iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL
FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** VIII **Month of publication:** August 2021

DOI: https://doi.org/10.22214/ijraset.2021.37787

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VIII Aug 2021- Available at www.ijraset.com

Study and Design a Spoiler to Understand Aerodynamics with Various Angle of Attack at Different speeds

Smit Shendge[1], Heet Patel[2], Yash Shinde[3]
[1, 2, 3]UG. Student, Department of Automobile engineering from University of Wolverhampton

Abstract: In this scope of study, various type of spoiler is researched out of which a pedestal spoiler is chosen to design as it generates a very good downforce and also has good aesthetic appeal to it, spoiler is designed considering actual scaled dimensions. Analysis on the designed pedestal spoiler is carried out to get to know how much the downforce is generated and at the same time how much drag coefficient is produced. Also, angle of attack of the spoiler in various degrees (9, 6, 4, 3, 2, 0, -2, -3, -4, -6, -9, -12, -15) is carried out to know downforce at various angle of attack with various velocity (10, 15, 20, 25, 30, 35, 40, 45, 50) inputs in meter per seconds. After carrying out more than 80 analysis, found that highest downforce generated by the spoiler's angle of attack is at (-6) degree with a 400 N of downforce and also with low drag. Velocity magnitude contour plot of each angle is provided to understand the air flow around each angle of attack. To validate the results given by the simulation tool a mathematical/analytical calculation are carried out for four angles of attack with a good result and also graphs are plotted for each validation to figure out the variation in them. Observing the validation's graphs and calculations the difference between computational results and mathematical/analytical results is less than 5% indicating a proper process carried out in simulation and approximately giving realistic values that can be given in a wind tunnel aerodynamic test.
Keywords: Spoiler, Aerodynamics, CAD, CFD, Drag coefficient, Lift coefficient, angle of attack.

I. INTRODUCTION

As the evolution in automobile took place the speed of the vehicles also increased, and at a high speed the velocity of the air faced by the vehicle is also high and as vehicle has some ground clearance to the body for other safety parameters, the wind gushes form this ground clearance gap continuously which can produce a lift in the vehicle thereby losing the traction of the vehicle and worst case scenario can lead to a fatal accident. To alleviate lift mishap a device is implemented on vehicle at rear and sometimes at front which is known as spoiler if it's at rear and air dams if it's in front of the car. A spoiler has an aerofoil shape like an aeroplane's wing but instead a upside down position is used in case of spoiler to produce a downforce instead of lift. This spoiler helps to generate downforce and maintain traction of the vehicle even at high speed thereby eliminating chances of lift of the vehicle at high speed. So, a spoiler is a safety device that are usually used in sports car, supercars and hyper cars to keep the car stick to the ground and maintain traction. A range of 260 Newtons to 445 Newtons of downforce is produced by a standard spoiler.

A. Aim

Do analysis on a designed spoiler considering various angle of attack of the spoiler and also at various velocity and to produce results from various cases and validate the results mathematically/analytically.

B. Objective

1) To choose a spoiler from types of spoiler
2) To design a spoiler with a good aerofoil (wing) design
3) To do analysis on various angle of attack of spoiler and analyze an angle with highest downforce.
4) To validate the computational results by solving using a mathematical/analytical method and compare the computational and mathematical values.

II. LITERATURE REVIEW

Divya Teja Ayyagari et. al**.** in this scope of research, an active split spoiler is used to control the yaw and roll motion of a high-speed road vehicle while taking sharp turns. Analysis of car with and without spoiler is compared, also as it's a split spoiler one spoiler with some degree and other with another degree is also considered to carry out analysis on that case scenario. In research analysis found 10 degree to 15 degree as highest downforce generating angle individually (for split spoiler). Also, analysis results are compared with wind tunnel test results to validate the generated results. [1]

Rubel Chandra Das et. al. in this study, a spoiler is designed in Autodesk considering spoiler as a safety system in high speed vehicles to generate downforce during high speed. A spoiler is designed in Autodesk and also analysis is done in Autodesk analysis tool. Analysis of spoiler is also done considering various angle of attack and also various velocity. Analysis is done to calculate lift, drag and pressure. [2]

III. METHODOLOGY

Methodology is divided in three parts according to the assignment brief

A. Part 1

1) *Research on Different types of Spoiler:* Did a research on various types of spoilers that are used in automobile and designed especially for various application purposes and the vehicle type.

Following are the types of spoiler that exist in current automobile market [3], [4]

a) Pedestal spoiler
b) Lip spoiler
c) Roof (Roofline) spoiler
d) Lighted spoiler
e) Truck spoiler
f) Front spoiler
g) Whaletail spoiler
h) Ducktail spoiler

2) *Selecting a Spoiler then sketching/designing a Spoiler:* From the various mentioned spoilers, choose the pedestal(post) spoiler. This post spoiler is used widely in racing application which are very well designed and tuned according to the car's dimensions. A post spoiler is attached on vehicle's rear end with a support as it names says 'pedestal" at a particular height with a wing width same as the rear end of the vehicle or a bit smaller than that, this wing is an aerofoil shape but placed in opposite direction(upside down) to produce downforce instead of giving lift to the vehicle. This post spoiler is attached for two reasons firstly, to give an aesthetic appeal to a vehicle due to its design and secondly, due to its ability of producing downforce at high speed and cornering. These are the two main reasons to select this pedestal (post) spoiler to design and work on.
3) *3D modelling a spoiler on CAD Tool:* Made a model of the spoiler on a CAD tool Onshape with a reference of the reference model of the spoiler. While designing gave a proper aerofoil design but in opposite direction (upside down) to the wings of the spoiler, also added side flaps to increase its aesthetic appeal and added a proper pedestal for the wing as a base support and this pedestal is not fully solid it is fully topologically optimized to reduce the weight and maintain its strength as good as a solid support. Width of the designed spoiler is 1700 mm and the length of spoiler is 320mm.

Reference spoiler Design [5]

Fig. 1. A Spoiler for Reference

CAD Modeled spoiler

Figure 2 Spoiler's isometric view

4) *Importing the Model in Analysis tool and Creating an Enclosure:* Imported the model in SIMSCALE analysis tool in a PARASOLID form to carry out an aerodynamic analysis on the made spoiler model. Created enclosure (flow domain) for the CFD analysis of the spoiler. The spoiler's length in meter is multiplied to get the enclosure, for enclosure's length multiplied by 20, for enclosure's width multiplied by 12, for enclosure's height multiplied by 5 and multiplied by 4 to keep the spoiler in enclosure at a distance from front side (inlet). In the analysis, have not considered supports of spoiler as analysis is done without a car and using supports will be unnecessary and will keep the results same without supports. After creating an enclosure created topological entities (named selection) to the enclosure.

5) *Mathematical Model:* In all the spoiler aerodynamic analysis a K-Omega SST model is used which is a turbulence with shear stress transport model. This model is widely used and also well known for external CFD analysis like aerodynamic analysis and gives results very realistic.
6) *Material:* Air is given as material for flow domain/flow region with Kinematic viscosity $1.52 \times 10^{-9}\ m^2/s$ and density as $1.196\ Kg/m^3$. (density of air according to 22-degree Celsius)
7) *Boundary conditions for all analysis*
a) Velocity inlet: To consider vehicle is moving at a particular speed, in this case 28 m/s (100.8 km/h) velocity considered.
b) Pressure outlet: Area through which air exits the test section
c) No slip (spoiler): Considering faces of the enclosure's cavity faces (Spoiler) as fixed object in flow domain to get results when air passes form inlet at a particular given velocity.
d) Moving wall (for bottom enclosure face): Considering bottom face as road at moving at same velocity as the inlet velocity to create a realistic scene of moving car.
e) Slip walls (side walls of enclosure as slip walls): Considering side faces as the side walls of the wind tunnel with an applied layer of slip liquid on it to keep the air flow smooth and not cause any resistance due to them.

8) *Grid/Mesh generation*
Created a Cartesian box for localizing the mesh position
Gave a region refinement of 0.01m maximum edge length to give a fine mesh in the location near to spoiler get realistic results.
Mesh setting: created a Hex-dominant mesh with a moderate fineness to reduce the analysis time.
Mesh event log to get to know how many nodes, face, hexahedra, prism, polyhedra and volumes are created in the created mesh.

B. Part 2
For part 2 took all the analysis variables same as part 1 only used a symmetry spoiler model for analysis to reduce simulation run time and at the same time maintain the result quality.

Fig. 3. Cross-Section of Spoiler at various angle of attack

1) Changing the angle of attack of spoiler with different velocity and at different temperature
Considered following angle of attack of spoiler in degrees
Considered following speeds in meter per seconds: 10, 15, 20, 25, 30, 35, 40, 45, 50
Considered three temperature 30, 22 and -5 in degree Celsius with two speed 30 m/s and 50 m/s for four angle of attack -6, -9, -12 and -15

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C. Part 3

Using a mathematical/analytical to validate the CFD simulation results
Made use of mentioned formulas to calculate lifting force and drag force

Lifting Force

The lifting force acting on a body in a fluid flow can be calculated

$$F_L = c_L\ 1/2\ \rho\ v^2\ A \qquad (1)$$

where

F_L = lifting force (N)

c_L = lifting coefficient

ρ = density of fluid (kg/m^3)

v = flow velocity (m/s)

A = body area (m^2)

Drag Force

The drag force acting on a body in fluid flow can be calculated

$$F_D = c_D\ 1/2\ \rho\ v^2\ A \qquad (2)$$

where

F_D = drag force (N)

c_D = drag coefficient

ρ = density of fluid (kg/m^3)

v = flow velocity (m/s)

A = body area (m^2)

Fig. 4. Formulas for Lift force and Drag force

IV. RESULTS

Similar to methodology result is also divide in three parts

A. Part 1

As spoiler has a curve design (aerofoil) at its bottom the velocity of the air is high, as seen in a contour plot as red and velocity above the spoiler wing is less, seen in green and blue color. In pressure plot blue is the region of low pressure as the air directly hitting on spoiler's curve is making the air to spread out generating low pressure region. For turbulence red is the region of highest as seen in velocity plot there no air flow behind the spoiler wing generating vortex and therefore high region of turbulence.

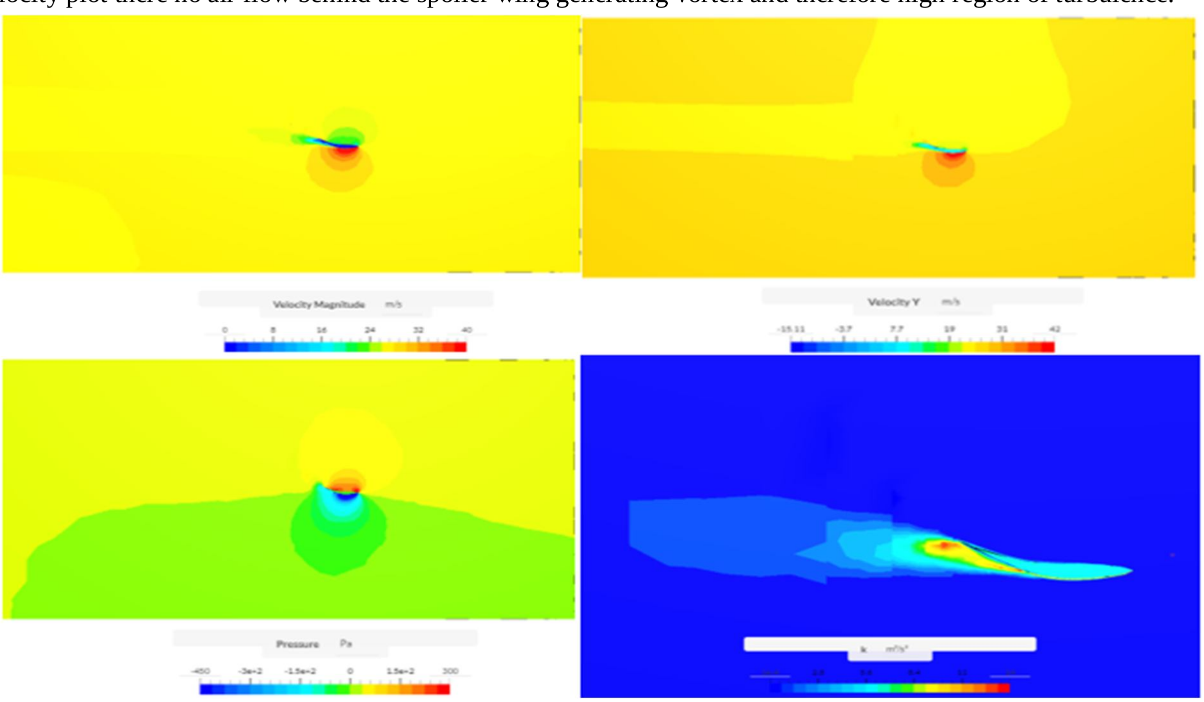

Fig. 5. Velocity magnitude, Velocity Y, Pressure and Turbulence(k) plot for 0-degree angle of attack at 30 m/s

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Velocity magnitude streamline flow around a spoiler

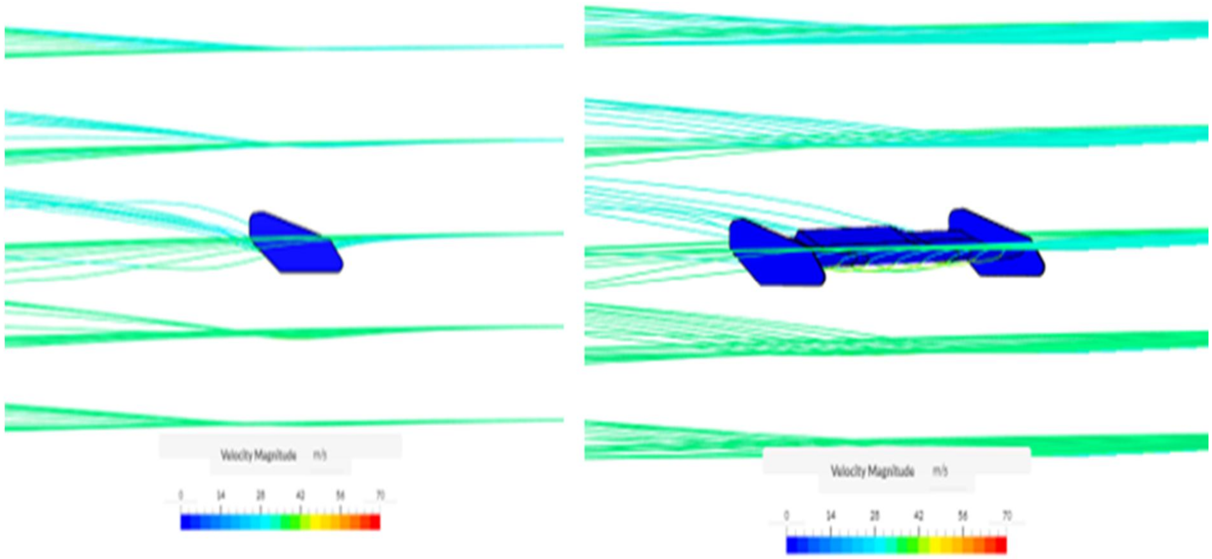

Fig. 6. Velocity magnitude Streamline flow fort 0-degree angle of attack at 30m/s

245 Newtons of downforce generated (Z-direction) at 28 m/s with 0-degree angle of attack of spoiler
26.805 Newtons of force generated in Y-direction (in the direction of air flow)

A 0.539 drag generated at 0-degree angle of attack of spoiler at 28 m/s

-4.699 lift produced for 0-degree at 28 m/s (negative sign indicates downforce)
Residual plot of 1e-4 reached for this analysis case
Mathematical/analytical calculations

To validate lift coefficient of the spoiler at 0-degree angle of attack with 28 m/s velocity

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

$$-245.415 = C_L \times \frac{1}{2} \times 1.196 \times 28^2 \times 0.11135230$$

$$-245.425 = C_L \times 52.205$$

$$C_L = \frac{-245.425}{52.205}$$

$$C_L = -4.701$$

To validate drag coefficient of the spoiler at 0-degree angle of attack with 28 m/s velocity

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

$$26.805 = C_D \times \frac{1}{2} \times 1.196 \times 28^2 \times 0.11135230$$

$$26.805 = C_D \times 52.205$$

$$C_D = \frac{26.805}{52.205}$$

$$C_D = 0.513$$

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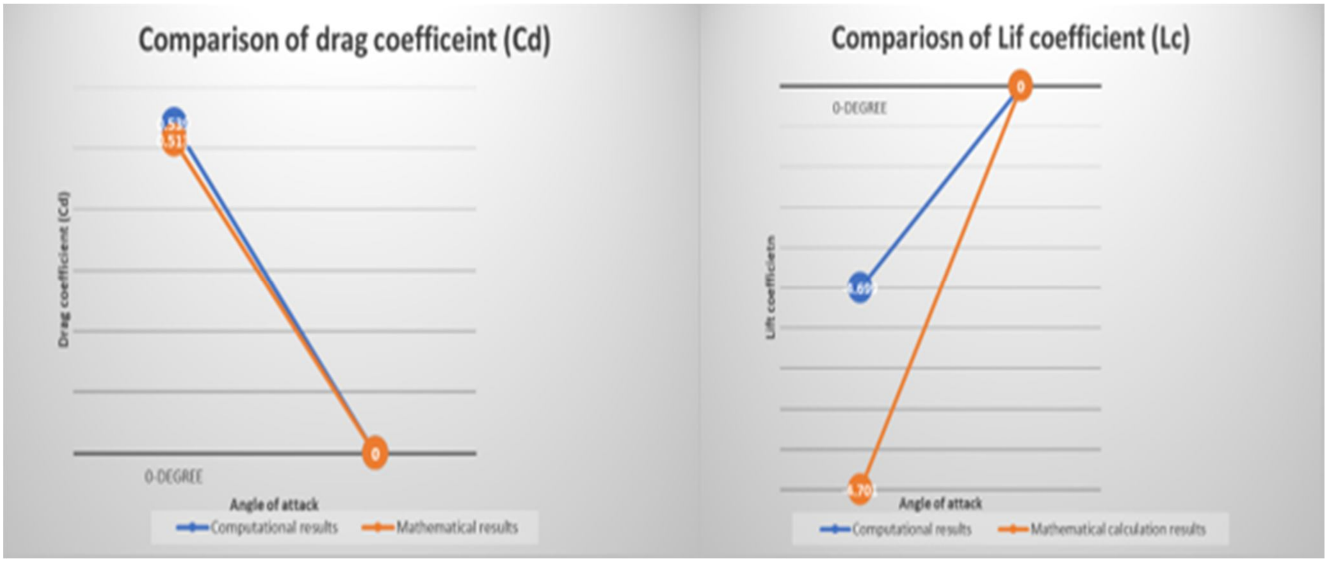

Fig. 7 Validation of Drag coefficient and lift coefficient for part 1

B. Part 2

These are computational results for drag and lift for different angle of attack and at different velocity in tabular

Velocity (in m/s	0-Degree		(-2) Degree		(-3) Degree		(-4) Degree		(-6) Degree		(-9) Degree		(-12) Degree		(-15) Degree	
	Drag	Lift	Drag	Lift	Drag	Lift	Drag	Lift	Drag	Lift	Drag	Lift	Drag	Lift	Drag	Lift
10	0.57	-4.357	0.494	-4.76	0.508	-5.151	0.488	-5.204	0.438	-5.745	0.378	-5.248	0.311	-4.422	0.268	-2.756
15	0.548	-4.598	0.489	-4.943	0.48	-5.493	0.485	-5.291	0.437	-5.772	0.373	-5.368	0.303	-4.608	0.255	-2.9
20	0.541	-4.621	0.486	-4.992	0.496	-5.288	0.488	-5.362	0.428	-5.886	0.368	-5.414	0.301	-4.789	0.25	-2.967
25	0.553	-4.662	0.481	-5.004	0.472	-5.548	0.48	-5.443	0.425	-5.944	0.366	-5.457	0.296	-4.819	0.245	-2.99
30	0.547	-4.721	0.487	-5.077	0.479	-5.621	0.473	-5.625	0.422	-5.96	0.362	-5.454	0.292	-4.835	0.244	-3.055
35	0.548	-4.766	0.48	-5.091	0.478	-5.679	0.47	-5.615	0.422	-5.986	0.361	-5.472	0.29	-4.846	0.238	-3.116
40	0.545	-4.735	0.481	-5.104	0.478	-5.706	0.471	-5.648	0.426	-6.016	0.36	-5.498	0.288	-4.855	0.235	-3.162
45	0.545	-4.78	0.477	-5.108	0.479	-5.726	0.471	-5.68	0.43	-6.139	0.359	-5.506	0.286	-4.858	0.232	-3.181
50	0.544	-4.798	0.48	-5.139	0.479	-5.751	0.47	-5.658	0.42	-6.042	0.358	-5.502	0.285	-4.862	0.233	-3.181

2-Degree		3-Degree		4-Degree		6-Degree		9-Degree	
Drag	Lift	Drag	Lift	Drag	Lift	Drag	Lift	Drag	Lift
0.658	-4.033	0.45	-2.861	0.683	-3.754	0.775	-3.469	0.986	-3.185
0.657	-4.058	0.453	-3.02	0.691	-3.768	0.777	-3.533	0.977	-3.201
0.655	-4.115	0.446	-3.01	0.699	-3.709	0.773	-3.551	0.994	-3.223
0.65	-4.156	0.447	-2.981	0.683	-3.689	0.771	-3.558	1.003	-3.335
0.671	-4.49	0.445	-3.007	0.687	-3.887	0.779	-3.57	1.024	-3.368
0.678	-4.493	0.465	-2.95	0.675	-3.794	0.782	-3.567	1.031	-3.384
0.675	-4.435	0.458	-3.051	0.69	-3.961	0.786	-3.581	1.047	-3.397
0.673	-4.167	0.476	-3.093	0.681	-3.897	0.789	-3.586	1.053	-3.405
0.677	-4.003	0.444	-3.114	0.694	-3.794	0.791	-3.594	1.059	-3.413

Fig. 8. Computational results for drag and lift for different angle of attack and at different velocity in tabular form (negative lift indicates downforce).

Comparison of total drag coefficient of a spoiler with different angle of attack and different velocity. The least drag is 0.23 at (-15) degree angle of attack as can be seen in graph as purple line graph and comparison of total lift coefficient of spoiler with different angle of attack and different velocity. The maximum downforce (390.257 N) created by the spoiler is at (-6) degree angle of attack as it can be seen from graph as light green.

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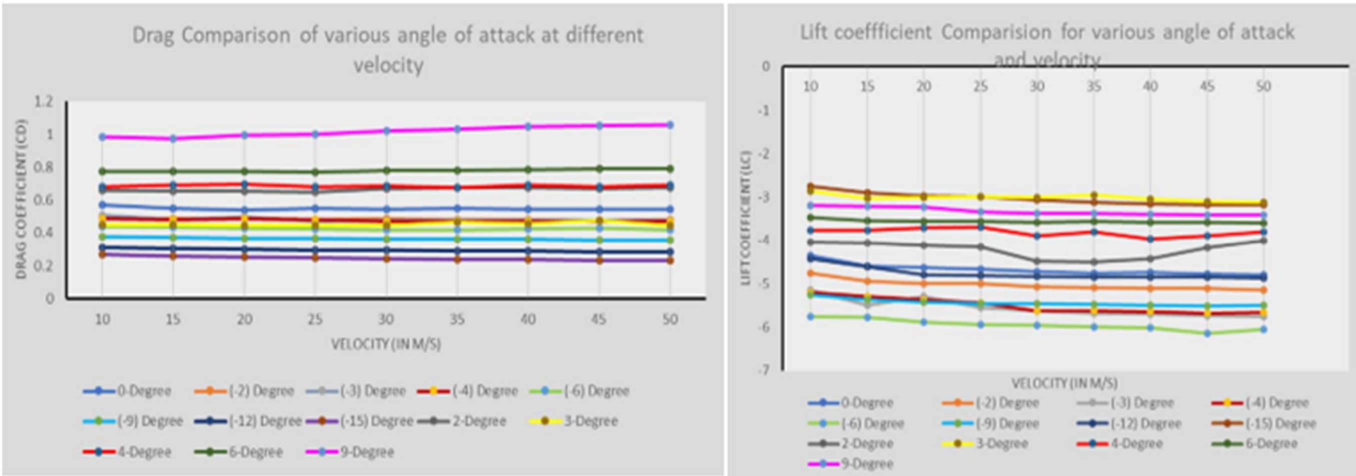


Fig. 9. Drag and lift coefficient comparison graph for various angle of attack of a spoiler

1) Velocity plot for different angle of attack at 10 m/s velocity

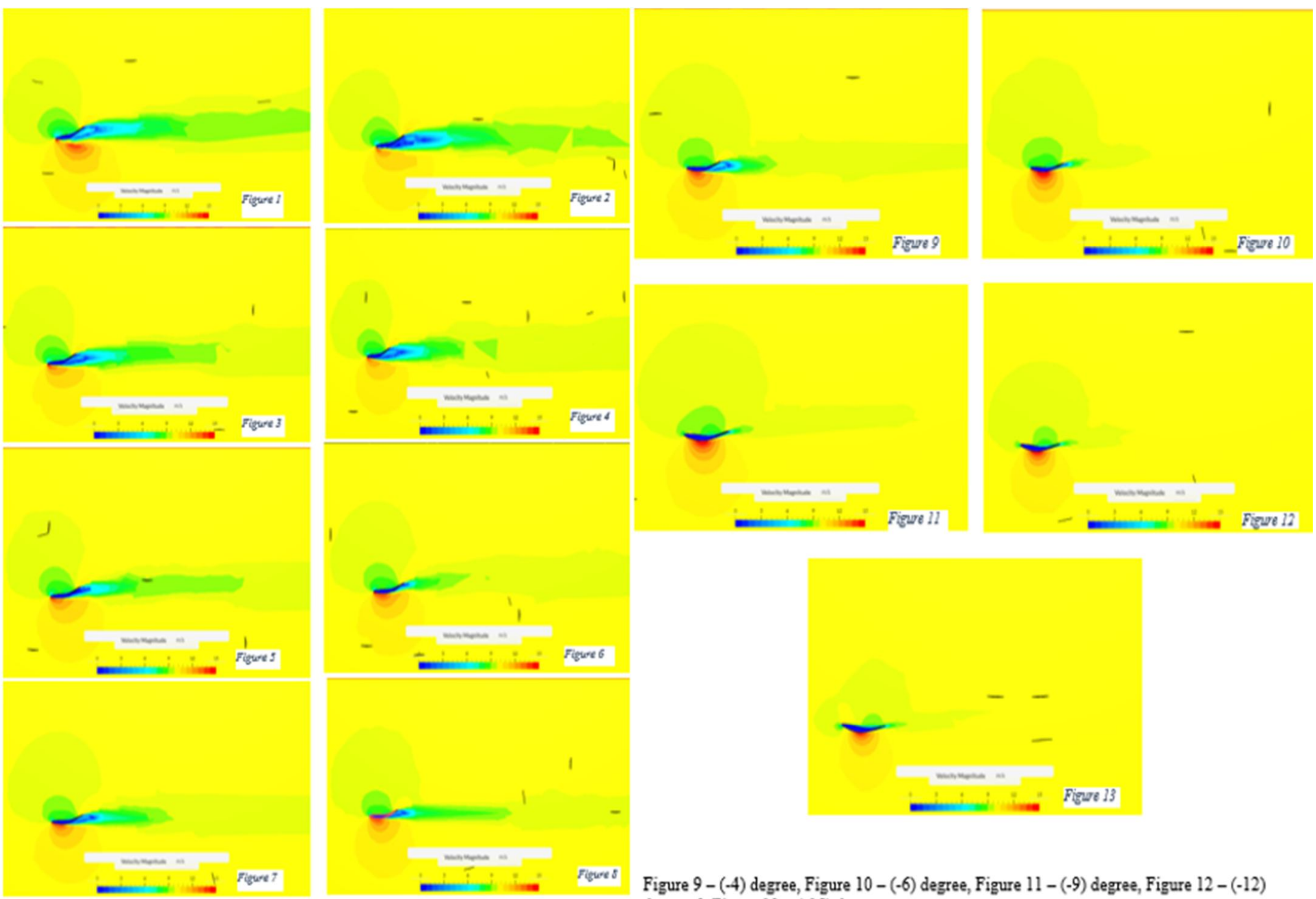


Figure 9 – (-4) degree, Figure 10 – (-6) degree, Figure 11 – (-9) degree, Figure 12 – (-12) degree & Figure 13 – (-15) degree.

Figure 1 – 9-degree, Figure 2 – 6-degree, Figure 3 – 4-degree, Figure 4 – 3-degree, Figure 5 – 2-degree, Figure 6 – 0-degree, Figure 7 – (-2) degree, Figure 8 (-3) degree

Fig. 10. Velocity plot for various angle of attack at 10 m/s

2) Temperature variation analysis for -6-degree angle of attack of spoiler

For (-6) degree angle of attack

	(-6) degree		
Temperature (in degree Celsius)	Velocity (in m/s)	Lift	Drag
30	50 m/s	-6.165	0.427
22	50 m/s	-6.042	0.42
-5	50m/s	-6.097	0.421

	(-6) degree		
Temperature (in degree Celsius)	Velocity (in m/s)	Lift	Drag
30	30 m/s	-5.958	0.423
22	30 m/s	-5.96	0.422
-5	30m/s	-5.994	0.422

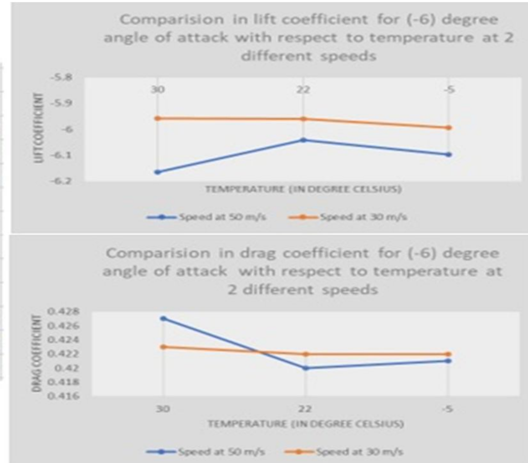


Fig. 11. Table and graph for -6-degree angle of attack of spoiler at 2 different speed

C. Part 3

Mathematical/analytical calculations for validation

$$=-14.833/((1/2)*1.196*10^2*0.04319193)$$

Fig. 12. Formula used in Excel to solve analytical part

The green underlined is the parameter where force Z is as input
The red underlined is the density of the air at 22 degree Celsius (considered as normal temperature for analysis)
The yellow underlined is the speed in m/s with square root (changes according to velocity given in analysis)
The purple underlined is the frontal area of spoiler (it changes as the angle of attack changes)

Similarly, for drag coefficient instead of force Z, force Y is input with other parameters as mentioned above.

Lifting Force

The lifting force acting on a body in a fluid flow can be calculated

$$F_L = c_L \, 1/2 \, \rho \, v^2 A \qquad (1)$$

where

F_L = lifting force (N)

c_L = lifting coefficient

ρ = density of fluid (kg/m^3)

v = flow velocity (m/s)

A = body area (m^2)

Drag Force

The drag force acting on a body in fluid flow can be calculated

$$F_D = c_D \, 1/2 \, \rho \, v^2 A \qquad (2)$$

where

F_D = drag force (N)

c_D = drag coefficient

ρ = density of fluid (kg/m^3)

v = flow velocity (m/s)

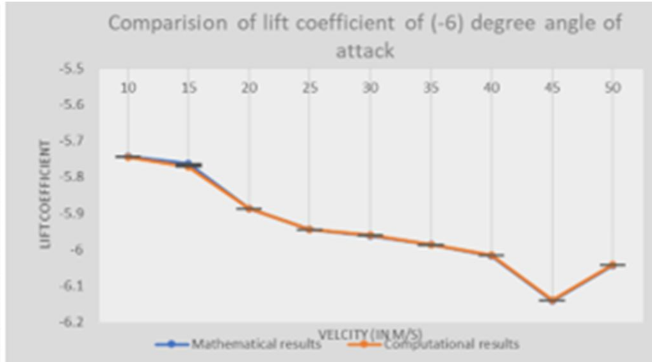
A = body area (m^2)

Fig. 13. Referred formula for calculations

All the mathematical/analytical sums to calculate the lift coefficient (downforce) and the drag coefficient are calculated in Excel to reduce time and also be accurate and create graph with those found value.

Mathematical validation of (-6) degree

Mathematical results		
(-6) degree		
Velocity (in m/s)	Lift	Drag
10	-5.742819973	0.438
15	-5.76290954	0.435
20	-5.886845391	0.427
25	-5.944687857	0.426
30	-5.961009017	0.425
35	-5.987184363	0.423
40	-6.017078052	0.422
45	-6.139922313	0.429
50	-6.043755664	0.42



Computational results		
(-6) Degree		
Velocity (in m/s)	Lift	Drag
10	-5.745	0.438
15	-5.772	0.437
20	-5.886	0.428
25	-5.944	0.425
30	-5.96	0.422
35	-5.986	0.422
40	-6.016	0.426
45	-6.139	0.43
50	-6.042	0.42

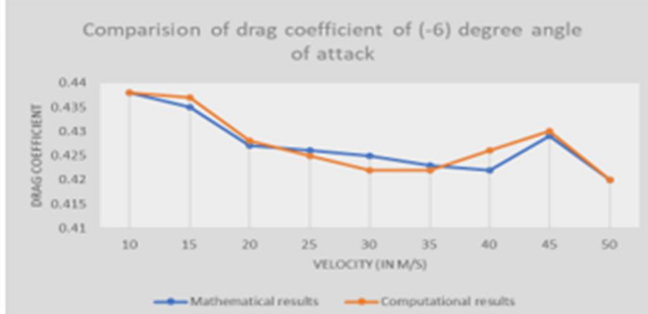


Fig. 14. Mathematical validation of Spoiler at -6-degree angle of attack with different speed

V. CONCLUSION

Studied the designed pedestal spoiler using analysis software to investigate downforce generated by the spoiler. Also, the angle of attack of the spoiler is changed with various velocity input in simulation to get an idea how the designed spoiler will perform if implemented on a car. After carrying out over hundreds of simulations it is found that the maximum downforce generated by the spoiler is 400 Newtons at (-6) degree angle of attack of spoiler with a low drag coefficient as well. The generated downforce is a well-suited downforce as downforce generated by standard spoiler should be between 265 N to 445 N. A proper validation is provided to compare computational and analytical results. To validate the results generated by the simulation, a mathematical/analytical method is used choosing four angles of attack with a sufficient result. They are compared with the help of line graphs made in Word Excel which gave a variation in less than 5% which is acceptable and correct indication of analysis process and overall generated results for the spoiler.

REFERENCES

[1] "Ayyagari and He - Aerodynamic analysis of an active rear split spoil.pdf."
[2] "Das and Riyad - 2017 - CFD Analysis of Passenger Vehicleat Various Angle .pdf." Accessed: Dec. 07, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1877705817332800/pdf?md5=2b3f3ff27e25877945e6dd151c58ba85&pid=1-s2.0-S1877705817332800-main.pdf&isDTMRedir=Y
[3] "Types of Spoilers | Front, Rear & Car Wings — 171car.com." http://www.171car.com/spoiler-types/ (accessed Dec. 11, 2020).
[4] "What are the diff varieties of car spoiler? - Quora." https://www.quora.com/What-are-the-diff-varieties-of-car-spoiler (accessed Dec. 11, 2020).
[5] "BestEquip Single Rear GT Wing 43.3inch GT Wing Spoiler Ad... | Automotive, Aluminium alloy, Car," Pinterest. https://www.pinterest.com/pin/727542514797329631/ (accessed Dec. 17, 2020).
[6] "Lift and Drag." https://www.engineeringtoolbox.com/lift-drag-fluid-flow-d_1657.html (accessed Dec. 12, 2020).