from the commuter vehicle.

Improved/Proposed Design

1st Design for simulation	
	
Isometric Front View	Isometric Rear view

This is the 1st design I have designed for simulation but it was not working according to plan it was throwing air outside and sometimes it is created turbulence inside the wheel arch and behind the vehicle, resultant it was messing with baseline and other aerodynamic parts.

Finalised design for Simulation	
	
Side view	Rear view

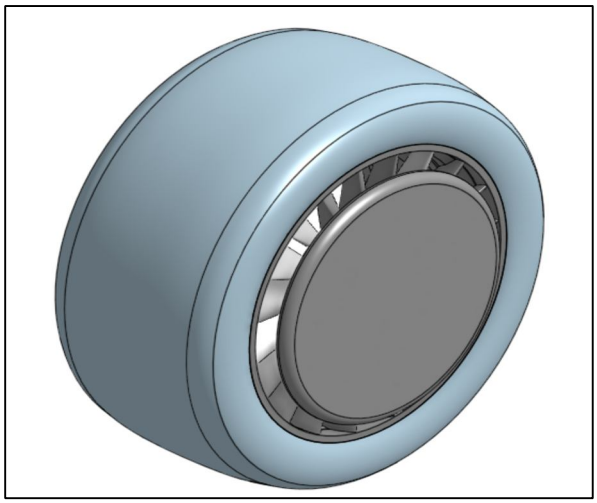
	
Front view	Isometric view

This is the final Improvised design of wheel which is working properly without messing with other parts. In this design air slowing from outside to inside with cooling of brake calipers and made car more stable also maintained baseline of car. Although air flowing inside of wheel it is not creating any pressure around fender

[7] 

Propeller Type Wheel Design

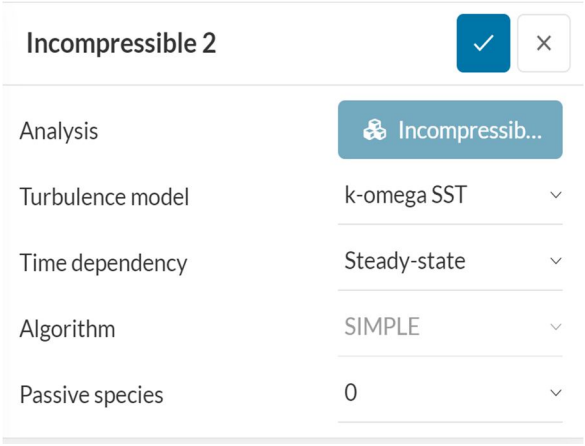
E. Simplified Simulation Model



Simplified model

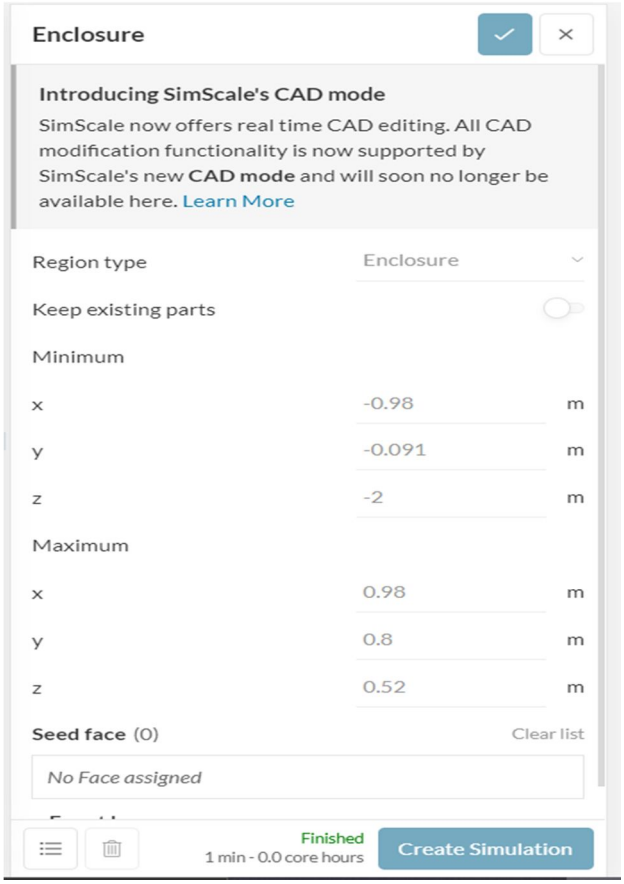
F. Simulation Setup

As a form of analysis, choose "Incompressible". This guide can be used in cases where the Mach number remains below 0.3 throughout the field.



G. Enclosure

First of all, I have created one enclosure around geometry (The enclosure option for external flow issues is usually used. The procedure is carried out by the size of the box and then the extraction operation is carried out. The following example shows a half air symmetry domain for a CAD geometry.)



Size of Enclosure: minimum X=-0.98, Y=-0.091, Z=-2

Maximum X=0.98, Y=0.8, Z=0.52

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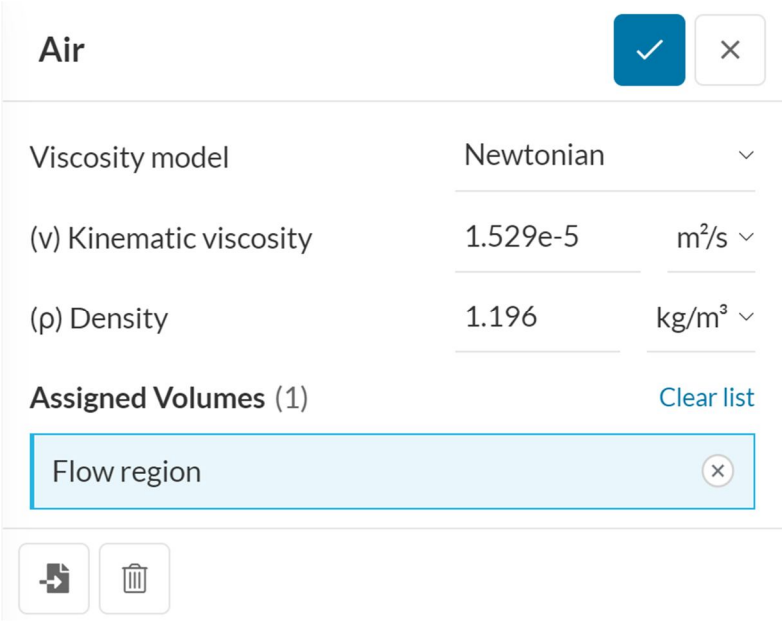
H. Materials

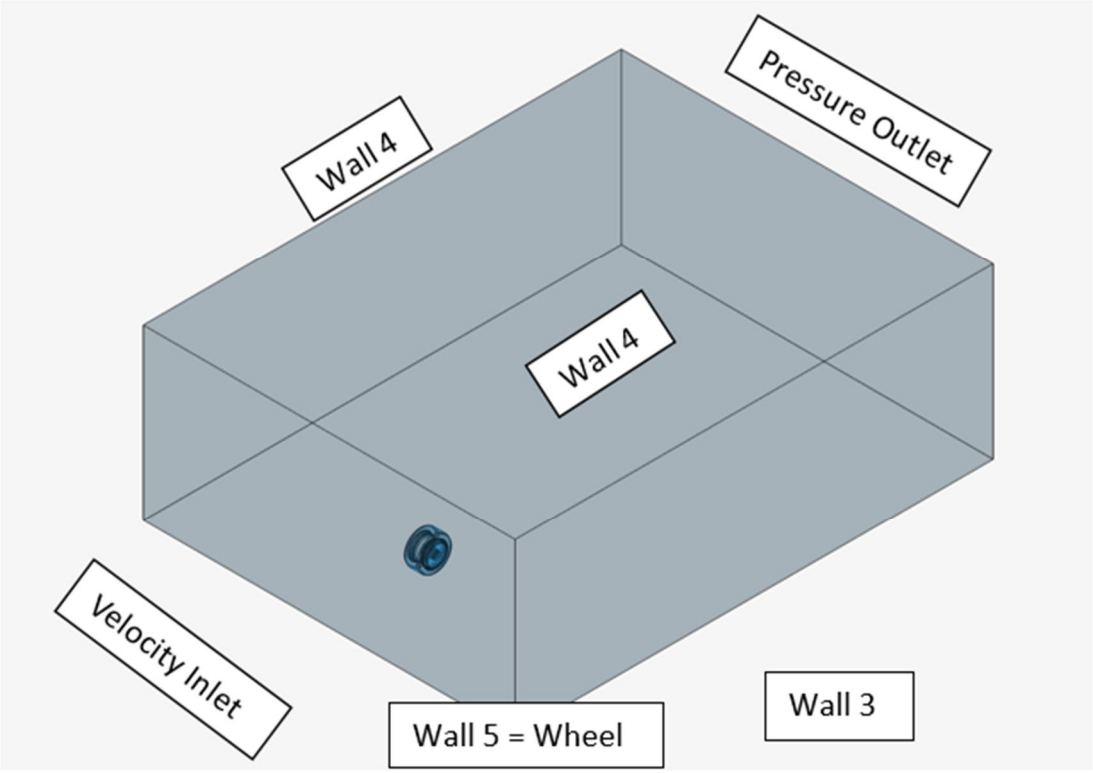
Select Air as a material inside enclosure with **density= 1.196** & Kinematic **viscosity=1.1529e-5**.



I. Boundary Conditions

The simulated physical situation consists of a wheel traveling through an unwind atmosphere at 70 km/h. In a CFD simulation, the speed of the wheel is now difficult to model directly. We get the same result if we change the mode: instead of a moving wheel, air without wind, and a street still standing, we allow the air around the wheel and the street to move at 70Km/h and make the wheel standstill.

Below you can find a description of the domain boundary conditions:



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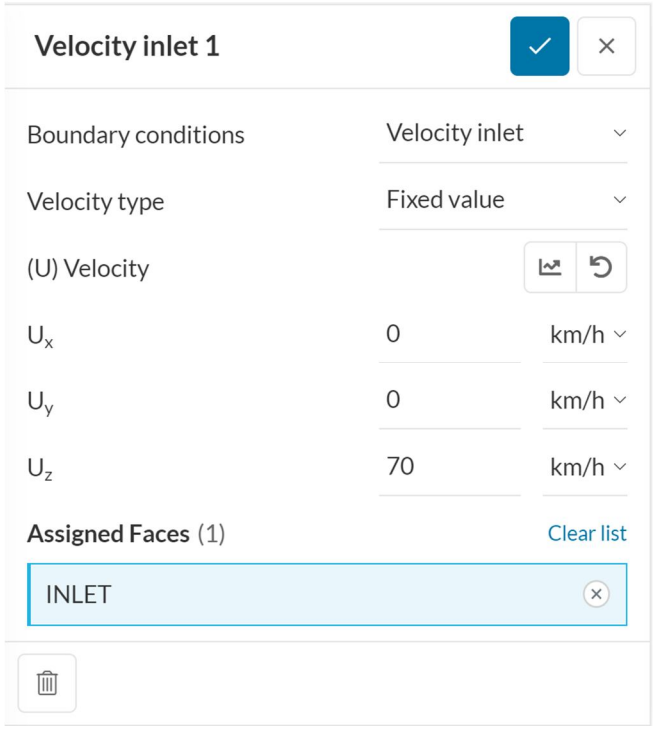
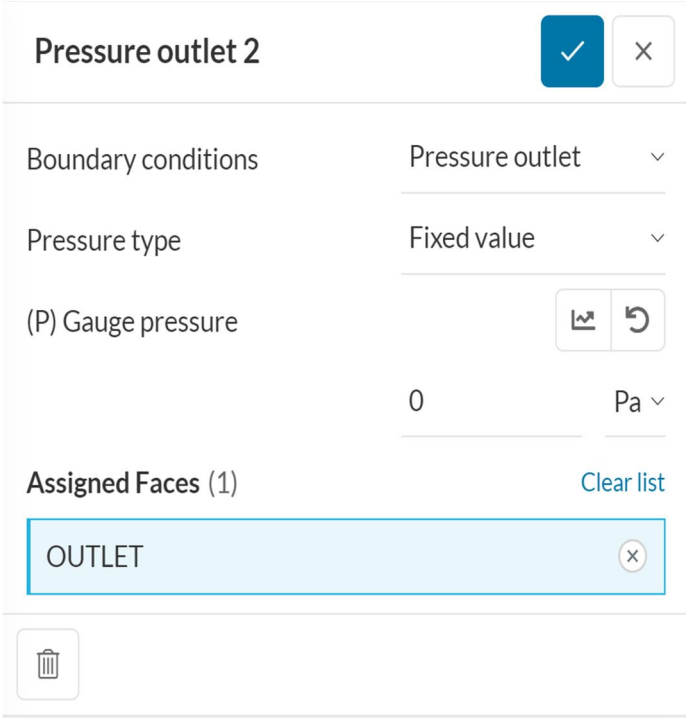
J. Velocity Inlet

Let's specify the inlet patch air velocity. To achieve this, establish a new limiting condition by selecting 'Velocity Inlet' and adding 70Km/h in the direction where your wheel is traveling (Towards Velocity Inlet).



K. Pressure Outlet

Create a new boundary condition, this time called a 'Pressure Outlet.' The user must define a gauge pressure in incompressible analysis. The gauge pressure is expressed as a percentage of a reference value.



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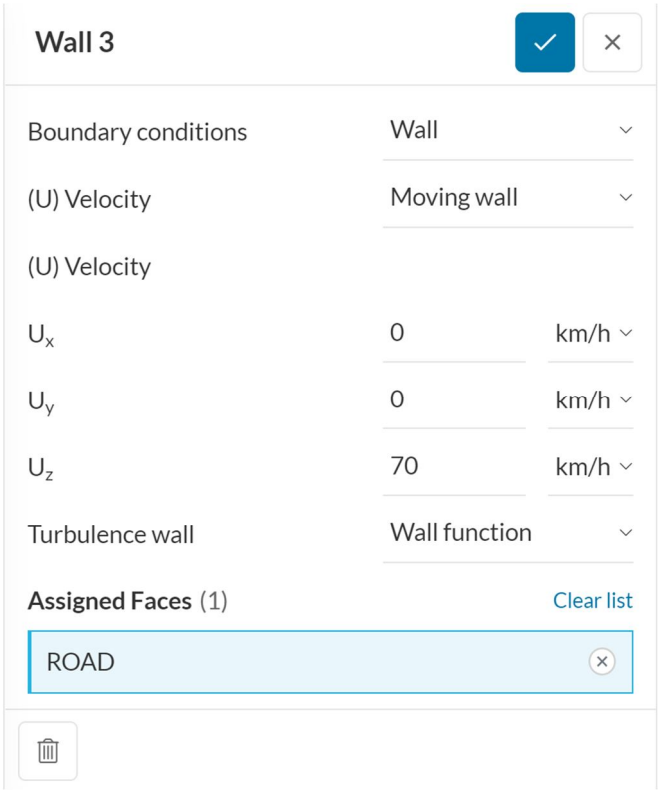
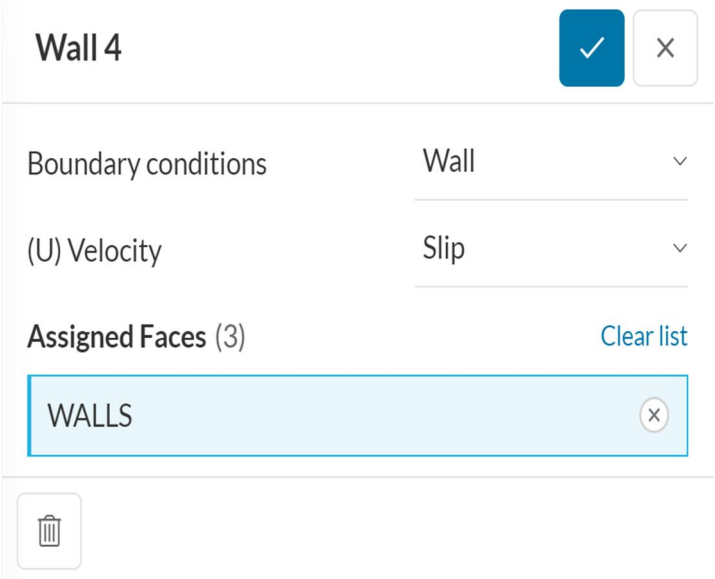
L. Wall 3

We're going to add a road boundary requirement now. Create a new boundary spot for the ‘wall.' Set the speed to 'moving wall' this time. Tangent components for fluid motion on user-assigned faces may be defined in this template.
In the Z-direction, describe a velocity of 70 km/h, which is the same vector as the velocity inlet limit:



M. Wall 4

The slip condition allows the contact to flow on the face but not in the normal direction. This is a good approach for Top and Side surfaces that are far from the wheel.



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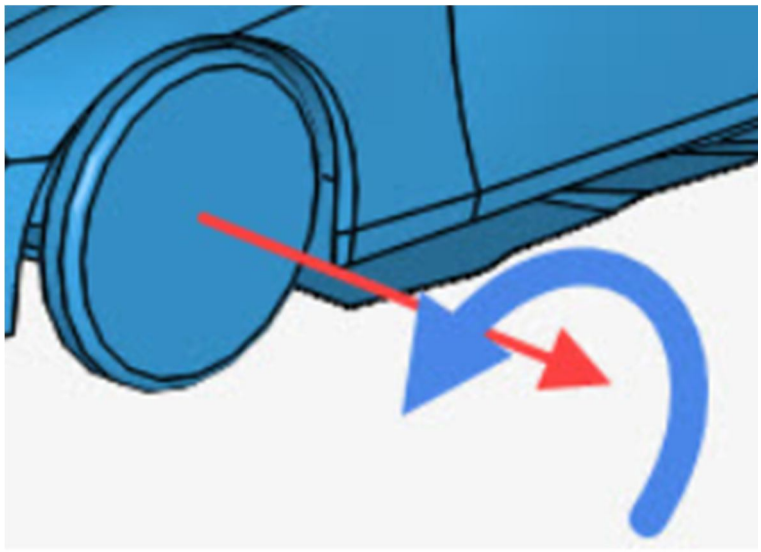
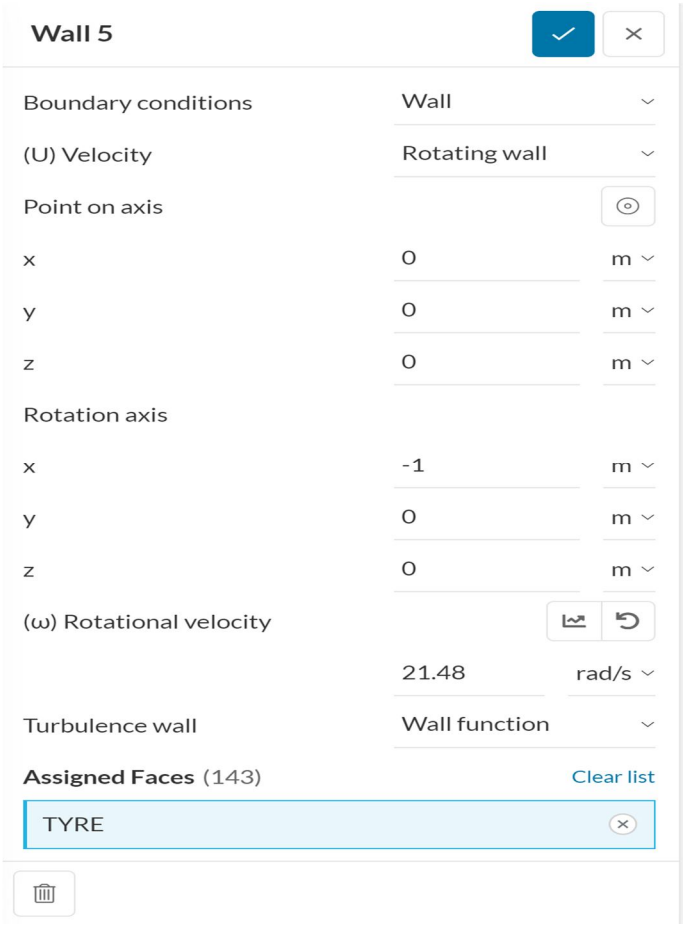
N. Wall 5

A 'Wall' boundary state can be used to model the spinning wheels. Choose 'Rotating wall' for (U) Velocity this time. To set up a rotating wall state, you'll need the following information:





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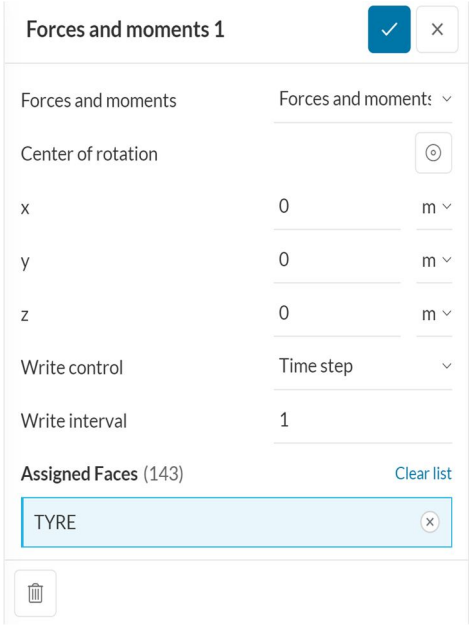
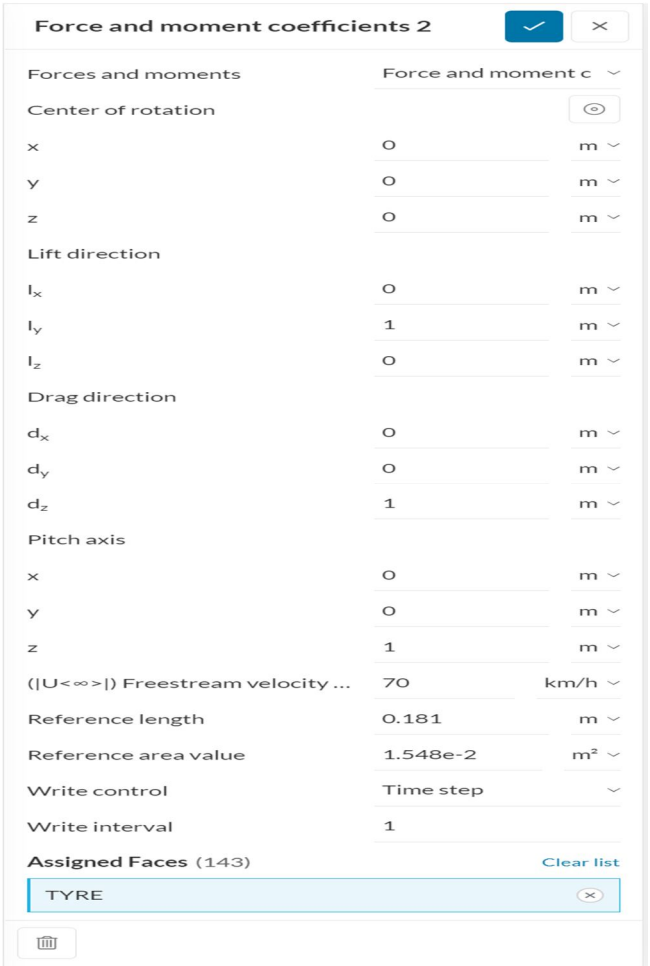
O. Force and Moments

By combining the pressure and skin-friction along a boundary, this outcome control item helps you to calculate forces and moments throughout the simulation. To measure the total force and moment on a series of boundaries, you should pick them.





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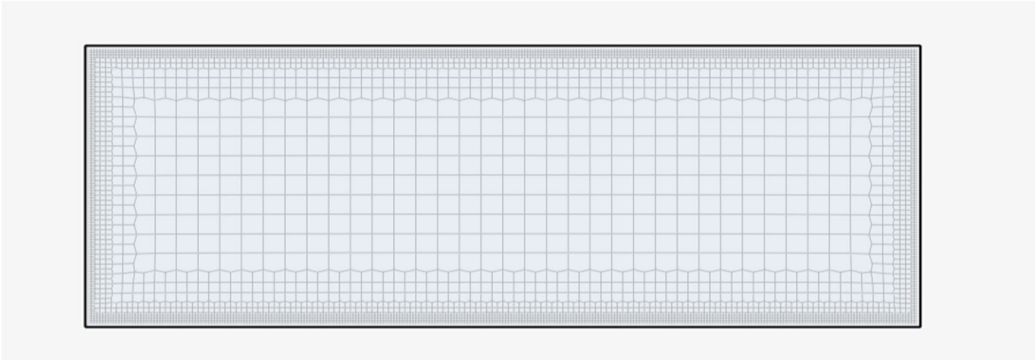
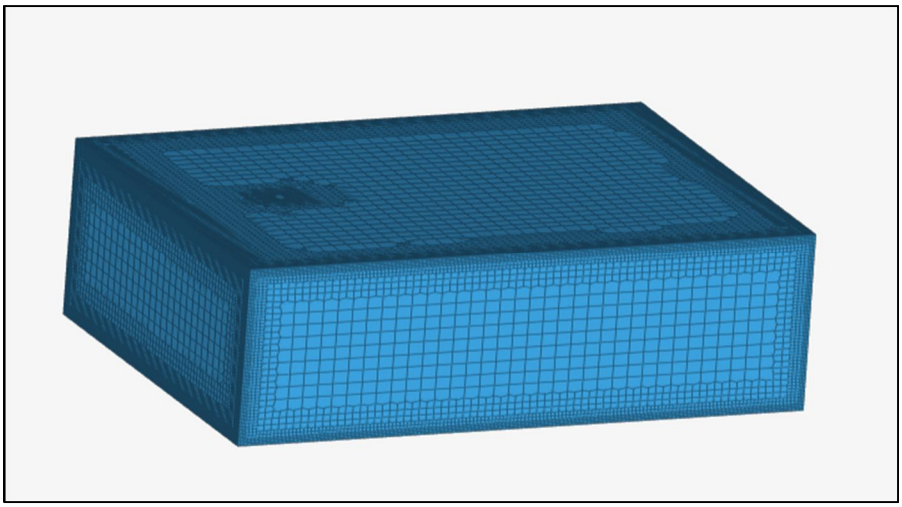
P. Meshing

1) *What is Meshing:* Meshing was quite challenging task to do. It took many attempts to get the exact value for the maximum edge length to get an extremely good quality mesh. Meshing is the method of breaking down an object's continuous geometric space into thousands or more shapes in order to better describe the object's physical form. The more complex a mesh, the more accurate the 3D CAD model, allowing for high-fidelity simulations. Meshing is an extremely important phase in the study of designs. The machine automated mesher produces a mesh based on global element dimensions, tolerance and local mesh power. Mesh control allows the part, facet, borders and vertices of various sizes of elements to be specified.



Simscale is used to build the computational mesh, and three different volume meshers can be used to do so: Polyhedral, Tetrahedral, and Trimmed Cell Mesher. Trimmed Cell Mesher is used in this thesis. The trimmed cell mesh offers an effective and robust method for generating a high-quality mesh for both simple and complex mesh generation problems. A prototype mesh made of hexahedral cells is used in the mesher model. The core mesh then produces a cut off and trimmed starting input surface. The mesh is rendered with the scale of the local surface mesh and the controls on local refinement.

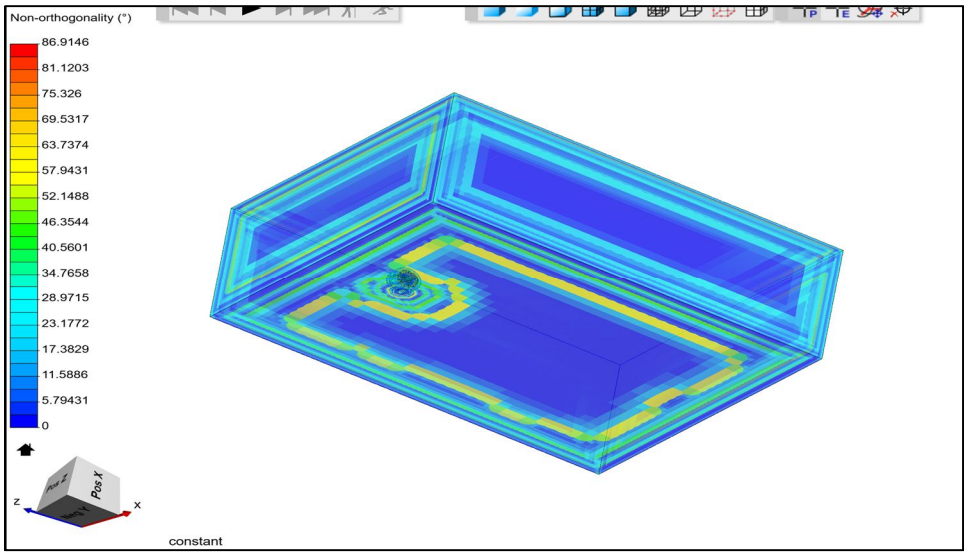
2) *Why MESHING is Important Before Simulation?:* Meshing is one of the most important components in achieving precise FEA data. In order to discrete tension gradients reliably, the components in the mesh must take several things into consideration.



To create orthogonal prismatic cells next to wall surfaces or boundaries, the prism layer mesh model is combined with the volume mesh. Since the highest gradients are located near the wall, the prismatic layer is needed to more accurately predict the flow. Finally, the Volume mesh primarily consists of hexahedral cells with trimmed cells and prism layers adjacent to the surface.

Mesh quality metric	Recommended range	Maximum recorded	Minimum recorded	Average recorded
Volume Ratio	<<100	75.62	1	1.91
Non Orthogonality	<<75	86.91	0	7.48
Skewness	<<0.6	10.09	0	0.09

Q. Non Orthogonality

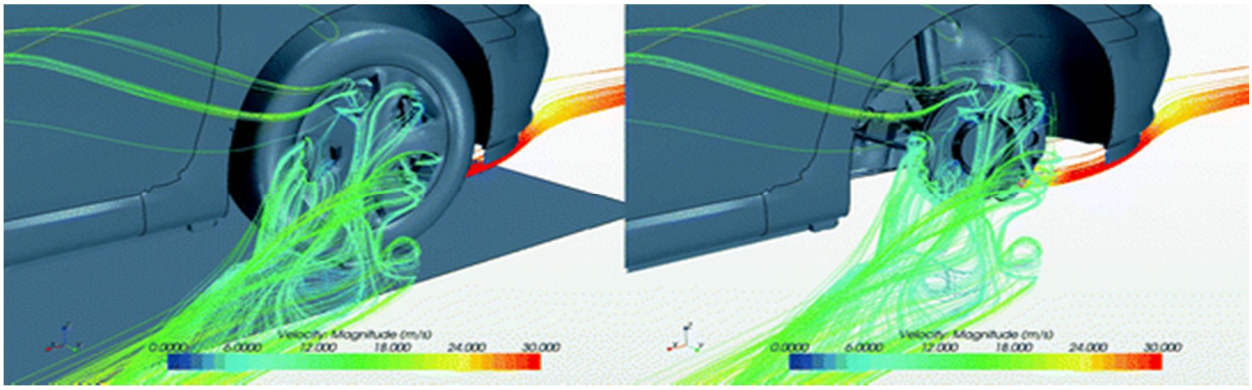


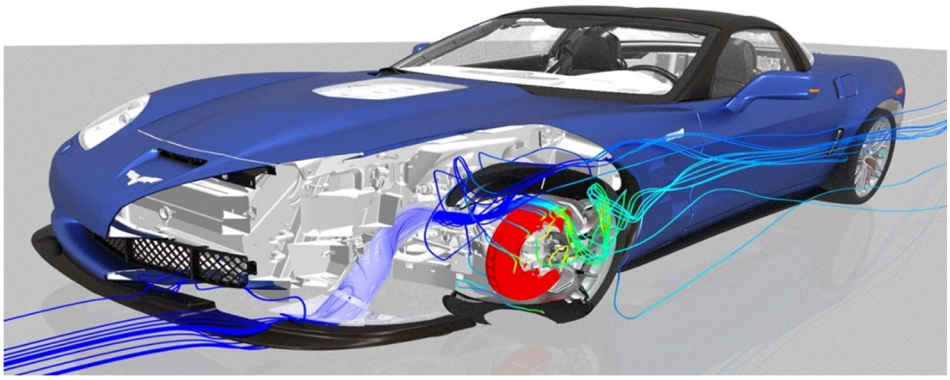
VII. RESULTS AND DISCUSSION

An extremely simplified 3D wheel model was considered which was not having any tire threads or any fancy edges so it can simplify meshing process and give much accurate results.

A. Simulation Where Air Travelling from Inside to Outside

In this simulation I have found that the air travelling from inside to outside is creating Huge turbulence around car body also creating sound on high speed

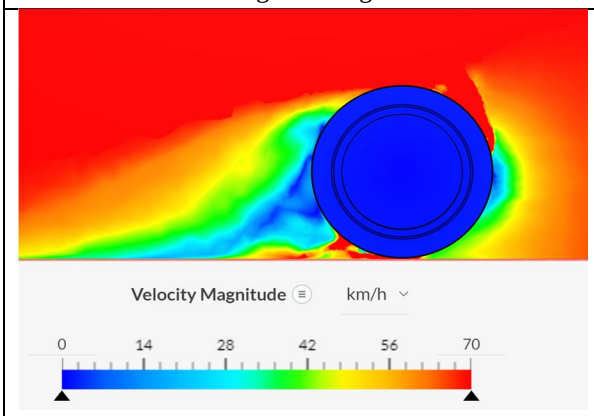
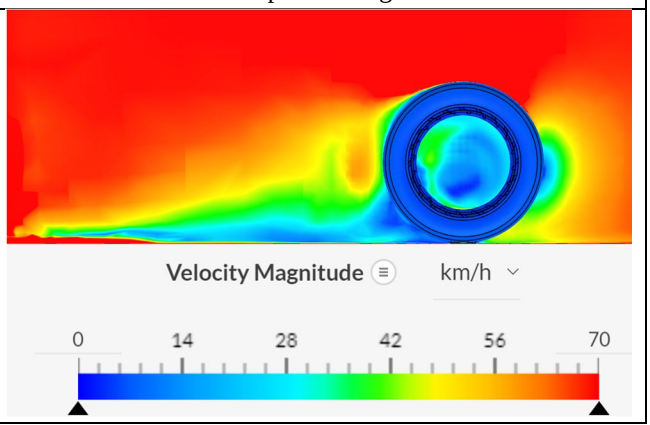




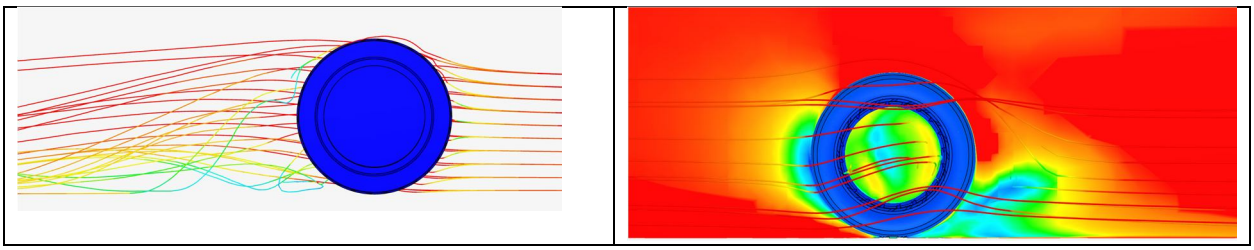
[8]

So I have changed the air flow direction from outside to inside with the help of wheel designed like propeller.

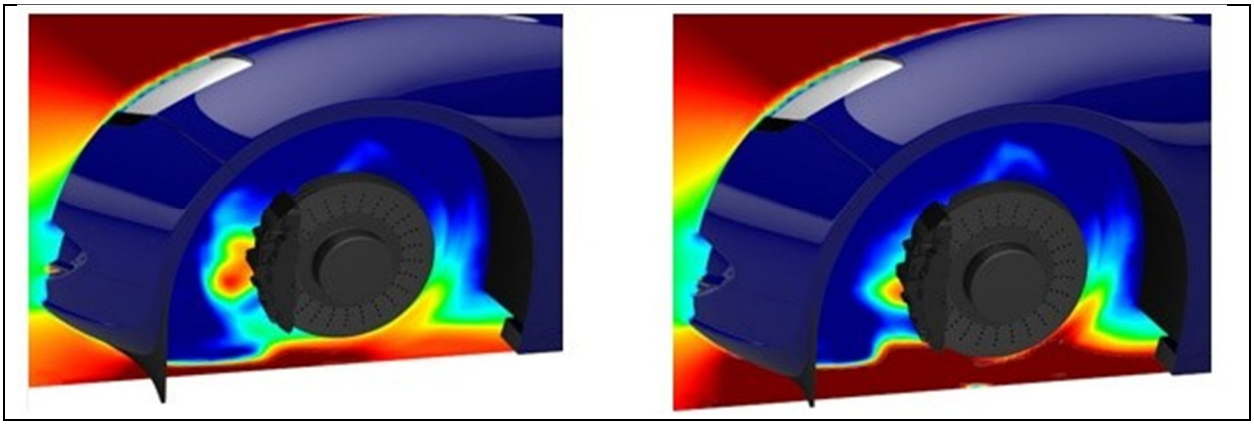
B. Contour Plot

Original design	Proposed design
	

In above pictures it shows velocity magnitude of wheel in which left side is existing design and right one is proposed designed. As you can see both pictures have different velocitie on same speed (tested on 70km/h). Air hiting Existing design and creats massive air velocity behind them on the countrary proposed designed created less turbulance and smoother air flow around wheel. also air flowing inside wheel to cool break callipers in proposed design but if you compared 1st images with designed wheel then you can air is not passing through wheel it is deflecting air when it hits to rims of a wheel that's why velocity hasent changed inside existing design.

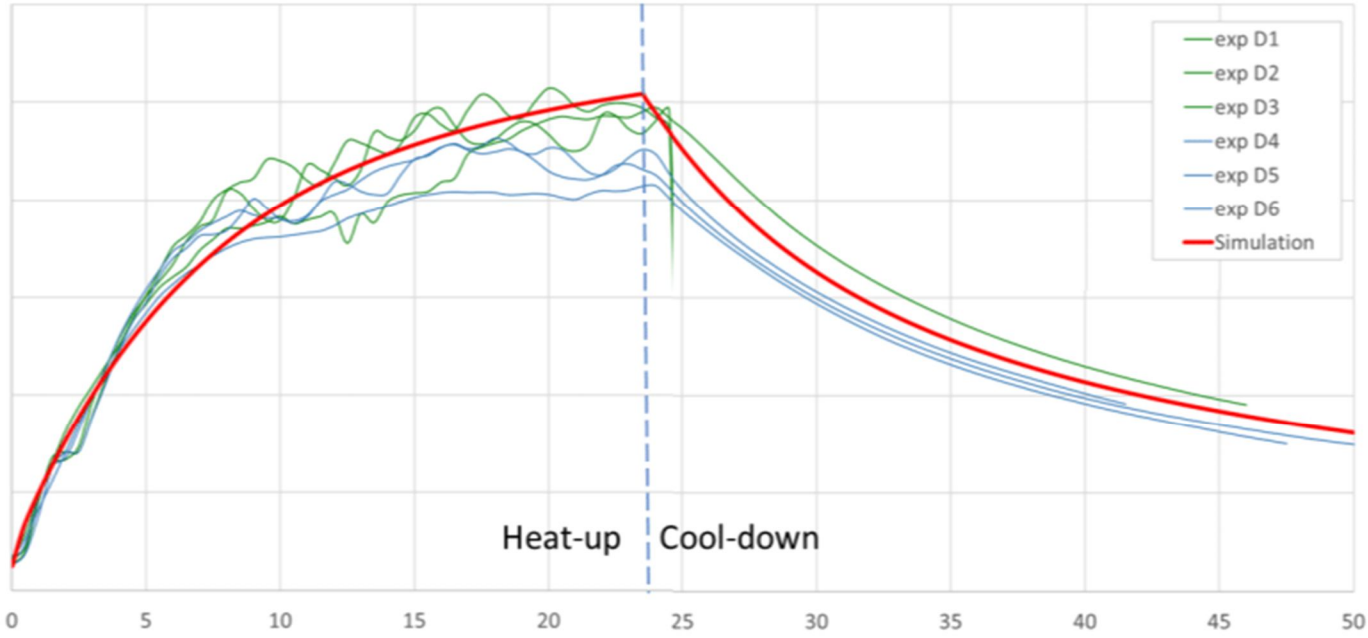


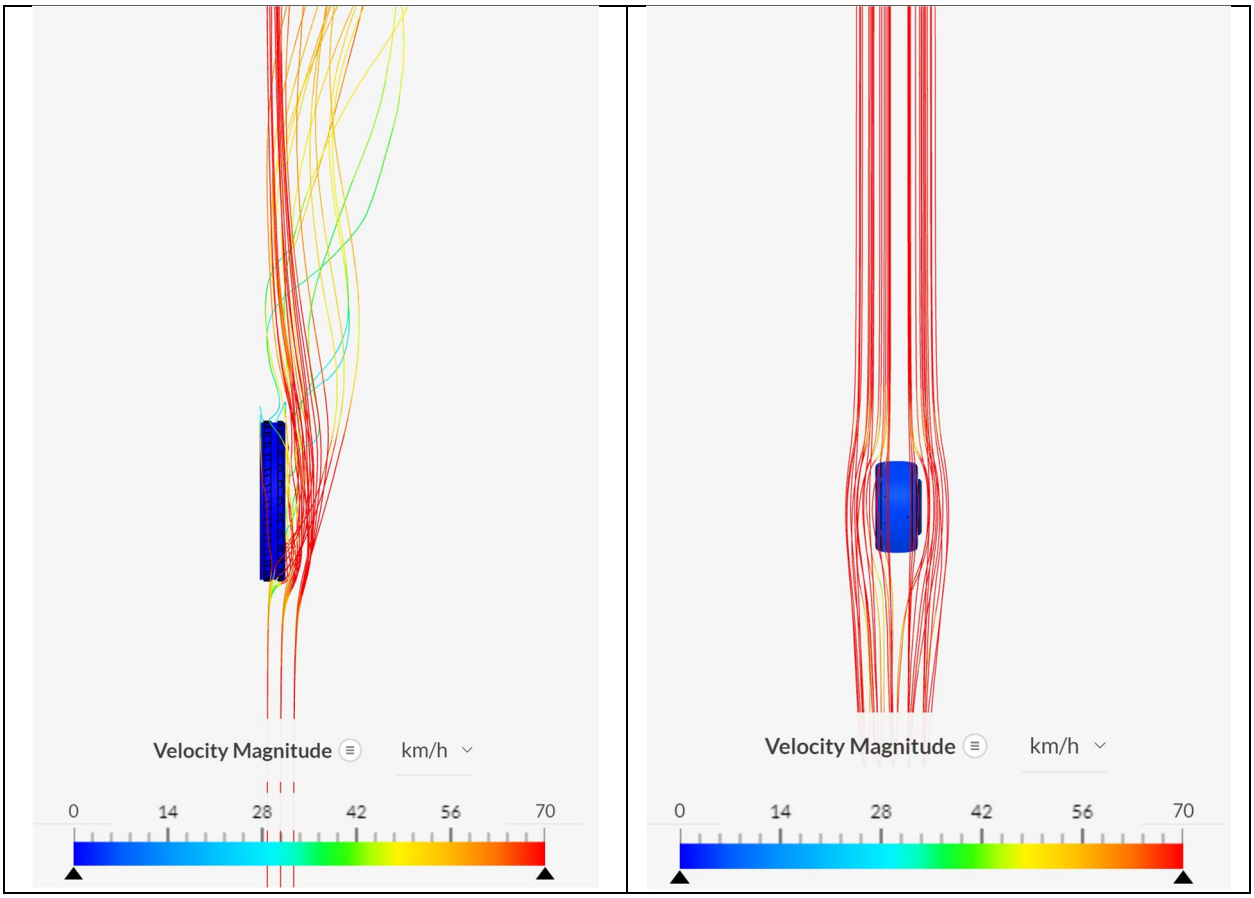
These shown images are proof for above statement. In this images streamlines are clearly visible and some passing inside wheel



First image shows Airflow transferring from inside to outside that's why it is creating more pressure inside wheel arch and it is directly affecting baseline of car.

But in another image it is improved because of changing direction of airflow from outside to inside it is creating less air pressure inside wheel arch and improved baseline of car also cool brake calipers.

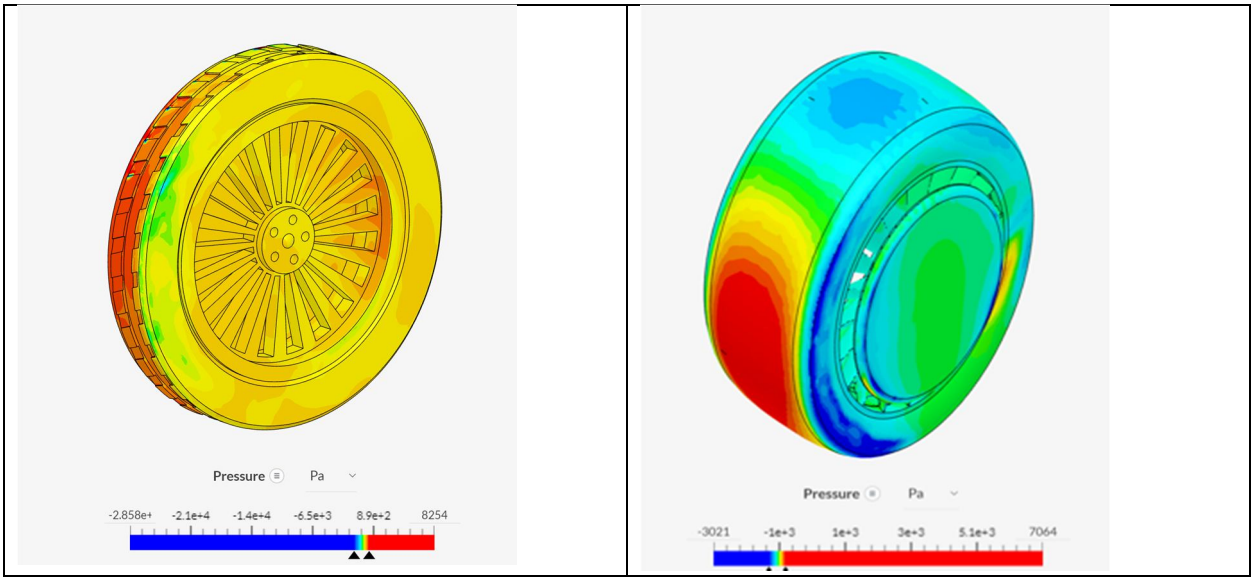




Above photos are specifically showing streamlines travelling across both wheels. And how both wheel design reacts on high speed. In existing design, you can see wheel is creating massive Turbulence behind them, Flow/Streamlines are not going in straight manner this will directly impacting on other aerodynamic aspects of car. Some streamlines are diverging after hitting wheel after hitting wheel air will slow down and its creating negative pressure on vehicle, it pulls car backward because there is some vacuum formation around wheel, resultant wheel creates more drag and turbulence which is not good for vehicle performance and other parts.

But as you can see other images which is representing proposed design is creating less turbulence which is negligible and when you see streamlines closely it is passing so close from wheel that's why there is no vacuum creation around wheel and air is flowing straight after hitting the wheel. Because of that it cannot affect other aerodynamics aspects of wheel.

C. Pressure on Wheel



Toggle Bar is set lower in order to show vivid and accurate colors for better understanding of pressure on wheel

VIII. CONCLUSION

In this study, a wheel is designed. Initially, after doing the literature review the design was created and analysis was done on cloud-based software. This device was proposed so that the aerodynamic forces acting on the vehicle can not only be used for better stability at higher speeds, but also for brake pads and wheel hub cooling through air on every speed so that brake pads will never worn out early. With the help of the CFD analysis, I have analyzed velocity of wheel, pressure on high speed & turbulence of wheel with streamlines so it's easy to understand and analyze the fault. Just doing CFD analysis was not enough to prove proposed designed was better than any other existing wheel design. That's why I had started working on different design alloys with its aerodynamic. Finally, after all the analysis the following conclusion can be made:

A. When car is travelling on streets they face different- different air flow condition based on weather and vehicles who travelling next to our car are creating turbulence behind them. This turbulence can effect on your vehicle stability. On high speeds they create turbulence behind them so its effect on car
B. This proposed design is able to reduce drag force
C. It can cool brake calipers with the help of rim design which can intake air inside wheels.
D. It can also reduce turbulence which exerted by wheel when air passes through wheel.
E. Improved baseline of car
F. It can make car more stable and it's not creating any vibration or unwanted sounds

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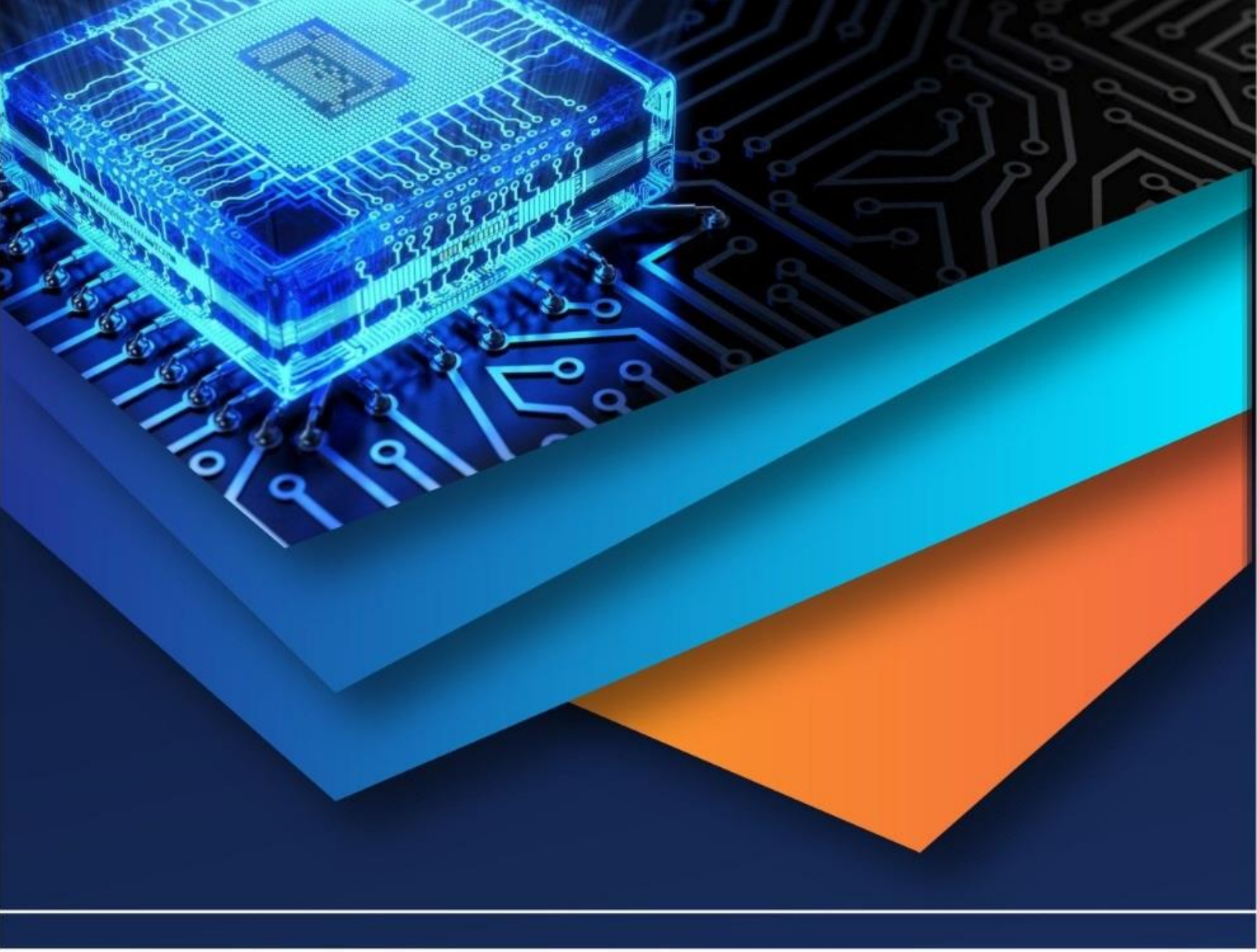

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