The Impact of NACA 4-series Aero Foil Rear Wing Spoilers on Sedan Car Aerodynamics and Fuel Efficiency: A Computational Fluid Dynamics Analysis

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Abstract— This research investigates the impact of integrating rear wing spoilers with NACA 4-Series airfoils on the petrol consumption and fuel efficiency of a sedan car at 100 km/h. The study evaluates the effects of NACA 0012, 2412, 4412, and 6412 airfoils at angles of attack of 0°, 5°, and 10° on the downforce, drag, and lift coefficients of the vehicle. Computational fluid dynamics (CFD) simulations using ANSYS Fluent software were conducted to analyze the airflow around the sedan, specifically a Hyundai Verna, equipped with various rear wing configurations. The findings indicate that the rear wing with NACA 2412 airfoil at a 0° angle of attack significantly improves aerodynamic efficiency, resulting in a 7.8% reduction in power consumption and an 8.5% increase in fuel economy, thereby enhancing the Verna's fuel efficiency from 19.2 kmpl to 21 kmpl. This study underscores the potential of aerodynamic modifications to significantly enhance vehicle mileage.

Index Terms- Aerofoil, Coefficient of Drag, Drag Force, Lift Force, Coefficient of Lift, Power Consumption, Fuel Economy.

I. INTRODUCTION

1.1AERODYNAMICS AND FLUID MECHANICS

Aerodynamics, a branch of fluid mechanics, studies air and gas motion around objects like aircraft and cars, focusing on lift, drag, and thrust. Fluid mechanics covers the behavior of all fluids, including liquids and gases, under various conditions. It provides the principles and equations used in aerodynamics, which is a specialized subset with applications in various engineering fields.

1.2 AEROFOIL AND TYPES

An aerofoil generates lift when air flows over it, crucial for aircraft wings and propeller blades. Types of aerofoils include:

- Symmetrical: Identical upper and lower surfaces, generating lift at a positive angle of attack.
- Asymmetrical (Cambered): Different surfaces, generating more lift at lower angles of attack.
- High-lift: Designed for greater lift at lower speeds or higher angles, often with flaps or slats.
- Supercritical: Minimizes drag at transonic speeds with a flattened upper surface.
- Elliptical: Smooth lift distribution with low induced drag, used in Spitfire aircraft.

1.2.1 NACA Aerofoil

The NACA aerofoil series optimizes aerodynamic characteristics. The 4-digit series indicates:

- Series number
- Design lift coefficient at zero angle of attack
- Maximum thickness as a percentage of chord length

For example, the NACA 2412 has a design lift coefficient of 0.12 and a maximum thickness of 24% of the chord length.

1.3 REAR WING SPOILER

A rear wing spoiler is an aerodynamic device mounted on a vehicle's rear to alter airflow, affecting performance by reducing drag, increasing downforce, or both. Key functions include:

- Drag Reduction: Optimizes airflow to reduce aerodynamic drag, improving fuel efficiency and performance.
- Downforce Generation: Creates vertical force for better traction and stability, especially at high speeds.

- Enhanced Stability: Increases stability by counteracting lift, reducing the risk of losing road contact.
- Improved Handling: Enhances grip and cornering performance, allowing higher speeds with better control.
- Aesthetic Enhancement: Adds a sporty appearance, integrated into the design of performance vehicles.

1.3.1 Role of Rear Wing Spoilers on Domestic Vehicles

Spoilers are common on various vehicles, influencing aerodynamics and performance, particularly at speeds above 60 km/h where drag significantly impacts engine power. They enhance stability and safety, especially during high-speed cornering, by improving traction and mitigating the risk of skidding. Spoilers function similarly to aerofoils, disrupting airflow to enhance stability.

1.4 KEY CONCEPTS

- Drag Force: Resistance encountered by an object moving through a fluid, opposite to the direction of motion. Reducing drag improves efficiency and performance.
- Drag Coefficient: Dimensionless measure of an object's aerodynamic drag. Lower values indicate better efficiency.
- Lift Force: Perpendicular aerodynamic force generated by pressure differences, crucial for aviation and relevant in automotive design for stability.
- Lift Coefficient: Dimensionless parameter quantifying lift. Lower values indicate better aerodynamic performance.
- Fuel Economy: Efficiency of fuel consumption, measured in distance per fuel unit. Improved by optimizing design and driving habits.
- Power Consumption: Rate of energy use in a vehicle, influenced by factors like drag and auxiliary systems. Reducing power consumption enhances efficiency and reduces costs.

II. PROBLEM STATEMENT

When vehicles are driven at high speeds, particularly on highways with speed limits up to 100 km/h, there is a significant risk of experiencing aerodynamic lift. This phenomenon arises due to the airflow dynamics around the windshield and rear window. As higher-pressure air moves over the windshield, it accelerates, leading to a pressure drop and exerting an upward force on the car's roof. Additionally, airflow over the rear window creates a low-pressure area, causing lift on the trunk. This lift can make the rear end of the sedan "light" and unstable, compromising safety and handling. To address this issue, rear spoilers are employed to disrupt the airflow, generate higher pressure in front of them, and counteract the low-pressure effects, thereby enhancing the vehicle's stability and performance.

III. VEHICLE GENERIC MODELS AND DIMENSIONS

The below Figure 4, outlines the steps before the lift and drag coefficient of New verna is obtained. The coefficient of lift is obtained for the front and rear sections of the car. The overall surface of the Verna is scanned and exported to CAD modeling software (CATIA) to smooth and repair the surface. The CFD analysis is done using Ansys Fluent. For the initial run, the result of Cd is compared to the standard published new Verna value of Cd which is around 0.308. If the initial run is far away from the standard value, then the CAD model is checked and repaired again until the Cd value comes within the 0.3> Cd >0.4 range. The values of drag and pressure coefficient are run at least 5 times and averaged. It is important to average this value to ensure the result is consistent and acceptable. Finally to ensure the vehicle achieves the occurrence of down forces at both the front and the rear side of the vehicle which ensures good vehicle stability.

Figure 4: Verna Side View

Figure 5: Verna Front View

Table 1: Drag values and Dimensions of Verna

Dimensions (lxbxh)	4,535 mm L 1,765 mm W 1,475 mm H
Frontal Area	2.65 m^2
Drag Coefficient (Cd) of Verna (Official)	0.308 Site Data
Drag Coefficient (Cd) a sedan with similar dimensions (Reference [4])	0.33
Drag Force Obtained through simulation	144.951 N
Cd obtained through simulation	0.366175
Cd Error with %	14.46 %
Cd Error when compared with existing model with similar dimensions	10.9621%

IV. NACA AEROFOILS SELECTED FOR THE STUDY

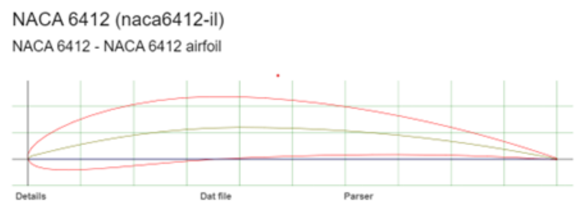

Figure 6: NACA 6412 profile

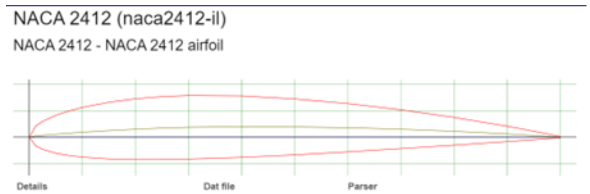

Figure 7: NACA 2412 profile

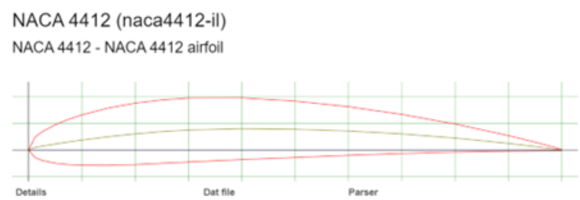

Figure 8: NACA 4412 profile

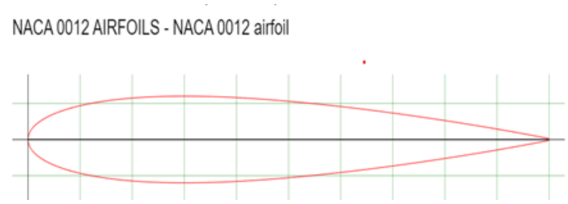

Figure 9: NACA 0012 profile

4.1 AEROFOIL GENERIC MODELS

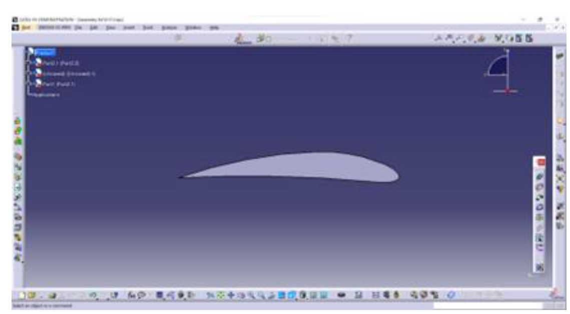

Figure 10: NACA 6412 CAD profile

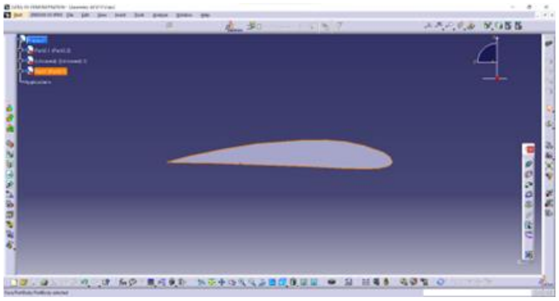

Figure 11: NACA 4412 CAD profile

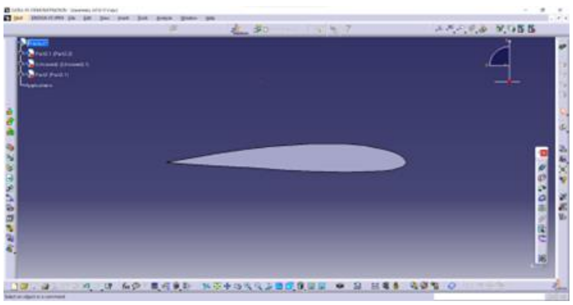

Figure 12: NACA 2412 CAD profile

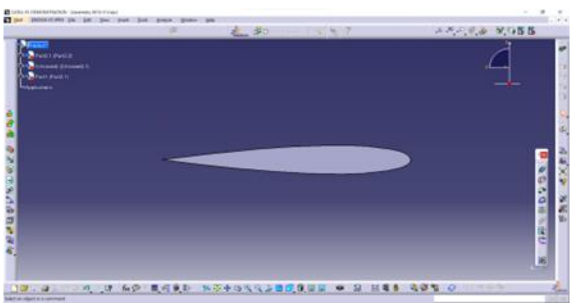

Figure 13: NACA 0012 CAD profile

4.2 GENERIC MODELS OF VERNA WITH AND WITHOUT REAR WING SPOILERS

Designing a Verna sedan using CATIA V5 involves creating a comprehensive 3D model of the vehicle, including its exterior body, interior components, chassis, and mechanical systems. CATIA V5 provides powerful tools for designing each aspect of the sedan with precision, allowing for detailed modeling, surfacing, and assembly.

Once the Verna sedan model is complete, the integration of a NACA aerofoil involves adding the aerofoil component at different angles of attack to the rear of the vehicle in the design environment. This process requires careful consideration of aerodynamic principles and the sedan's overall design aesthetics.

To integrate the NACA aerofoils, three different angles of attack are considered. This involves adjusting the orientation of the aerofoil relative to the sedan's body at varying angles to study its impact on aerodynamic performance. CATIA V5 facilitates this by enabling the manipulation of the aerofoil's position and orientation within the design space.

After integrating the NACA aerofoils at each angle of attack, simulations, and analyses can be conducted to evaluate the aerodynamic effects on the sedan's performance. CATIA V5 offers capabilities for performing aerodynamic simulations and analyzing results to assess factors such as drag, lift, and airflow patterns.

Overall, designing a Verna sedan using CATIA V5 and integrating it with NACA aerofoils at different angles of attack involves a systematic approach to ensure both aesthetic appeal and optimal aerodynamic performance.

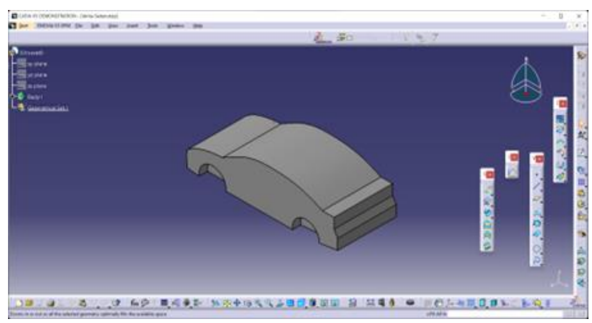

Figure 14: Verna CAD Model (Isometric View)

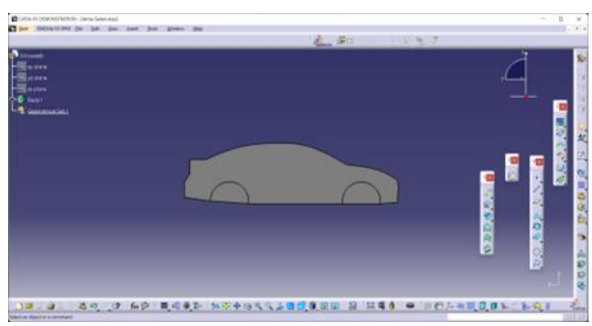

Figure 15: Verna CAD Model (Side View)

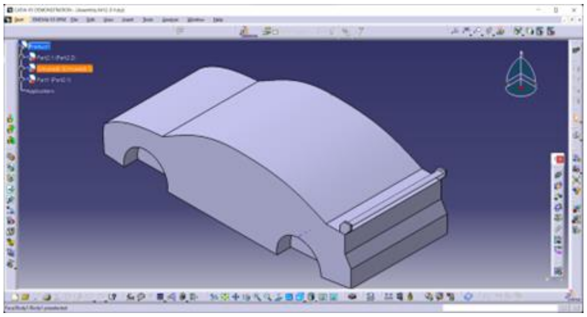

Figure 16: Verna CAD Model with rear wing spoiler (Isometric View)

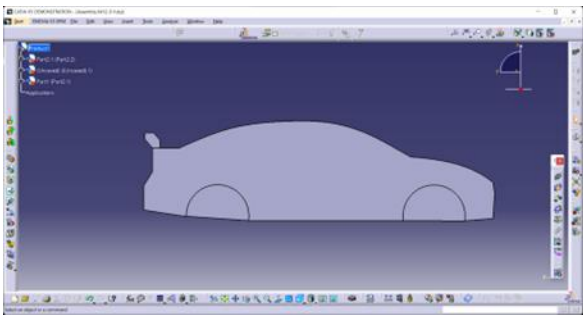

Figure 17: Verna CAD Model with rear wing spoiler (Side View)

V. ENCLOSURE AND VEHICLE ORIENTATION

A virtual airbox has been created around the 3D CAD model , which represents the wind tunnel in real life. Since we are more interested in the rear side of the vehicle, which is where the "wake of vehicle" phenomenon occurs, more space has been left in the rear side of the vehicle model to capture the flow behavior mostly behind the vehicle.

Due to the complexity of the simulation with limited computer resources and time, the complete domain was divided into half using a symmetry plane (YZ plane), which means, the simulation would be calculated for just one side of the vehicle, and since the other side is symmetric and YZ plane has been defined as symmetric boundary in the solver to make the boundary condition as "a slip wall with zero shear forces"; the simulation results would be valid for full model as well. All 5 surfaces of the virtual wind tunnel (air-box) have been named so the numerical solver of ANSYS FLUENT® would recognize them and apply the appropriate boundary conditions automatically. The final meshing can be seen in . The same procedure to create high-resolution meshing has been followed for both the cases (Case #1: Vehicle itself, Case #2: Vehicle with spoiler).

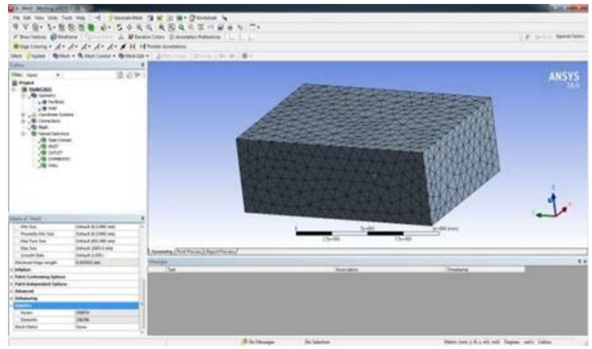

Figure 18: The final mesh

VI. CFD ANALYSIS

Computational fluid dynamics (CFD) is an engineering method for simulating the behavior of systems, processes, and equipment involving the flow of gasses and liquids, heat and mass transfer, chemical reactions, and related physical phenomena. More specifically CFD, or fluid simulation, can be used to reduce pressure drops, to predict aerodynamic lift or drag, to predict the rotor thrust, to calculate the airflow in air-conditioned rooms, to ensure adequate cooling, to optimize mixing rates, and so on .ANSYS combines the most respected names in fluid simulation — ANSYS ® FLUENT® and ANSYS® CFX® — to expertly address your evolving CFD needs at a time when product reliability, safety, and market performance are paramount. ANSYS offers the most complete suite of advanced CFD software tools available, coupled with unrivaled modeling capabilities, to help you achieve a faster total time to solution. More product development leaders worldwide trust ANSYS software as their fluid dynamics simulation platform for its accuracy, reliability, and speed. ANSYS is committed to providing world-class high-fidelity fluid dynamics technology for Simulation Driven Product Development. In addition to providing the most well-validated and used CFD products on the market, its ANSYS® Workbench™ platform is built on the ability to co-simulate. Users of ANSYS‟ CFD solutions can include structural mechanics or electrical aspects to a model through our other industry-leading solver solutions. ANSYS provides integrated tools that not only help you to conveniently understand which parameters the design is most sensitive to, but also determine which design parameters require the tightest control. Integrated tools for design (shape) optimization and Six Sigma analysis are also available. With ANSYS tools, your designers have the power to create better products more profitably. Because they can yield significant benefits (incl. more innovation, cost savings, reduced development time, and increased quality), they have become an integral part of the engineering design and analysis environment of companies in the widest range of industries.

Solver Settings:

Tabel 2: Solver Settings

Space	3D, Pressure based RANS Solver.
Time	Steady
Viscous	Standard K – ε
Wall Treatment	Standard Wall Treatment
Default Interior	Yes

Tabel 3: Solver Settings

Space	3D, Pressure based RANS Solver.
Time	Steady
Viscous	Standard K – ε
Wall Treatment	Standard Wall Treatment
Default Interior	Yes

Tabel 4: Solver Settings

Descretization Scheme

Pressure	Standard
Momentum	First Order Upwind
Turbulent Kinetic Energy	Second Order Upwind
Turbulent Dissipation Rate	Second Order Upwind

VII. DATA RESUCTION AND CFD

Tabel 5: Formulae Used

S.No.	Denotation		Formula
1	Cd	Coefficient of Drag	$Drag/(\rho V^2 A)2$
2	Cl	Coeficient of Lift	$Lift/(\rho V^2 A)2$
3	P	Power Consumption	Drag Force *V/0.65
4	MPG	Fuel Consumption	$1.3/(bsfc.*Cd*A*1.225*V^2)$

7.1 CFD Analysis without spoiler

The CFD Analysis was done using Ansys Fluent and the velocity contours, vectors and streamlines for both with and without rear wing spoilers are presented below.

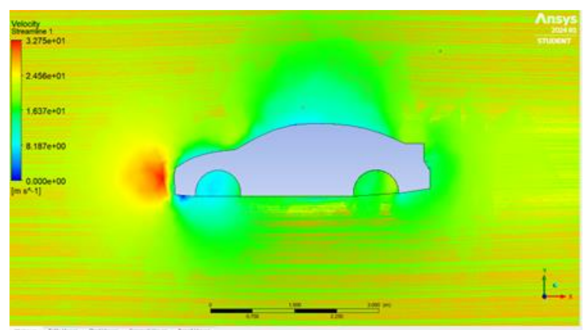

Figure 19: Velocity Contour(without spoiler)

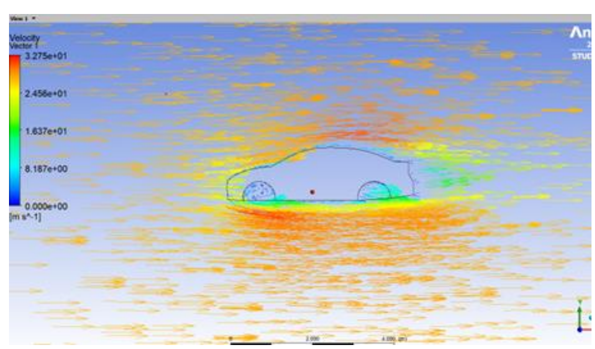

Figure 20:Velocity Vectors(without spoiler)

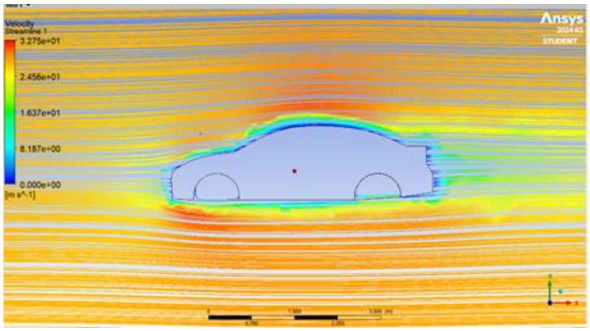

Figure 21: Velocity Streamline (without spoiler)

7.2 CFD Analysis with rear wing spoiler at angle of attacks (0,5 and 10 degrees)

The CFD Analysis was done using Ansys Fluent for the rear wing spoilers with NACA Aerofoils at 3 different angles of attack (0.5 and 10 degrees).

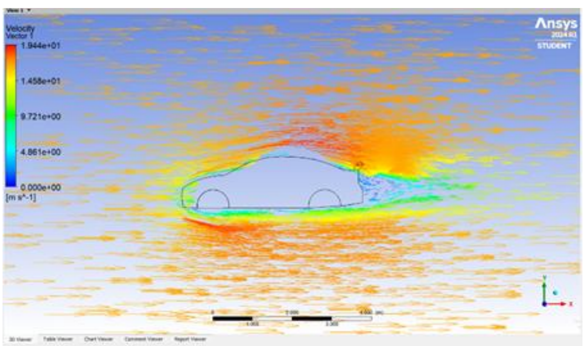

Figure 22: Velocity Vectors (with spoiler)

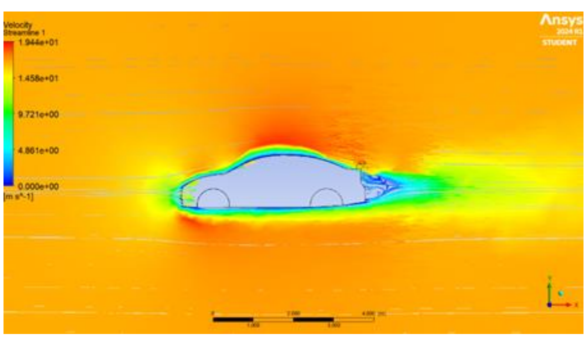

Figure 23: Velocity Streamline(with spoiler)

VIII. RESULTS AND DISCUSSION

The purpose of this chapter is to provide a review of past research efforts related to car aerodynamic drag & lift and its attachment for aerodynamic aids which act as rear spoilers. A review of other relevant research studies is also provided. Substantial literature has been studied on aerodynamic drag, aerodynamic lift and influences from both and purpose of rear spoiler as one of the aerodynamic aids. The review is organized chronologically to offer insight to how past research efforts have laid the groundwork for subsequent studies, including the present research effort. The review is detailed so that the present research effort can be properly tailored to add to the present body of literature as well as to justly the scope and direction of the present research effort

IX. DATA PRESENTATION

In comparing a car equipped with a rear wing spoiler to one without, several key performance metrics are evaluated. Firstly, the power consumption of each configuration is analyzed to understand the impact of the spoiler on energy requirements. Additionally, lift coefficients are compared to ascertain how the spoiler affects lift forces experienced by the vehicle. Drag coefficients are also examined to assess differences in aerodynamic drag between the two setups. Furthermore, fuel economy data is scrutinized to determine the spoiler's influence on overall fuel efficiency. Through this comprehensive analysis, insights into the effectiveness of the rear wing spoiler in improving aerodynamic performance and fuel economy are gained, providing valuable information for vehicle design and optimization efforts.

Table 6: Drag and Power Consumption of Car without Rear Spoiler

Spoiler	Area	Drag Force [N]	Velocity(m/s)	Drag Coefficient	% Cd drop	Power Consumption(W)
NONE	2.65	454.06	27.77	0.362751752		19398.84031

Table 7: Lift of verna without spoiler

S.No	Area	Drag Force [N]	Velocity(m/s)	Lift force [N]	Lift Coefficient
1	2.65	454.06	27.77	-49.9042	-0.039868819

Table 8: Drag and Power Consumption of Car with Rear Spoiler – NACA 0012

Angle of attack	Aerofoil Type	Area	Drag Force [N]	Velocity(m/s)	Drag Coefficient	% Cd drop
0	NACA 0012	2.65	416.9037	27.77	0.333	8.18
5	NACA 0012	2.65	420.74	27.77	0.33613	7.33
10	NACA 0012	2.65	422.32	27.77	0.33739	6.99

Table 9: Drag of Car with Rear Spoiler – NACA 2412

Angle of attack	Aerofoil Type	Area	Drag Force [N	Velocity(m/s)	Drag Coefficient	% Cd drop
0	2412	2.65	418.89656	27.77	0.33465	7.74
5	2412	2.65	424.71	27.77	0.3393	6.46
10	2412	2.65	423.974	27.77	0.33871	6.62

Table 10: Drag of Car with Rear Spoiler – NACA 4412

Angle of attack	Aerofoil Type	Area	Drag Force [N	Velocity(m/s)	Drag Coefficient	% Cd drop
0	4412	2.65	416.761	27.77	0.33295	8.21
5	4412	2.65	417.608	27.77	0.33362	8.02
10	4412	2.65	424.23	27.77	0.33892	6.56

Table 11: Drag of Car with Rear Spoiler – NACA 6412

Angle of attack	Aerofoil Type	Area	Drag Force [N	Velocity(m/s)	Drag Coefficient	% Cd drop
0	6412	2.65	427.67	27.77	0.34166	5.81
5	6412	2.65	413.96	27.77	0.33071	8.83
10	6412	2.65	416.802	27.77	0.33298	8.2

Table 12: Drag of Car with Rear Spoiler NACA 0012

Angle of attack	Aerofoil Type	Area	Drag Force [N	Velocity(m/s)	Drag Coefficient	% Cd drop
0	NACA 0012	2.65	416.9037	27.77	0.333	8.18
5	NACA 0012	2.65	420.74	27.77	0.33613	7.33
10	NACA 0012	2.65	422.32	27.77	0.33739	6.99

Table 6 shows us the drag force and power consumption of Hyundai Verna at 100 kmph.

Table 7 shows us the lift force and lift coefficient of the Hyundai verna without rear wing spoiler at 100 kmph. In order to decrease the lift coefficient of the vehicle at higher speeds, rear wing spoilers are integrated, about which we will be studying in the below results.

Tables 8, 9, 10, and 11 provide the corresponding values of Drag Coefficient and Drag Force at 100 km/h for different aerofoils (NACA 0012, NACA 2412, NACA 4412, NACA 6412) with 3 different angles of attack (0°, 5°, 10°). As shown in these tables, the drag force increases for NACA 0012, NACA 2412, and NACA 4412 as the angle of attack increases. However, in the case of NACA 6412, the drag force decreases as the angle of attack increases due to the aerofoil reaching its critical point. From these tables, we can interpret that the most significant decrease in the coefficient of drag occurs when the aerofoil is at a 5° angle for the NACA 6412 type, which is about 8.83%.

Table 13: Power Consumption and Fuel Economy of Car with Rear Spoiler – NACA 0012

Angle of Attack	Aerofoil Type	Area	Drag Force [N]	Velocity (m/s)	Power Consumption(W)	Power Consumption is decreased by	Fuel Economy is increased by
0	12	2.65	416.9	27.77	17811.4	8.18	8.91
5	12	2.65	420.74	27.77	17975.3	7.33	7.91
10	12	2.65	422.32	27.77	18042.8	6.99	7.51

Table 14: Power Consumption and Fuel Economy of Car with sRear Spoiler – NACA 2412

Angle of Attack	Aerofoil Type	Area	Drag Force [N]	Velocity (m/s)	Power Consumption(W)	Power Consumption is decreased by	Fuel Economy is increased by
0	2412	2.65	418.89	27.77	17896.54	7.74	8.39
5	2412	2.65	424.71	27.77	18144.91	6.46	6.91
10	2412	2.65	423.97	27.77	18113.47	6.62	7.09

Table 15: Power Consumption and Fuel Economy of Car with Rear Spoiler – NACA 4412

Angle of Attack	Aerofoil Type	Area	Drag Force [N]	Velocity (m/s)	Power Consumption(W)	Power Consumption is decreased by	Fuel Economy is increased by
0	4412	2.65	416.76	27.77	17805.31	8.21	8.94
5	4412	2.65	417.6	27.77	17841.498	8.02	8.72
10	4412	2.65	424.23	27.77	18124.41	6.56	7.03

Table 16: Power Consumption and Fuel Economy of Car with Rear Spoiler – NACA 6412

Angle of Attack	Aerofoil Type	Area	Drag Force [N]	Velocity (m/s)	Power Consumption(W)	Power Consumption is decreased by	Fuel Economy is increased by
0	6412	2.65	427.67	27.77	18271.37	5.81	6.17
5	6412	2.65	413.96	27.77	17685.644	8.83	9.68
10	6412	2.65	416.8	27.77	17807.063	8.2	8.93

Table 17: Lift of Car with Rear Spoiler NACA 0012

AoA	Aerofoil type	Area	Velocity(m/s)	Lift force	Lift Coefficient
0	NACA 0012	2.65	27.77	-83.134	-0.066416342
5	NACA 0012	2.65	27.77	-52.2512	-0.041743854
10	NACA 0012	2.65	27.77	-5.752242	-0.004595507

Table 18: Lift of Car with Rear Spoiler NACA 2412

AoA	Aerofoil type	Area	Velocity(m/s)	Lift force	Lift Coefficient
0	2412	2.65	27.77	-83.3701	-0.066604964
5	2412	2.65	27.77	-38.0026	-0.030360546
10	2412	2.65	27.77	-2.34912	-0.001876729

Table 19: Lift of Car with Rear Spoiler NACA 4412

AoA	Aerofoil type	Area	Velocity(m/s)	Lift force	Lift Coefficient
0	4412	2.65	27.77	-52.799	-0.042181495
5	4412	2.65	27.77	14.0843	0.011252047
10	4412	2.65	27.77	19.2148	0.01535084

Table 20: Lift of Car with Rear Spoiler NACA 6412

AoA	Aerofoil type	Area	Velocity(m/s)	Lift force	Lift Coefficient
0	6412	2.65	27.77	-43.859	-0.035039266
5	6412	2.65	27.77	-7.66506	-0.006123671
10	6412	2.65	27.77	22.113	0.017666232

Tables 13, 14, 15, and 16 provide the corresponding values of Power Consumption at 100 km/h for different aerofoils (NACA 0012, NACA 2412, NACA 4412, NACA 6412) with 3 different angles of attack (0°, 5°, 10°). As shown in these tables, the Power Consumption increases for NACA 0012, NACA 2412, and NACA 4412 as the angle of attack increases. However, in the case of NACA 6412, the drag force decreases as the angle of attack increases due to the aerofoil reaching its critical point.

From these tables, we can interpret that the most significant decrease in power consumption occurs when the aerofoil is at a 5° angle for the NACA 6412 type, which is about 8.831%, and the corresponding increase in fuel economy is by 9.68%.

Tables 17, 18, 19, and 20 provide the corresponding values of Lift Coefficient and Lift Force at 100 km/h for different aerofoils (NACA 0012, NACA 2412, NACA 4412, NACA 6412) with 3 different angles of attack (0°, 5°, 10°). As shown in these tables, the Lift force increases for NACA 0012, NACA 2412, and NACA 4412 as the angle of attack increases. However, in the case of NACA 6412, the Lift force decreases as the angle of attack increases due to the aerofoil reaching its critical point.

From these tables, we can interpret that the most significant decrease in lift force occurs when the aerofoil is at a 0° angle for the NACA 2412 type, which is -83.37 N.

X. RESULTS COMPARISON

TABLE 21: COMPARISON OF THE RESULTS

AoA	Aerofoil Type	Area	Drag Force [N]	Velocity (m/s)	Drag Coefficient	% Cd drop	Power Consumption(W)	Power Consumption is decreased by(%)	Fuel Economy is increased by(%)	Lift force	Lift Coefficient
NONE	NONE	2.65	454.06	27.77	0.36275		19398.8403			-49.9042	-0.03986
		2.65	165.21	16.66	0.36671		4234.45939			-52.2561	-0.11599
0	2412	2.65	418.89	27.77	0.33465	7.74	17896.549	7.74	8.39	-83.3	-0.0666
5	6412	2.65	413.96	27.77	0.33071	8.83	17685.644	8.83	9.68	-7.6	-0.00612

Table 21 represents the accumulated data from Tables 6 - 20 which present the data about the drag,lift,power consumption and fuel efficiency of the sedan with various aerofoils.

By examining the data, it is observed that the most significant drag reduction occurs when using a NACA 6412 aerofoil at a 5° angle, both at 100 kmph.

However, despite the greater drag reduction with the NACA 6412 at 5°, our objective was to identify an aerofoil that minimizes both drag and lift, or maximizes downforce. In this regard, the NACA 2412 aerofoil at a 0° angle appears suitable for the Hyundai Verna.

It reduces power consumption and enhances fuel economy by producing less drag while generating more downforce compared to the NACA 6412 at a 5° angle.

CONCLUSION

- The NACA 0012 Aerofoil at 100 km/h, when integrated as a rear wing at three angles of attack (0°, 5°, & 10°): The most efficient performance, with the least drag force, lift force, minimal power consumption, and improved fuel economy, was observed at an angle of attack of 0°. This configuration resulted in an 8.18% reduction in drag force and power consumption, along with an 8.91% increase in fuel economy.
- Similarly, the NACA 2412 Aerofoil at 100 km/h, when integrated as a rear wing at three angles of attack (0°, 5°, & 10°): The most efficient performance, with the least drag force, lift force, minimal power consumption, and improved fuel economy, was observed at an angle of attack of 0°. This configuration resulted in a 7.74% reduction in

drag force and power consumption, along with an 8.39% increase in fuel economy.

- The NACA 4412 Aerofoil at 100 km/h, when integrated as a rear wing at three angles of attack (0°, 5°, & 10°): The most efficient performance, with the least drag force, lift force, minimal power consumption, and improved fuel economy, was observed at an angle of attack of 0°. This configuration resulted in an 8.21% reduction in drag force and power consumption, along with an 8.94% increase in fuel economy.
- The NACA 6412 Aerofoil at 100 km/h, when integrated as a rear wing at three angles of attack (0°, 5°, & 10°): The most efficient performance, with the least drag force, lift force, minimal power consumption, and improved fuel economy, was observed at an angle of attack of 5°. This configuration resulted in an 8.83% reduction in drag force and power consumption, along with a 9.68% increase in fuel economy.
- In conclusion, the study highlights the significant impact of rear wing spoilers on the aerodynamics of a sedan, particularly utilizing the NACA 2412 Aerofoil at a 0° angle of attack, on the performance of vehicles like the Verna. The data presented demonstrates that integrating such aerodynamic features can lead to tangible improvements in power consumption and fuel economy, with reductions of 7.8% and increases of 8.5% respectively. These enhancements are primarily attributed to the combined effects of increased downforce and decreased drag force provided by the aerodynamic configuration.
- By integrating a rear wing spoiler, the Hyundai Verna, which typically offers an average mileage of 19.2 kmpl, experiences a notable enhancement in fuel efficiency. This addition facilitates the optimization of the car's aerodynamics, effectively reducing drag and improving airflow around the vehicle. Consequently, the Verna's mileage is boosted to 21 kmpl, showcasing the significant impact of aerodynamic modifications on fuel economy.
- Moreover, the benefits extend beyond fuel efficiency alone. Increased downforce and decreased drag not only reduce fuel consumption and power usage but also offer advantages in stability, particularly at higher speeds. By enhancing the vehicle's aerodynamic profile, these improvements contribute to safer and more efficient driving experiences, particularly in scenarios where stability and control are paramount.

Thus, the integration of aerodynamic features like the NACA 2412 Aerofoil can lead to multifaceted benefits, encompassing fuel efficiency, power consumption, and overall driving stability. These findings underscore the importance of aerodynamic design in optimizing vehicle performance and efficiency, ultimately enhancing the driving experience while also promoting environmental sustainability.

Advantages of using spoiler:

- Increases tires capability to produce cornering force
- Increases fuel economy
- Stabilizes vehicles at high speed
- Improves braking performance
- Gives better traction

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