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Dimples Effects on a Spoilers Aerodynamics

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Abstract: Over the evolution of automobiles, performance, mileage, and grip have dramatically improved. Nevertheless, there have been some improvements, but now the ideal design has been reached for design of engine, airflow & tires, & ergonomics. This means that even very small design improvements could result in high performance enhancements. As fuel is becoming more expensive, the need for improved aerodynamics is becoming more acute. Thus, the purpose of this paper is to examine the effect of golf-like dimples on the aerodynamic properties of a spoiler. As such, numerical calculations and computational fluid dynamics calculations were performed to investigate the impact on aerodynamics and turbulence spoilers with various surface roughness and angle of attack. Based on the recorded data, this test will provide the best information on the appropriate size for the dimple. The data collected on the test model will be used to calculate the drag coefficient, the downforce, and the wake produced at 56 m/s speed, at four different attack angles. Different sizes & depths of dimples will be used to improve the aerodynamics of spoilers, which will improve their downforce, drag force and wake formation.
Keywords: spoiler, aerodynamics, dimples, downforce, aerodynamic forces

I. AIM

To carry out Computational Fluid Dynamics and Numerical validation to investigate the effects on aerodynamic performance of an automotive spoiler by applying multiple surface roughness's in the form of dimples & conclude the effects of dimple on the aerodynamics of a surface based on the results collected.

II. INTRODUCTION

In the past, after getting the patent for the first automobile, most of the time was devoted to researching and developing the engine to increase fuel economy, performance, power, and torque generated by the engines. In fact a drop in sales since fuel prices went up in the 1970's led the auto manufacturers to realize that they needed to figure out how to increase the fuel efficiency for commercial cars, because the study of aerodynamics before this time was only done on racing cars. The automobile manufacturers understood that the amount of fuel a car consumes can be decreased by improving the efficiency of the engine and the transmission, the amount of power needed to make the car move from the initial stage to motion, and most importantly, the shape of the car. In the early 20th century computers helped dramatically develop the aerodynamics of vehicles, allowing for them to work more efficiently. When a vehicle is running on a road, it has to overcome things such as the aerodynamic drag from the air which slows the vehicle down, which is something we may have noticed [1].

In aviation, airfoils are a type of aerodynamic wing traditionally utilized to generate lift force. In addition, in the automobile industry and the motorsport industry, airfoils can be used to produce downforce, allowing the vehicle to turn more smoothly & control it's path more precisely.

By increasing the car's weight, one can increase the grip between the wheels and the road without using aerodynamic downforce, however this has disadvantageous effects such as decreasing the acceleration and maximum speed. Nevertheless, if the downforce is increased, there is a possibility that it increases the drag and this is likely to have an effect on the performance of the vehicle, particularly relevant to motorsports in the long run.

In order to reduce the drag forces experienced by the spoiler the design of the spoiler is similar to that of a golf ball that has dimples on its surface, which thus results in a large reduction of the drag experienced on a racing car. The turbulence boundary layer is created by generating a rough surface on top of the airfoil, allowing the air to move rapidly around the wing, thus reducing the length of the wake area left behind.

Additional lift is generated based on the idea of golf balls. A golf ball with dimples on it will travel farther than a golf ball with a smooth surface. The additional momentum provided by the dimples on the golf balls causes flow separation to be delayed which reduces the total drag. Figure 1 presents the impact of air on a golf ball with and without dimples. [2].

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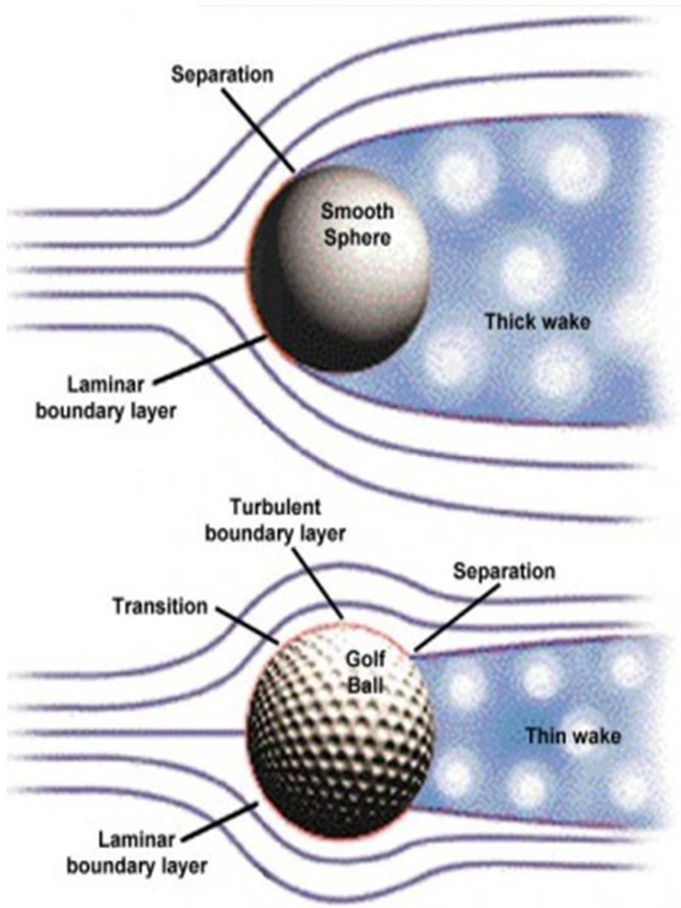

Figure 1: Golf Ball with & without dimples [3].

For purposes of increasing lift force, an aerofoil wing that uses an asymmetrical shape is chosen for reducing the drag in the car. Aerofoil flow separation is likely to occur at high angles of attack due to the existence of a thin boundary layer. Furthermore, due to the presence of a viscous boundary layer within the fluid, the flow motion is reduced and subsequently creates a flow recirculation region, as there is not sufficient momentum to move fluids into a fast moving flow region. The success of this study depends on understanding how dimples can affect the lift and drag of the airfoil. The theory behind how dimples affect the dynamic performance of an aerofoil is very much under-researched. The primary objective of this study is to investigate the effect of the number of dimples on the flow behavior around the wings using a computational fluid dynamics (CFD) analysis. The results of Computational Fluid Dynamics (CFD) analysis will be verified by numerical calculations.

III. NEED OF AERODYNAMICS OF SPOILERES

Currently, several surface modifications are being examined to help cars handle more smoothly & enhance its manoeuvrability. Many automotive spoilers are modified using vortex generators. Turbulence is created by creating vortices which delay the boundary layer separation, which in the end reduces the pressure drag and also increases the angle of stall. Additionally, it reduces pressure drag at high angle of attack and as a consequence is able to increase the overall lift of the spoiler. In the study, dimples are being considered as the surface modification. As with vortex generators, application dimples on aerofoils work the same way. This delays the separation of the boundary layer and reduces the wake, thereby reducing the pressure drag. At small angles of attack, flow separation becomes apparent, but attached flow continues to dominate. As the angle of attack increases, the separated regions at the tip of the wing will increase in size, reducing the ability of the wings to produce lift. Above a critical angle of attack, separated flow dominates so that further changes in angle are likely to reduce lift and increase drag. An experiment has been carried out on an inwardly dimpled aerofoil in order to examine the effects of dimples. A variety of dimple sizes was taken into consideration.

IV. LITERATURE REVIEW

Students of the MIT University have been working on the concept of dimpled car body and its effects on efficiency. The student found that the golf ball dimples make it more efficient when compared to smooth surface golf ball. The rough surface allows air to separate after a longer duration keeping minimal wake point. But the problem with using dimples on the car body is that it doesn't look good aesthetically, and since 89% of people buy cars that look aesthetically good and which suit to their standard, the chances of buying a dimple textured car in fairly less even though these cars will give higher mileage and better handling than the normal cars. Hence the students came up with a rubberised skin for outer covering and a cavity inside it. The surface texture is controlled using engine vacuum the vacuum sucks the rubber surface through the small cavities in the body which pulls the rubber surface inside and this in return creates wrinkle like pattern on the surface which works exactly like the dimples on the golf ball. In normal conditions the skin is smooth but when requires aerodynamic advantages vacuum is created in the cavity and the rubber skin shrinks like a raisin and forms dimple like wrinkles which creates a rough surface thus making air flow stick for longer time & thus reducing the turbulence created at the end of the part [4]–[7].

An aerofoil is usually used in aeroplanes & automobiles to either generate lift or downforce as per the need for better handling and grip. The paper test NACA 6615 aerofoil with dimples of 5mm, 10mm, and 15 mm at 5 degree, 10 degree, 15 degree & 20 degree Attack of angle of aerofoil the dimple are place on the bottom side of the aerofoil. The test was conducted on a 3D printed model and it was tested in a wind tunnel facility at wind speed of 30 m/s. The results of this test were that adding dimple on the bottom side of the aerofoil did help in reducing drag and turbulence but it was not satisfactory results. The smallest dimple provides the highest increment in lift to drag ratio [8].

S.Dol in his paper studied on the dimple for improving the car aerodynamics by adding different pattern of dimples on the body and see the results produced by it and see if dimples help in delaying air flow separation and generating smaller wake. The results of his test were positive, all the dimple ratio gave smaller coefficient of drag when compared to smooth finish model. The coefficient of drag of the model with dimple ratio 0.4 is reduced by 1.95% [3].

Similar to above paper these researchers were interested in the effects of dimples on the surface of car, spoiler & side mirror. The paper concludes that the depth of the dimple is directly proportional with reduction of coefficient of drag. The dimples with depth of 14 mm and at 60 kmph speed gave the car body reduction in coefficient of drag by 9.4% & 4.93% for spoiler & 2.52% for side mirrors. The dimples were placed on the cars bonnet and trunk lid. The reduction in fuel consumption is directly proportional to reduction is drag [9].

Similarly applying dimples on the roof line of the car will also help in reducing drag and increasing downforce. This type of arrangement is best suited for NASCAR's as the usually run at their maximum speed and have to face cross wind and running on inclined surfaces hence downforce, grip & handling is very important to be in the race. The dimples on the roof help the car to minimise the drag and also minimise the crosswind effect. In the study almost all the dimple designs reduced drag coefficient [1].

The researchers determined forces that were applied up on three distinct portions of a vehicle, the Hindustan Ambassador, Lamborghini Aventador LP 700-4 and F1 car, by testing their designs in a Wind tunnel. An examination is done between the three models for the best streamlined & aerodynamic highlights. The scaled models are tried under various wind conditions in. It was discovered that the F1 vehicle is the most streamlined among the three followed by the Aventador and afterward Hindustan Ambassador. The previous two has this outcome because of its low profile body. Likewise the linings of the car help in flowing the air when the vehicle is moving which drives the air to the backside where spoilers are given which gives extra grip at high speeds[10], [11].

The researchers had performed mathematical considerations to research the decrease in the aerodynamic drag of a vehicle by utilizing a dimpled non-smooth surface. The idea was approved by the test information detailed in writing. The system and the impact of the dimpled non-smooth surface on the drag decrease were uncovered by examining the streamlined flow field structure of the wake. To boost the drag decrease execution of the dimpled non-smooth surface, an aerodynamic enhancement technique dependent on a Kriging substitute Ahmed model was utilized to plan the dimpled non-smooth surface. At that point a multi-island hereditary calculation was utilized to get the ideal answer for the substitute model. At long last, the substitute model and the simulation results indicated that the ideal blend of plan factors can diminish the aerodynamic drag coefficient by 5.20% [12].

The researcher implemented the investigation of dimple attributes on golf balls. Their motivation of the paper was to look at the aerodynamic impact of on golf balls with 11 unique varieties in dimple profundities. The drag coefficient for the golf balls were found to change with shifting dimple size & dimension. The measurable information additionally settled a positive direct connection between relative harshness/roughness and drag coefficient. This thought cleared our approach to change the surface harshness/roughness of our vehicle spoiler to check in the event that we can lessen drag or not[9], [13].

The purpose of dimple is to add roughness to the flow path, so that laminar flow is changed to turbulent flow quickly. As a result of the generated turbulence, the flow remains attached to the wing surface and smaller wakes are generated. The wake enhances lift in the wing by reducing drag [14].
The dimple can either be inward or outward. The inward dimple is usually the depression made on wings and the outward dimple is usually a bump or projection on wings.
Many scientists have looked into using the dimple mechanism to minimise lift and drag on aerofoils. A similar attempt was made in the current study to assess the impact on lift and drag characteristics by adding various dimple shapes such as rectangle, triangle, and square. Previously, an aerofoil model with only two dimples on the surface of the plane had been created. Previously, an aerofoil model with only two dimples on the surface of the aerofoil was made. The findings were then used to create a sequence of dimples around the entire surface of the aerofoil.
Amzad Hossain et al. (2015) performed experiments on a dimpled NACA 4415 aerofoil. The flow separation in the aerofoil was delayed by the dimples over the surface of the aerofoil, and the lift generated of the aerofoil was increased up to 16.4 percent and a reduction in drag of 46.7 percent [15].

V. EXISTING CONCEPT

A. Hexa Concept

A French designer had come with a concept of a solar car with hexagonal dimple like pattern which was inspired from the golf ball itself, it was estimated that the pattern helped in decreasing the coefficient of drag thus increasing aerodynamics and while help the solar panels below when in cloudy weather. The hexagonal dimple cavity on the roof if the car is made out of unique material that allows light to seep in from all the sides and concentrate it at a focal point like a lens. The designers explains the reason behind why this concept is so unique, this dimples when used in surfboard makes the face less resistance due to water because of the hydrofoil effect, the same happens with the roof of the car making air stick to the roof for a longer time producing less wake [16]. The concept presented by the designer is shown below.

B. ZIPP Speed Weaponary

Zipp is a cycle wheel manufacturer who have patents under their name for dimpled disc wheels & dimpled rim wheels. These wheels actually work and give better results which is the reason why almost every top tier team use them on their cycles. As per Zipp the reynonds number of their normal disc wheel is much higher than the dimpled version, this explains that the dimples help in decreasing the Reynolds number. The dimples help to make the active turbulent flow stick close to the wheel for longer time reducing wake & recapturing the air leaving the rim. The round tyre makes first contact with the air upfront and the rough surface keeps the air separating stick together and creating minimal back turbulence.[17]

C. Mythbusters

A TV show named mythbusters tested a myth that dirty vehicles are more aerodynamic than the new vehicle, since a golf balls dimple act as a rough surface increasing its travel and efficiency. They came to a conclusion that dirty cars do not increase the fuel efficiency and it was a myth, but they further tested by making two identical clay smoothly sculpted similar car bodies but later on gave one of then dimple like cavities throughout the surface of the body, and test run it at 50 MPH speed on both the cars and tested the fuel economy of both the cars.
The results, 29 MPG for dimpled car & 26 MPG for non-dimpled car. This shows that the dimples will increase the efficiency of the car.[18]–[22]

D. OAK Team Spoiler

In 2011 for the Le Mans race event, the oak team had made small yet noticeable changes in their previous year's race car most of the noticeable changes were don on aerodynamics of the car and very little done on the mechanical domain. The most noticeable design change done was on spoilers this time they were having dimples extruding upwards from the spoiler surface. As per design team this was done to make the air flow to stick together and be attached to the spoiler for the maximum time possible. This technique helped in increasing the efficiency of the spoiler thus giving the car maximum downforce while turning at high speed corners.[23]

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VI. METHODOLOGY

As a result of the leading edge in the spoiler, flow separation often occurs. With the aim of delaying flow separation, decreasing wake length, and to minimizing turbulent energy loss on the upper surface of the spoiler, a non-smooth surface with dimples was added right after the leading edge of the spoiler.

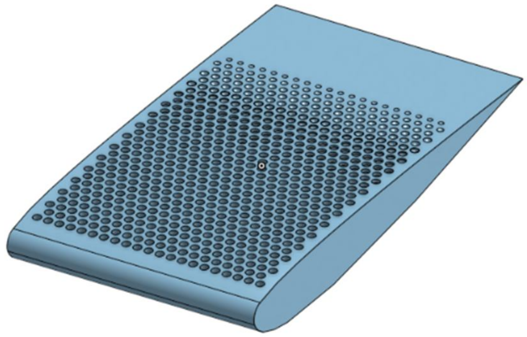

Figure 2 Proposed spoiler design representing arrangement of dimples

Before finalizing the values for dimples, a background research was conducted to determine which values were the most appropriate to get accurate results. After reviewing multiple papers, it was determined that dimples with a depth of 4.5 mm to 6 mm are most common & has generated positive results with dimple size being 10mm. The difference in results between the two types of arrangements of dimples was determined by the type of spoiler design you choose. Some positive results were obtained with inline rows of dimples whereas others had positive results with offset rows. In order to conclude the dimple sizing and dimple configurations, a few test simulations were performed only to determine whether the above mentioned ideas should be implemented in our design. The experiment was conducted on a NACA 2412 spoiler and three models with differing depths of 4mm, 5mm, and 6mm were used to generate a row of 10mm dimples. The purpose of the tests was to identify the depth that is most effective for the NACA 2412 spoiler design to reduce drag & improve downforce when compared to other tests. The test was carried out at speed of 30 m/s and 0°, 10°, and 15° AOA. Simulation results show that spoilers with 5 mm & 4 mm deep dimples produced less downforce than spoilers with 6 mm dimples. However, the spoiler with the 6 mm depth dimple produced more drag than the other two spoilers. Hence dimple depth of 5 mm is selected since the drag generated is less than a dimple depth of 6 mm and the down force generated is greater than 4 mm dimples.

The second test was performed at 30 m/s & 0°, 10°, and 15° AOA. The dimples arrangement on one for the spoiler, had their rows aligned in the same order. And the second spoiler with their rows being offset with each other as shown in figure. Simulation results indicate that the spoiler with offset rows is effective in reducing wake, which was the intended outcome of the tests.

After getting results from the test it was finalised that dimples with 5 mm depth & offset rows will be used for the research in this paper. The transverse distance between the dimples was 2 times of D (Diameter), the vertical distance between the dimples was 1.5 times of D (Diameter), the depth of each dimple was 5 mm and the width of each dimple was 1.5 times of D (Diameter).

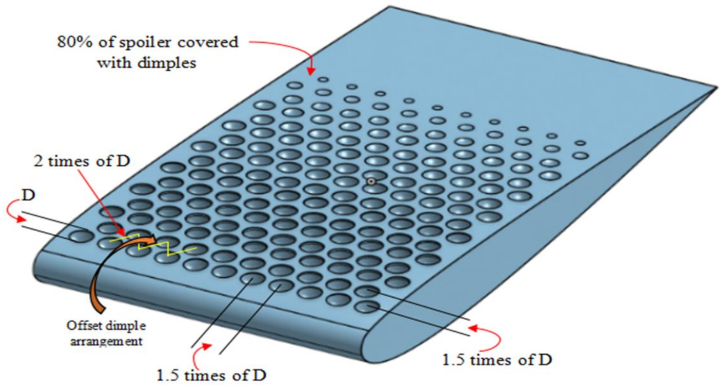

Figure 3 Arrangement of dimples with dimensions

VII. GEOMETRY

The present study uses a spoiler model, namely the NACA 2412 spoiler, as shown in Figure A. Cars are designed for low speed and so the compressibility of air can be ignored & the NACA 2412 is designed for low speed applications; it's maximum operating speed is 210 kmph or approximately 60 m/s, which is beyond an average passenger car's range. The maximum percentage for the mean-line from the chord is indicated by the first integer of every four-digit numbering scheme in the NACA. The distance between the edge and the highest camber is indicated by the second integer. The thickness of the aerofoil is calculated using the last two values. The first two digits in the case of NACA 2412 suggest a maximum camber of 2% at a chord duration of 40%. The number's last two segments are "12," which denotes the aerofoil's maximum thickness; this means that the maximum thickness is 0.012 times the chord length. The model's dimensions are mentioned in table 1.

Table 1 Spoiler Dimensions

PARAMETERS	DIMENSIONS (MM)
Chord Length	300
Width	155
Max Depth	40% of chord
Dimple Depth	5

The span and chord of the aerofoil is 300 mm and 155 mm. Four 3D models were used, a smooth surface wing, a wing with 5 mm dimple, a wing with 10 mm dimples, and a wing with 15 mm dimples. The dimples are configured to cover 80% of the spoiler surface to minimize wake separation till the very end of the spoiler while increasing turbulence. Each dimple has a fillet to reduce shear stress around it.

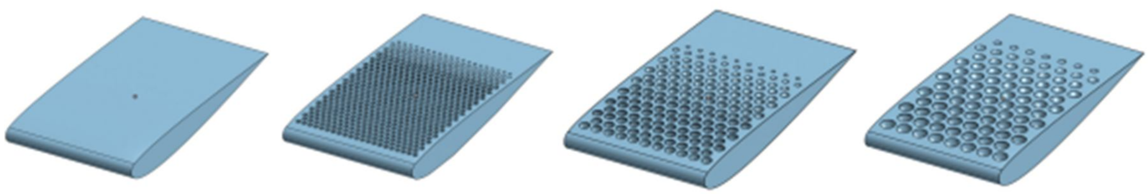

Figure 4 3D Models of the spoilers to be tested with & without dimples.

VIII. MATHEMATICAL MODEL

The spoiler is surrounded by a huge enclosure that eliminates the possibility of unwanted non-natural acceleration caused by the air squeezing against the surface of the enclosure. To prevent this, the spoiler is positioned at the velocity inlet four times the length of the spoiler and on the pressure outlet side sixteen times the length of the spoiler. The spoiler is placed in the middle of the enclosure with a symmetry wall touching the end of the spoiler and with a side wall that is 3 times the length of the spoiler. The enclosure's roof and floor extend four times the length of the spoiler.

IX. MESHING

All 3D grids and the computational grid were generated locally by Simscale using hexahedral non-structured grids. (Figure). The computational domains grid topology is made up of a number of rectangular blocks. In order to minimize grid distortion, “O” grid was used around the dimples. For numerical simulations, validation and verification are essential steps in assessing their accuracy and reliability [24], [25]. In addition, the mesh settings used for the present simulation were hex-dominant algorithms, with intramural meshing mode, automatic sizing of the mesh, fixed distribution of an individual particle in mesh, with a moderate fineness, and no changes were done to the settings. The configurations for calculating the forces, moments and pitch that are applicable to spoilers were done through results control where the pitch, drag and the lift directions of the spoiler were entered and the speed of the test, reference area, and length were entered for accurate calculation of the results. The meshes are segregated into two refined meshes, as illustrated in figure. The outer mesh grid is of greater size and while the inner grid is becoming smaller and smaller in size, to perform neutral simulation tests the Cartesian boxes and edge lengths were set to a standardised value. The generated mesh grid had 3.7 million elements & 3.9 million nodes. The figure 4 shows the Mesh quality & detailed information about the mesh quality.

X. MESH QUALITY

Table 2 Mesh Elements

Number of nodes	997392
Number of edges	2189
Number of faces	160155
Number of volumes	1960929
Number of triangles	159930
Number of quadrangles	225
Number of tetrahedra	1133616
Number of hexahedra	729682
Number of prisms	16001
Number of pyramids	81630

Table 3 Mesh Quality

Mesh quality metric	Recommended range	Maximum recorded	Minimum recorded	Average recorded
Volume Ratio	<<100	47.765	1	1.983
Non Orthogonality	<<75	70.453	0	4.278
Skewness	<<0.6	2.673	0	0.057

A. *Volume Ratio*

You must keep the volumetric ratio lower than 100. Despite the maximum recorded value being less than half the recommended range of 47.765, the maximum recorded value is under recommended value. This indicates that the mesh generated has a very good quality, as the average value is very low.

B. *NON-Orthogonality*

Often, the maximum recommendation is 75. There have been no records of values exceeding that amount. However, when the maximum is taken into consideration, the average amount is much less than the maximum amount. As a consequence, it is concluded that a very small number of factors directly contribute to degradation in mesh quality.

C. *Skewness*

As for the skewness, the situation is the same. In comparison with the recommended value, the maximum recorded value appears much higher. There was a significant decrease in the average value. Hence, the final mesh reflects the most accurate measurement possible, as a result of the majority data recorded being necessary. Data analysis shows that the majority of data recorded is necessary to create as accurate mesh as possible, leading to more precise results.

D. *Turbulence Model*

The compressibility of the air is insignificant in automobiles since they are low-speed means of transportation. Furthermore, the aim of this study was primarily to investigate how dimples affect aerodynamic performance (drag and downforce). Therefore, ignoring further the effect of the surface forces on the body in addition to the heat source, the continuity equation and momentum equation that govern the 3D fluid flow are as follows:-

Equation 1 Turbulence model equation

$$\frac{\partial u_i}{\partial x_i} = 0; \ \& \ \frac{\partial \rho u_i u_j}{\partial x_i} = -\frac{\partial \rho}{\partial x_j} + \frac{\partial \tau_{ij}}{\partial x_i};$$

Respectively;

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Where;
u_i = velocity components,
x_i = components of the position or coordinate vector,
r = pressure,
τ_{ij}= components of the viscous stress tensor,
ρ = density.
A turbulence model is very important to simulations of external flow fields around the spoiler. Many studies have been conducted to evaluate the performance of the turbulence model.

XI. PROPOSED DESIGN

Modern cars are having highly fine-tuned aerodynamics which make it difficult to improve the aerodynamics & improving the fuel efficiency, but improving aerodynamics of small components like side mirrors, shark fin, roof, bonnet, spoiler, trunk lid, etc. can help in improvement of fuel economy. In this paper we are checking if adding dimples to the spoiler will decrease the coefficient of drag or it won't affect at all. Adding dimples to the surface of the part is our solution to the fuel efficiency challenge since we research about the effects of surface roughness on the spoiler in simulation. If we see any improvement in comparison with normal spoiler it can create new area to explore for enhancing aerodynamics, handling & grip & most importantly fuel economy. I'll be comparing the results of normal spoiler with my uniquely designed dimpled spoiler. The dimples will be spread throughout the suction side of the spoiler wing, which is the top side. The dimples is divided in three rows and each dimple differs in size from the previous dimple, the bottom dimple row being the biggest while the top most row dimples being the smallest. The reason behind varying dimple sizes is that it creates a lot of vacuum in the first dimple and it results in making the air stick to the spoiler creating increase in downforce & the smaller dimples allow the air to produce minimal drag.
Before I could design the spoiler, I had to first figure out the various types of spoiler designs used in the automotive industry, such as front spoilers, lighted spoilers, pedestal spoilers, roof spoilers, lip spoilers, truck spoilers, and active spoilers. So, after learning about various spoilers, I decided to design pedestal spoilers, but first I needed to figure out the design and shape of the aerofoil. NACA 2412 is one of the most common four-digit NACA aerofoils. The first integer in a four-digit NACA numbering scheme denotes the limit of the or mean-line value (in percent of the chord). The second integer specifies the distance between the edge and the maximum camber position (in tenths of the chord). The thickness of the aerofoil is determined by the last two (in tenths of percent of the chord). The first two digits of NACA2412 are zeros, indicating a maximum camber of 2% at a chord length of 40%. The last two digits are "12," which indicate the aerofoil thickness in tenths of a chord length. This implies that the chord length is 0.012 times the maximum thickness. The NACA 2412 is a slow-speed aerofoil used in single-engine Cessna 152, 172, and 182 aircraft.
The computation investigation of the effects of dimple shapes on characteristics is presented. NACA 2412 is the aerofoil that was used in this study. For various shapes, the effects of dimples on flow separation on the aerofoil are investigated. The aim of this study is to find the best dimple shape for delaying flow separation and achieving good aerodynamic properties like lift and drag reduction. For the research, ONSHAPE is used to model the aerofoil. ONSHAPE is used to model the NACA 2412 aerofoil. The CAD models of the necessary number of aerofoils with or without dimples are produced using geometrical tools. CAD versions of the NACA aerofoil with and without dimpled surfaces are shown in Figure 3.

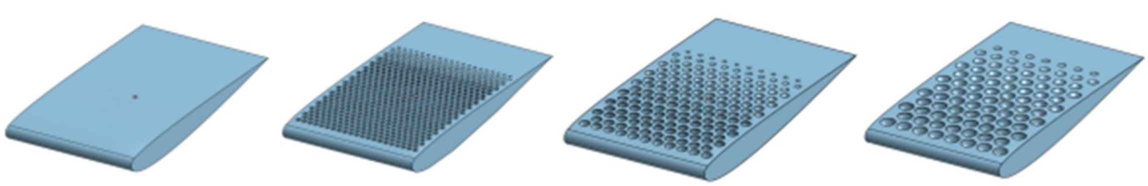

Figure 5 CAD Models.

After reviewing and analysing the literature, the following research deficiencies were discovered: only a few studies have used computational analysis. Dimples of different designs must be considered and computationally analysed. The majority of studies have only looked at dimples with smooth edges. For a deeper understanding, the influence of sharp edged dimples must also be investigated. Many studies do not consider the 3D analysis of various wings with dimples. SIMSCALE will be used to perform the numerical analysis, with the boundary conditions shown in table 2 and the wing dimensions shown in table 5.

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Table 4 Wing Dimensions

PARAMETERS	DIMENSIONS (MM)
Chord Length	300
Width	155
Max Depth	40% of chord
Dimple Depth	5

Table 5 Wing Boundary Condition

PARAMETERS	VALUES
Velocity Of Flow	56 m/s
Operating Temperature	1.529e-5 m^2/s
Turbulence	K-omega SST
Density Of Fluid	1.196 kg/m^2
Attack Of Angle	0 to 20 Degree

XII. RESULTS

Designing an automobile requires that you take into consideration the following two factors: drag & downforce. These factors result in improved handling & stability. The addition of aerodynamic techniques, such as spoilers to a car, usually serve the purpose of improving balance and handling, as well as helping the car to be more aerodynamic. The high air velocity behind and on top of our vehicles is the major reason for the downforce they produce. The spoiler is typically placed on the roof or the back of a car, not in the front or bottom of the car. Following are some of the results of numerical simulations and numerical calculations using Computational Fluid Dynamics software called Simscale.

A. Body Results

In order to allow the vehicle to be driven more efficiently, the spoiler is primarily used for reducing drag and producing downforce. The spoiler should provide the adequate downforce to the vehicle, but if it does not, it is regarded as an impractical design. Therefore, it is crucial to validate the design before proceeding to testing. Hence to make the simulations work perfectly with the dimples and for simulating accurate results for all the spoiler designs first we have to find out which attack of angle works efficiently with the NACA 2412 spoiler. For the purpose of testing a small section of 300 mm by 155 mm of the NACA 2412 spoiler is been simulated at a speed of 56 m/s at multiple attack of angles such as 0°, 10°, 15° & 20°. Since the spoiler is straight and not curved on horizontal axis, using a small section will have much difference with the values of full length spoiler, also it will reduce the simulation time. The following table compares the values of drag & lift from results of the simulation performed on the NACA 2412 spoiler.

Table 6 Velocity & Pressure Plot at 56 m/s for NACA 2412 Spoiler at various attack of angles

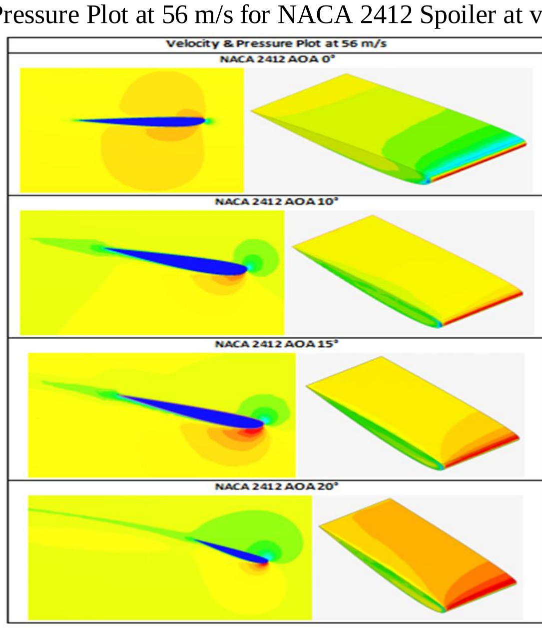


Table 7 Coefficient of Drag & Lift of NACA 2412 Spoiler at various attack of angles

Attack Of Angle	Coefficient of Drag	Coefficient of Lift (Downforce)	Drag-Lift Ratio
NACA 2412 @ 0°	0.1067	-0.565	0.187
NACA 2412 @ 10°	0.2817	-1.970	0.142
NACA 2412 @ 15°	0.405	-2.290	0.176
NACA 2412 @ 20°	0.530	-2.311	0.229
Average value	0.325	-1.787	0.181

This table illustrates that the small section of the NACA 2412 spoiler performs the best in terms of downforce of 2.311 at an AOA of 20° while also having the highest drag coefficient of 0.530. Aerodynamics of automobiles say that systems can only be considered efficient if they reduce aerodynamic drag and have more downforce. In this scenario, the spoiler at a high angle of attack produces maximum lift and maximum drag. Therefore, average values & drag-to-lift ratio using the formula below will determine which model is the most efficient AOA out of all four models.

Equation 2 average equation

$$Average = \frac{(Sum\ of\ Coefficient\ of\ Drags)}{(No.of\ AOA)} = \frac{(Sum\ of\ Coefficient\ of\ Lifts)}{(No.of\ AOA)};$$

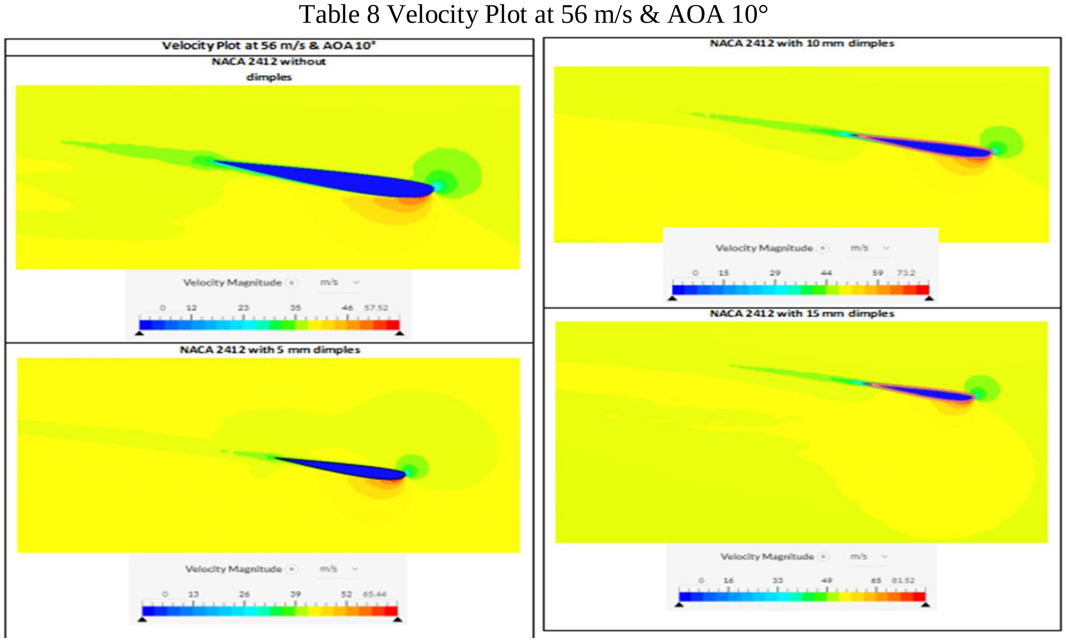
Equation 3 drag-lift ratio

$$(Drag - Lift)\ Ratio = \frac{Coeffiecent\ of\ Drag}{Coeffiecent\ of\ Lift};$$

Average values for the coefficients of drag and lift are 0.325 and -1.787 respectively. It means that for a model to be called efficient it must limit drag to 0.325 and have downward force greater than -1.787. Furthermore, if multiple values meet our needs then we need to take the lowest drag/lift ratio into consideration. We only have one model which fits the average requirement, which has a lower coefficient of drag (0.2817) than the average coefficient of drag (0.325) and a higher downforce (-1.970) than the average downforce (-1.787). Additionally, its drag to lift ratio (0.142) is lower than the average drag to lift ratio (0.181). This means the NACA 2412 spoiler provides optimal performance when placed at a 10-degree Attack of Angle. As a consequence additional testing will be conducted to determine the impact of different dimples sizes on the NACA 2412 after maintaining two things at constant speed (56 m/s) and attack of angles (AOA 10°).

A. *Velocity Plot*

Table 8 Velocity Plot at 56 m/s & AOA 10°



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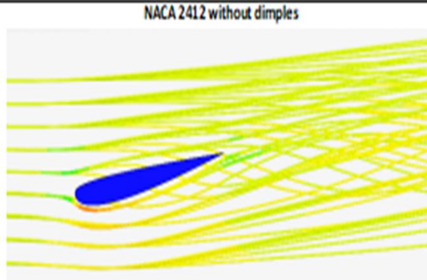
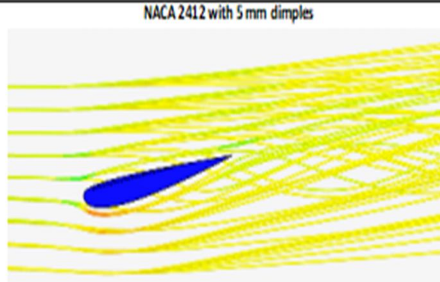
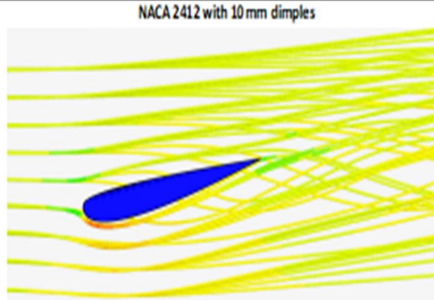
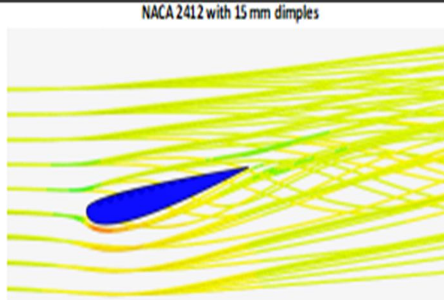
B. Streamline Plot

Table 9 Streamline Plot at 56 m/s & AOA 10°

Streamline Plot at 56m/s & AOA 10°
NACA 2412 without dimples

NACA 2412 with 5 mm dimples

NACA 2412 with 10 mm dimples

NACA 2412 with 15 mm dimples


Here, the colour scale represents air flow as it passes below the spoiler with a greater velocity than air flow above it. High velocity is represented by warm hues of red, orange, & yellow, while low velocity by a cool hue of blue, cyan, & green. It is noted that spoiler with dimples have much higher velocity below the spoiler when compared to spoilers without dimples. After looking at the velocity plot it was found that the frontal lower end of the spoiler is the area where highest velocity change is noticed the lowest high velocity recorded in our test was 57.52 m/s while the highest velocity recorded was 81.52 m/s. Similarly the top end of the spoiler is experiencing low velocity & thus producing negative lift in the font section of the wing, the low velocity is defined by the green, cyan and blue contour plots. The rear section of the wing also known as the tail is also have low velocity magnitude recorded during the test and is thus generating negative lift in the rear section.

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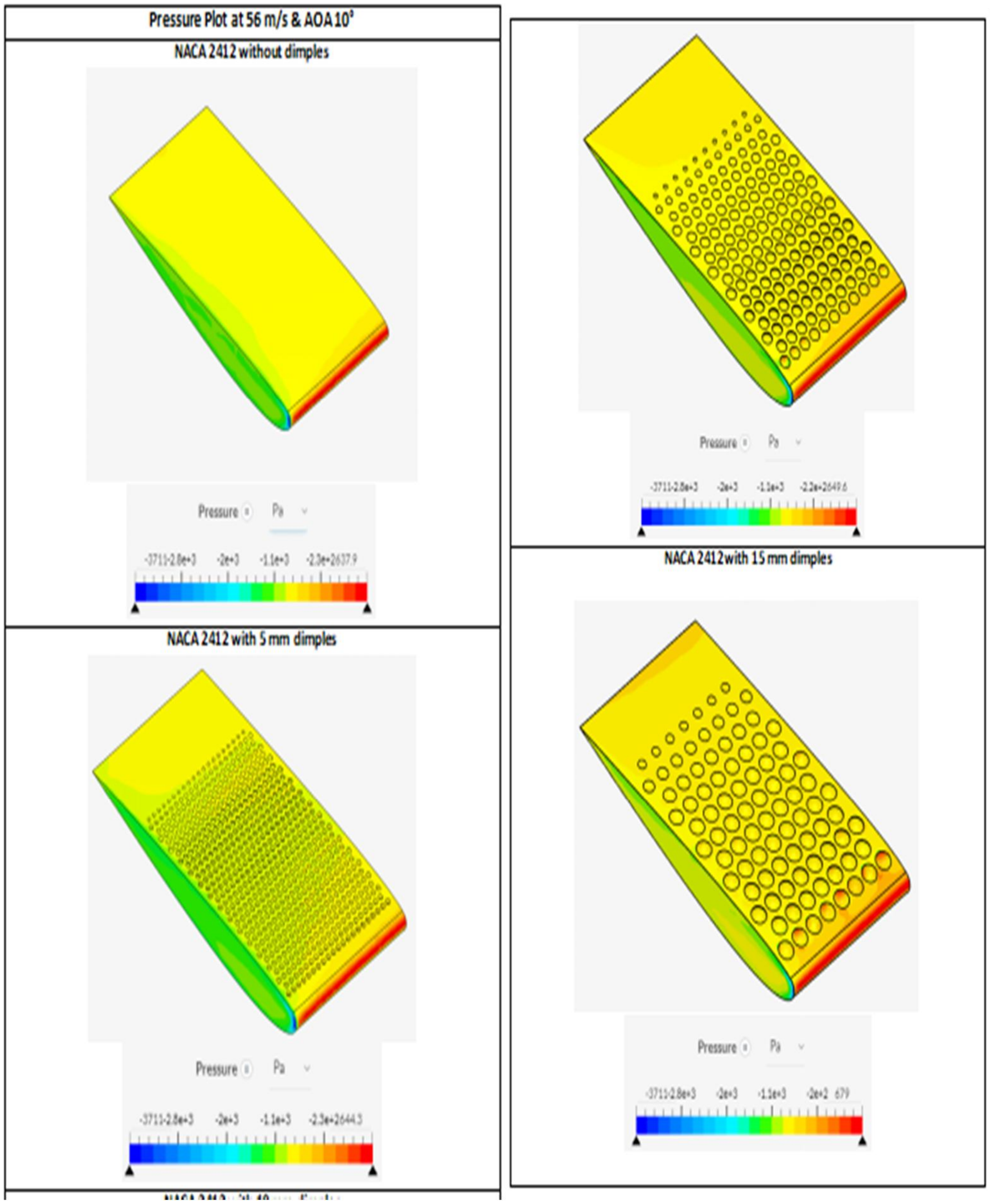
C. Pressure Plot

Table 10 Pressure Plot at 56 m/s & AOA 10°



The above figures show that the air flow at the beginning of the spoiler has a higher pressure when compared to the air flow at the end, it is represented by warm colours such as red, orange, & yellow for high pressure while cool colours such as blue, cyan, & green for low pressure. It can noted that spoiler with dimples have much higher pressure at the front of the spoiler when compared to spoiler without dimples that have low pressure at the front of the spoiler represented with blue, green, & yellow colour representation. The highest high pressure noted in all the test was in 15 dimple of 679 Pascal's while lowest high pressure being 637 Pascal's for spoiler without dimples. It can be noticed that the dimples in the first few rows have high pressure representation in red or orange colours while the remaining dimples are experiencing slightly lower pressure which is represented in yellow & green shades in it, this explains that the frontal dimples are more active than the dimples behind them when it comes to producing downforce. Turbulence & Streamline Plot.

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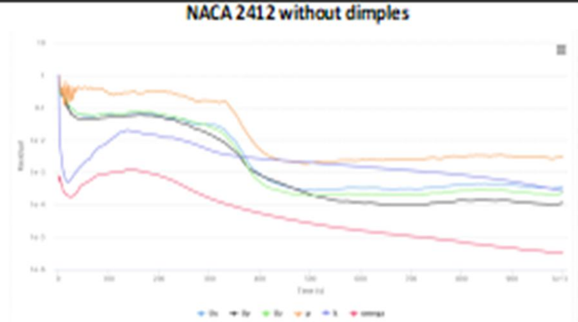
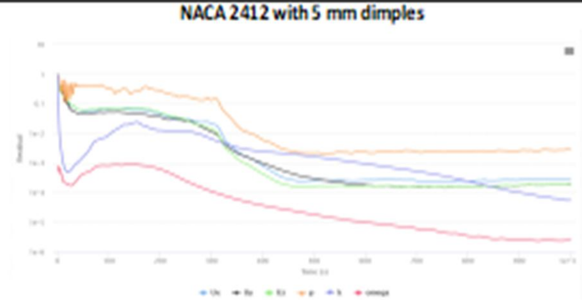
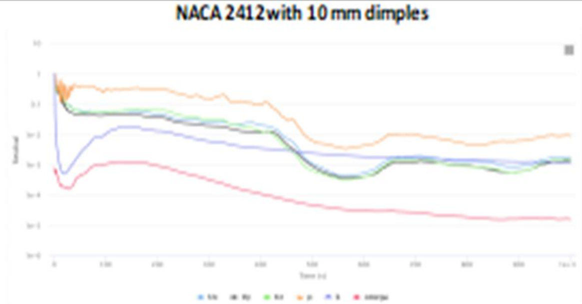
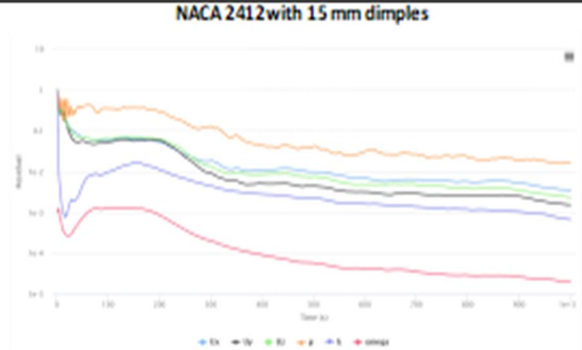
D. Residual Plot

Table 11 Residual Plot (K) at 56 m/s & AOA 10°

Residual Plot (K) at 56 m/s & AOA 10°
NACA 2412 without dimples

NACA 2412 with 5 mm dimples

NACA 2412with 10 mm dimples

NACA 2412with 15 mm dimples


It is said that the residual in between 1x10-3 & 1x10-6 to be the best for any aerodynamic analysis also the residual must be tend to get constant after a certain point and speed. The figure above shows all the residual plot for the spoiler with speed constant at 56 m/s & AOA at 10°. It can be seen for all the graphs the residual (k) in all the graphs is below the 1e-3 which when converted is 0.001 or also as 1x10-3, if the values are not in between the required values a higher refined mesh has to be generated. The graphs also show that the values are getting to a constant stage after 700 seconds time and if given time the will ultimately become straight lines. Since the plots meet the requirement it can be said that the test run were done correctly as the values are in the limit & are getting constant after certain period of time.

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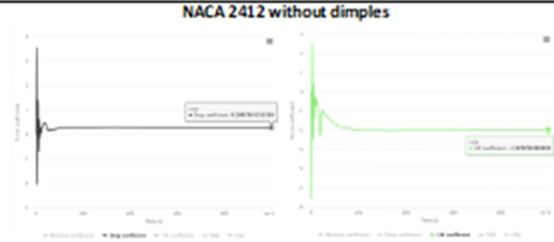
E. *Coefficient Drag & Lift*

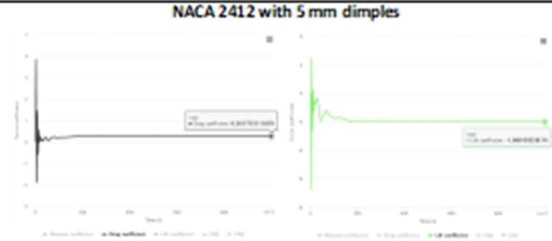
Table 12 Coefficient of Drag & Lift at 56 m/s & AOA 10°

Coefficient of Drag & Lift at 56 m/s & AOA 10°

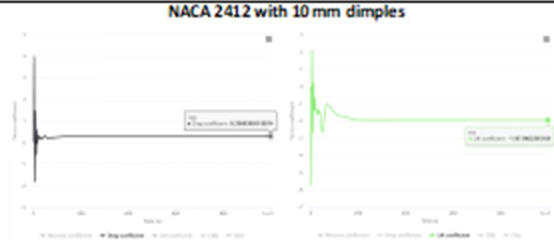
NACA 2412 without dimples



NACA 2412 with 5 mm dimples



NACA 2412 with 10 mm dimples



NACA 2412 with 15 mm dimples

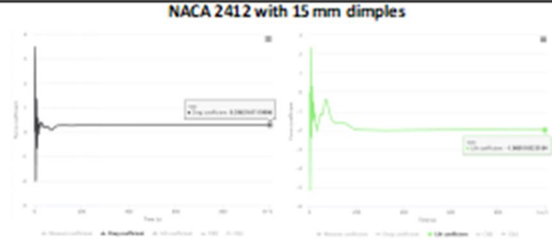


Table 13 Coefficient of Drag & Lift with different surface roughnesses

Spoiler Model	Coefficient of Drag	Coefficient of Lift	Drag to Lift Ratio
NACA 2412 without dimples	0.28	-1.97	0.142
NACA 2412 with 5 mm dimples	0.26	-1.99	0.136
NACA 2412 with 10 mm dimples	0.29	-1.95	0.148
NACA 2412 with 15 mm dimples	0.29	-1.98	0.146

The table above shows all the values that were recorded after the test on smooth and rough surface spoilers were done. It is clear that the spoiler with 5 mm dimples produce highest downforce with less drag coefficient lowest Drag to Lift ratio. The 5 mm dimples when compared with non-dimpled smooth surface spoiler, it generates more lift coefficient by -0.02 than smooth surface spoiler & lower drag coefficient by 0.02. The values of 5 mm dimpled spoiler meet the average values considered while test were performed on NACA 2412 spoiler for to determine most efficient AOA.

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F. Validation Of Simulations

Our simulation approach included affecting multiple surface roughnesses in order to determine the amount of downforce produced by each spoiler with regard to speed and AOA, which can be verified by determining the net downforce in Nm, and this will also be compared to mathematical calculations. At 56 m/s speeds, the better lift coefficient of the spoiler without dimples with an angle of attack of 10° & less drag are obtained, hence the validation calculations are done holding the angles of attack, speed & temperature constant at 10°, 56 m/s & 22°C respectively. All the values shown below in the table are in Nm & it can be seen that all the data of lift force is having negative values. As spoilers produce downforce rather than lift force, but the formula is made to calculate lift, resulting in negative values. Negative lift is referred to as downforce. Graphs below show the comparison between the computation and mathematical results:-

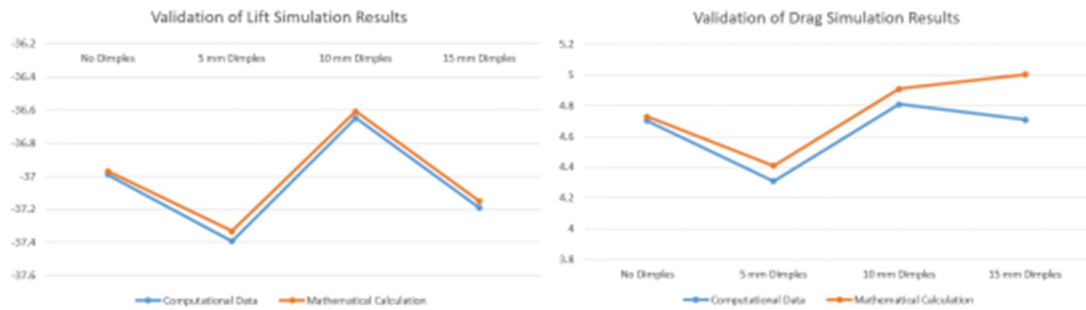


Figure 5 Validation of Lift & Drag simulation results

Table 14 Validating Lift & Drag Force by mathematical calculation with Computational Data

Spoiler Model	Computational Data		Mathematical Calculation	
	Fl (Nm)	*Fd (Nm)*	*Fl (Nm)*	*Fd (Nm)*
NACA 2412 without dimples	-36.99	4.70	-36.97	4.73
NACA 2412 with 5 mm dimples	-37.39	4.31	-37.33	4.41
NACA 2412 with 10 mm dimples	-36.65	4.81	-36.61	4.91
NACA 2412 with 15 mm dimples	-37.19	4.71	-37.15	5.00

These values are displayed in the table above using the analytical method. The following formulas were used to calculate and validate the lift and drag force in Newton meters. Also, the values in the above tables were calculated using a symmetry function with only half the spoiler used for reduced computation time. The mathematical calculation are almost close to the values we have received from the computational data. The difference in both the values is just of +/- 0.3 for both Lift force and Drag force. Since the values from the simulation results match with the values from the mathematical calculation it can be concluded that the simulation results are accurate and can be trusted to make final conclusion for this research. Both the Computational data and the mathematical calculation show that the spoiler with 5 mm dimples generate the highest lift force of -37.39 Nm & drag force of 4.31 Nm. After validating effects of dimples on the Lift & Drag force generated now the only area remaining to validate is the wake formation by each spoiler.

G. Numerical Calculation

Given:- For a automotive spoiler with velocity 56 m/s. wing are 0.01, coefficient of drag 0.2617 & coefficient of lift -1.9901.

The drag force is calculated by:-

Equation 4 Drag Force Equation

$$F_D = \frac{1}{2} \times \rho \times V^2 \times C_D \times A$$
$$= \frac{1}{2} \times 1.1965 \times 56^2 \times 0.2617 \times 0.01$$
$$= 4.41\ Nm$$

The lift force is calculated by:-

Equation 5 Lift Force Equation

$$F_L = \frac{1}{2} \times \rho \times V^2 \times C_L \times A$$
$$= \frac{1}{2} \times 1.1965 \times 56^2 \times (-1.9901) \times 0.01$$
$$= -37.33\ Nm$$

Where;

Drag force:

$F_D = \frac{1}{2} \rho V^2 C_D A$

Where,

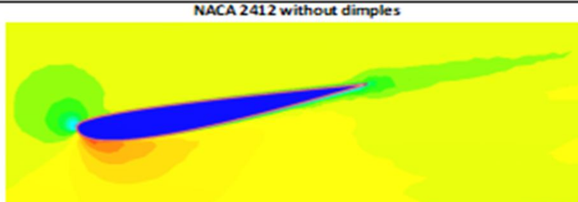
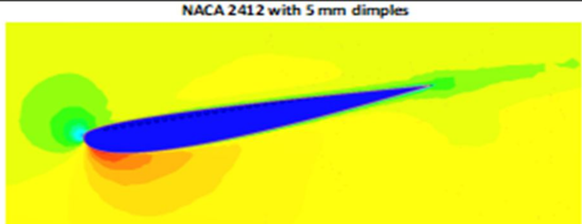
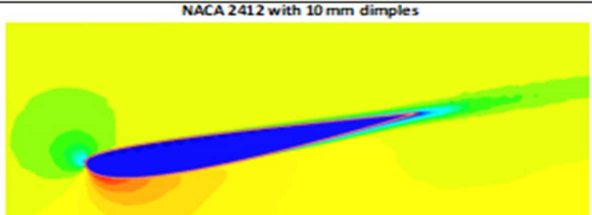
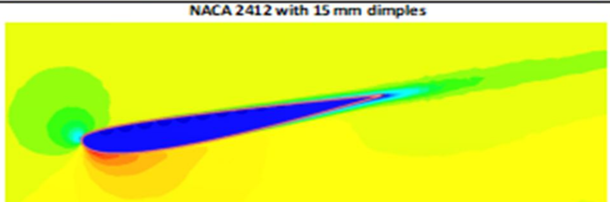
F_D is the drag force.
ρ is the fluid density.
V is the fluid velocity.
C_D is the drag coefficient
A is the cross sectional area.

Lift force:

$F_L = \frac{1}{2} \rho V^2 C_L A$

F_L is the lift force.
ρ is the fluid density.
V is the fluid velocity.
C_L is the lift coefficient
A is the cross sectional area.

Table 15 Wake Comparison

Wake Comparison
NACA 2412 without dimples

NACA 2412 with 5 mm dimples

NACA 2412 with 10 mm dimples

NACA 2412 with 15 mm dimples


The table above represents the wake formed by each spoiler at 56 m/s speed & 10° attack of angle. By looking at each spoilers wake formation at the tail-end of the spoiler it is clear that the 5 mm dimpled spoiler is generating the least amount of wake compared to other spoilers. The second least wake if formed by the spoiler without dimples. The spoiler with 15 mm dimples is forming the most wake as shown in the table above. The blue and cyan colours in the contour plot represent low velocity that slows down the spoiler. Spoiler with 10mm & 15mm dimples is generating larger wake with blue and cyan colours in the plot indicating low velocity resulting in slowing down the spoiler. And it is clear that non dimpled spoiler and spoiler with 5 mm dimples is not generating much longer wake with fewer blue and cyan colours in the plot.

XIII. CONCLUSION

With the work I have done now the outcome was that, dimples on aerodynamic parts, for example, spoiler significantly affect the vehicle aerodynamics. Investigating the current innovations gave me a thought of the requirement for development in this specific region to improve efficiency aerodynamic parts. I saw that the profundity of dimples influences the coefficient of drag, size of wake and the measure of downforce created. It very well may be seen that when there was a need to diminish the drag, larger and deep dimples turn out best for the laminar flow of air. While smaller & shallow dimples turn out best for keeping the wind current remain together for a long interval to keep the size of wake point small. All these examination gave me a thought of the potential changes I could make to my plan for both having the most reduced conceivable drag for rapid speeds and the most conceivable downforce and least wake distance. The dimple size that has worked for me and the other researchers in the most efficient way is the 5 mm dimples. The 5mm dimples has approximately improved aerodynamics of the NACA 2412 spoiler by 5% with respect to drag, lift & wake produced. With all the test performed personally on the spoilers with various dimples sizes I can conclude that dimples does affect aerodynamics of a spoiler in a positive and a negative way. Choosing the correct dimple size & depth for your use is a crucial decision that will determine if the dimples will work in improving the spoiler aerodynamics or messing with its aerodynamics. In my case after many test simulations before finalising any size, shape & pattern of arrangement I had to test every possible configurations to fully test the potential of dimples on improving spoiler's aerodynamics.

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