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Aerodynamic Analysis of Spoiler at Varying Speeds and Angles

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Abstract: Spoilers have been there in practice since years for the purpose of improving aerodynamics of a car. The pressure drag created at the end of the vehicle, referred to as wake region affects handling of the vehicle. This could be hazardous for the cars at high speeds. By adding a spoiler to the rear of the car reduces that pressure drag and the enhanced downforce helps in better traction. The paper presents aerodynamic analysis of a spoiler through Computational Fluid Dynamics analysis. The spoiler is designed using Onshape software and analyzed through SIMSCALE software. The simulation is carried out by changing angles of attack and velocities. The simulation results of downforce and drag are compared on the basis of analytical method.
Keywords: Designing a spoiler, Design and analysis of spoiler, Aerodynamics of spoiler, Aerodynamic analysis of spoiler, Computational fluid dynamics, CFD analysis, CFD analysis of spoiler, Spoiler at variable angles, Types of spoilers, Analytical aerodynamic analysis.

I. INTRODUCTION

Spoiler, as the term suggests it spoils the undesirable airflow across the vehicle also referred as turbulence. Spoilers have been fitted on high performance vehicles since ages and nowadays it can be seen attached to the passenger cars. In high performance vehicles it is necessary to control the movement of the car at high speeds.

The disruption in movement and handling of the cars at high speeds occur due to turbulence and lift force generated. These forces can be minimized by using a spoiler. It produces downforce which is opposite to lift force and also smoothens the airflow behind the vehicle providing less turbulence.

The main purpose of the spoiler is to produce downforce and thus adding more traction to the car for better handling. Other uses of the spoiler can include the flip up function that can be seen on hyper-cars. Such spoilers change its angle while braking and reduces the speed of hyper-car by acting as an air-brake. Being in the state of angle of air-brake the spoiler does not produce much downforce, instead it produces maximum drag possible.

There are three main types of spoilers:

1) *Roof Spoilers:* Roof spoilers are fitted on the roof of the car, commonly seen in hatchback and SUV cars.
2) *Front Spoilers:* These spoilers are also known as lip spoilers, which are fitted onto the front bumper. They reduce the amount of airflow passing under the car and also decrease drag.
3) *Rear Spoilers:* Rear spoilers are very common and can be seen on any high-performance car or sedan passenger car. These are further categorized in the following types-:

a) *Lighted rear spoiler* – this type of car spoiler comes with an additional tail light.
b) *Rear lip spoiler* – this spoiler gives more aesthetic looks to the car by fitting onto the lip of the trunk.
c) *Whale tail spoiler* – it helps in reducing lift from rear portion of the car and also counters to the oversteer.
d) *Duck tail spoiler* – similar to the whale tail spoiler but as it fits on a sedan car it looks like a duck tail.
e) *Pedestal spoiler* – these spoilers are available in the aftermarket but also comes as a standard company fitted. It helps in improving drivability.

In the following research a spoiler is designed by keeping the idea of a rear spoiler in vision. A 3D model of the spoiler is simulated using CFD analysis to evaluate the performance it gives in context of downforce and drag-force. Analytical results are also interpretated and compared with simulation results.

II. AIM AND OBJECTIVES

The aim of the research is to design a spoiler and showcase the amounts of drag-force and down-force for it to give efficient performance at varying speeds at varying angles of attack.

The objectives are as follows:

A. To research the uses and types of spoilers.
B. To design a 3D model of visioned spoiler.
C. To analyze the spoiler by simulating through CFD analysis.
D. To simulate the spoiler at varying speeds and angles of attack.
E. To compare the simulation data and analytical data and interpret the results.

III. LITERATURE REVIEW

The thesis presents a computer-based car model and two spoiler designs which would be added to the car design while performing simulations. The simulation is carried out by attaching the spoilers to the rear end of the car at different locations. For the simulation, ANSYS Fluent software is used.[1] The paper aims for the aerodynamic analysis of a race car with and without rear spoiler. The geometry was created using ANSYS FLUENT software and analyzed under different vehicle speeds. The results are compared with wind tunnel experiment results of a Nascar.[2]

IV. METHODOLOGY

A research on types of spoilers was carried out and its functions are understood. A 3d model of the proposed spoiler is created with the help of ONSHAPE 3D modeling software. The model was then imported to the SIMSCALE software for CFD analysis. After meshing and applying some boundary conditions to the model, a simulation was done at a particular air velocity and results of downforce and drag-force are interpretated. Next, few angles of spoiler are selected and this is done by editing the 3D model in ONSHAPE. Again, the models are imported to the SIMSCALE software and five different air velocities are applied to each angle and simulated. The results of downforce and drag-force are noted. For each result it was compared with result obtained by analytical method.

V. PROCEDURE FOLLOWED

For a spoiler to be designed, true sizes of spoiler and its types are noted. By the end of the research, a 3D model of the spoiler was created in the ONSHAPE software. Given the features, ONSHAPE provides ease of creating 3D geometry.

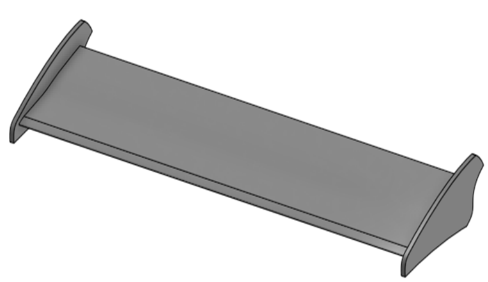

Figure 1: 3-D Designed Spoiler

The spoiler is then imported to the SIMSCALE software for CFD analysis. After importing the spoiler, an enclosure was created around the spoiler to substitute a flow region for the air. The creation of flow region was followed by simulating incompressible flow. The material “Air” is chosen for the flow material inside the enclosure. We have to give necessary boundary conditions to the faces of the flow region so as to simulate the desirable air flow.

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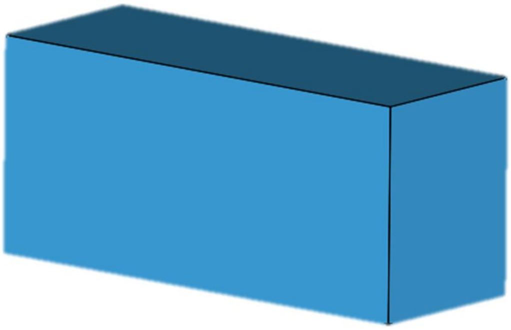

Figure 2: Encloser with spoiler inside

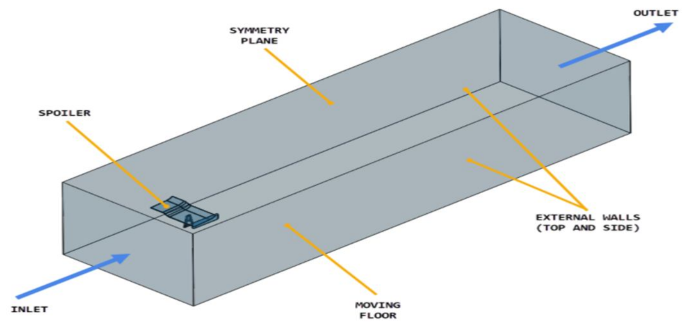

Figure3: Example of boundary conditions

The geometry is then prepared for meshing process. Before starting the mesh a geometry premetive cartesian box is created inside the enclosure around the spoiler by using region refinement command. The geometry is then set for meshing.

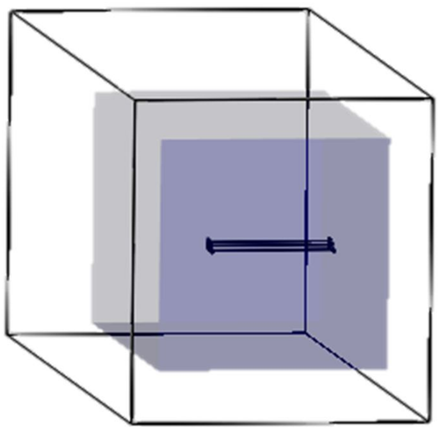

Figure 4: Cartesian box inside enclosure

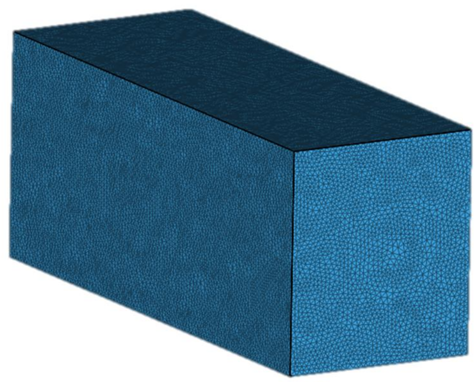

Figure 5: Meshing result

After the meshing process, the simulation is run, provided air velocity is 30m/s or 108 km/hr. The results of the simulation are shown below.

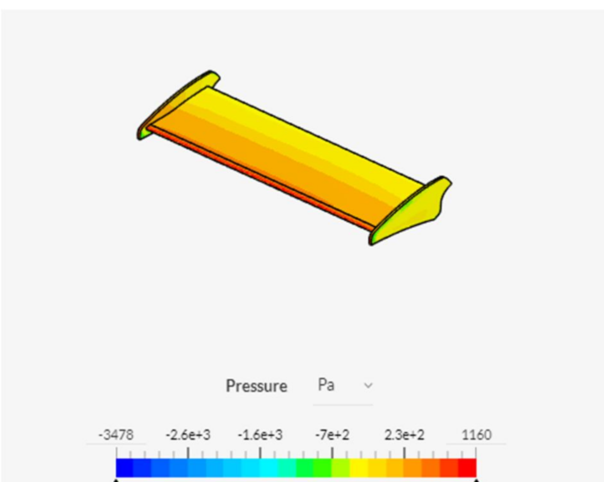

Figure 6: Pressure plot

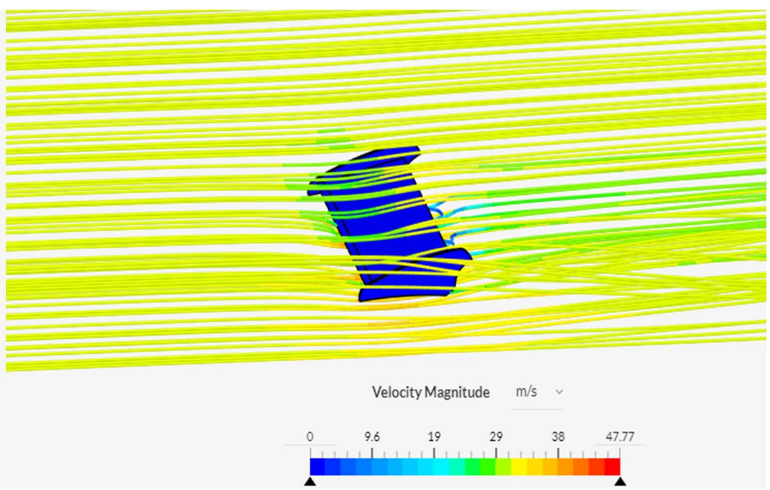

Figure 7: Streamlines Plot

In the above results the blue region shows the minimum value of the designated parameter while the red region shows maximum value.

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Through the simulation the values of drag force, lift force, drag coefficient and lift coefficient are noted as shown in the following graphs.

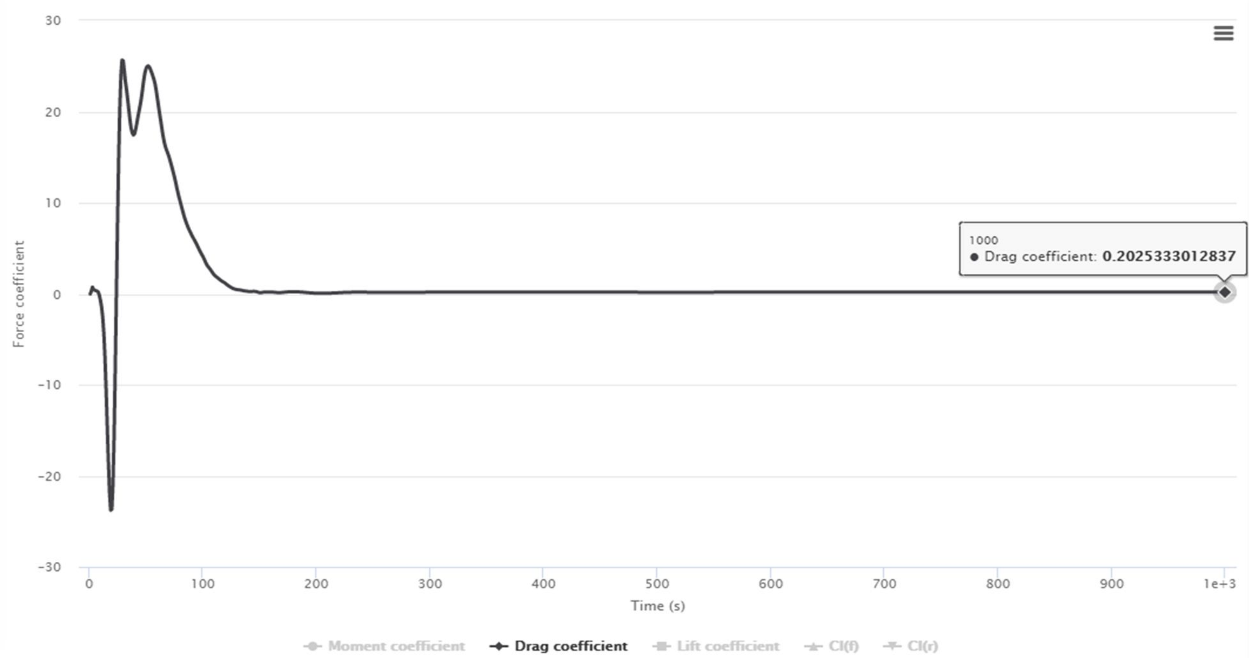

Figure 8: Drag Coefficient (0.2)

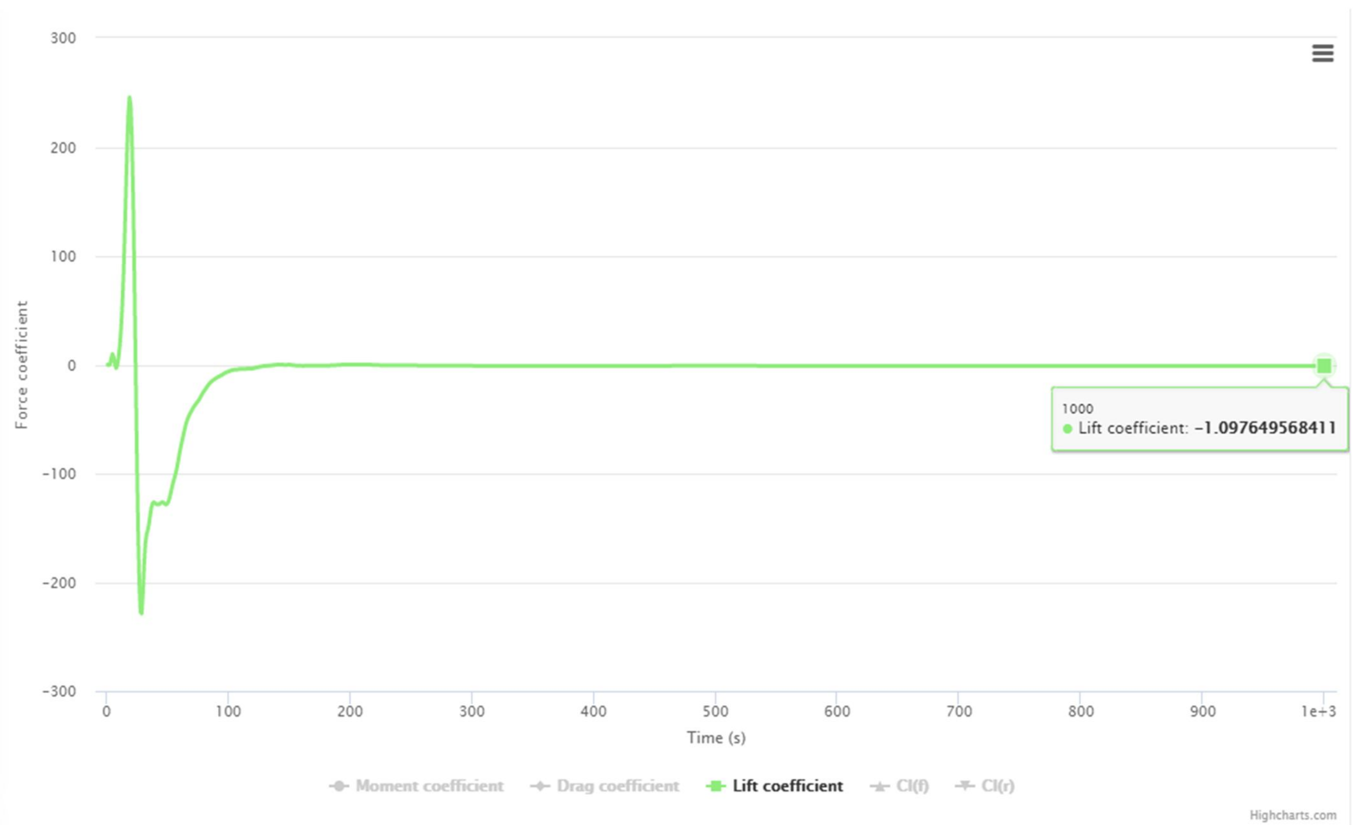

Figure 9: Lift Coefficient (-1.09)

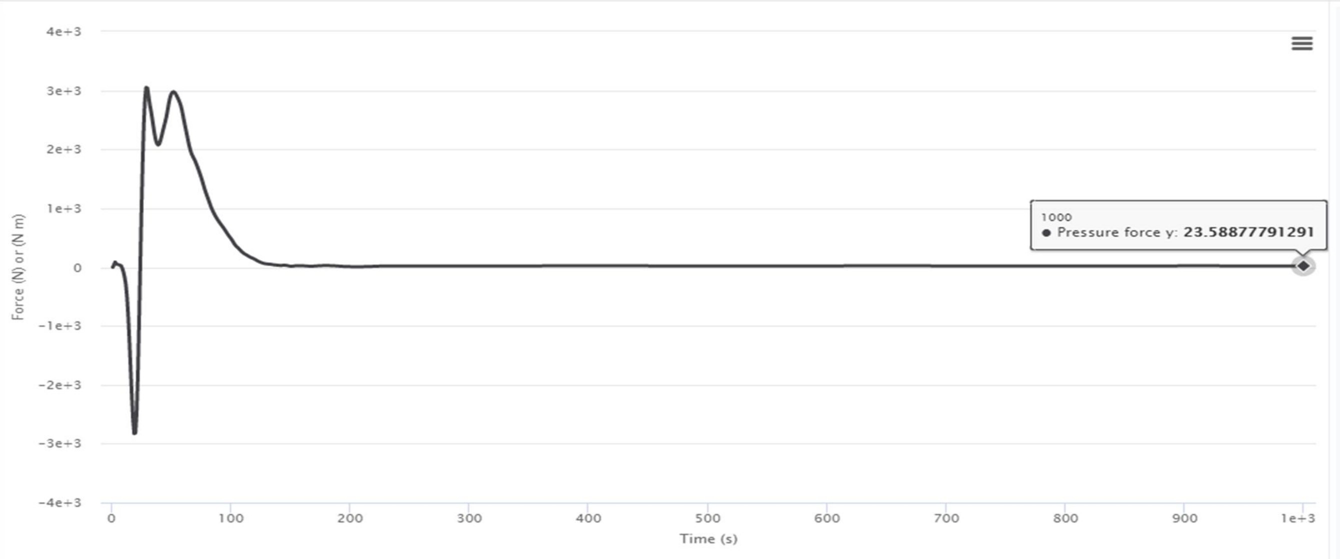

Figure 10: Drag Force (23.58 N)

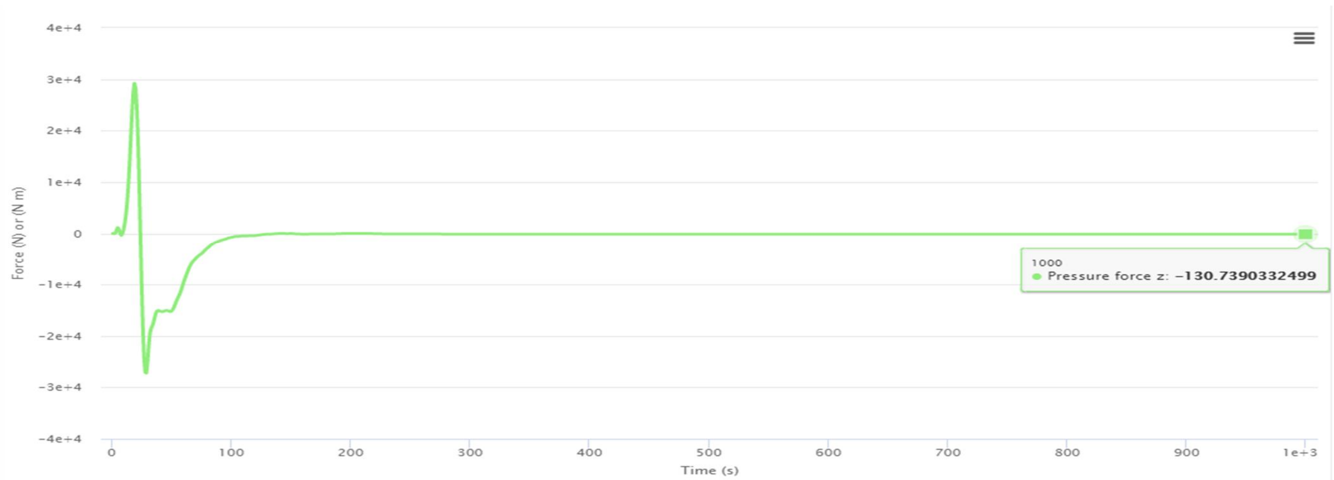

Figure 11: Lift force (-130.73 N)

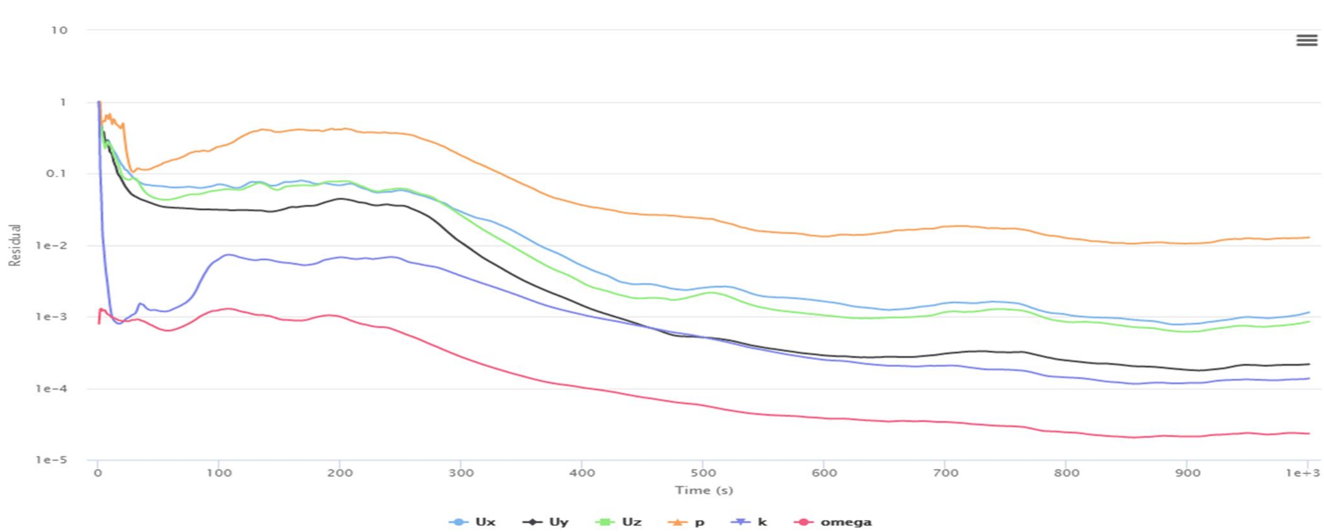

Figure 12: Residual Plot

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Similarly, further simulations are carried out.

Proceeding forward, the simulations were done at varying speeds and angles of attack. The spoiler was set at different angles to interpret the performance of spoiler and its results according to the real scenarios. The results of downforce generated by the spoiler at different speeds are also evaluated. Each angle is simulated with five different speeds of air. Similar to the simulation done above, the contours and plots are obtained. The values of downforce and drag-force at different speeds and angles are showcased below in the tabular form.

	-10 degrees	-8 degrees	-6 degrees	-4 degrees	-2 degrees	2 degrees	4 degrees	6 degrees	8 degrees	10 degrees
126 km/hr	10.32	11.70	14.10	17.95	23.85	39.14	43.24	61.42	74.06	75.62
144 km/hr	14.09	15.32	18.44	23.44	31.19	58.97	64.28	90.52	101.97	87.93
162 km/hr	17.91	19.44	23.38	29.78	39.49	80.17	80.48	108.57	124.09	144.23
180 km/hr	22.17	24.05	28.90	36.80	48.79	98.20	89.12	122.14	148.15	152.01
198 km/hr	25.66	29.15	34.87	44.55	59.03	116.36	138.67	178.08	195.38	201.34

Table 1: Values of downforce in Newtons(N)

	-10 degrees	-8 degrees	-6 degrees	-4 degrees	-2 degrees	2 degrees	4 degrees	6 degrees	8 degrees	10 degrees
126 km/hr	19.48	54.24	89.01	121.99	157.56	158.36	138.64	192.03	201.29	178.78
144 km/hr	26.03	70.82	116.17	159.07	205.92	257.46	203.33	304.64	271.82	188.97
162 km/hr	32.89	89.65	147.02	201.74	260.52	365.53	258.09	361.42	336.27	357.66
180 km/hr	40.62	110.70	181.55	249.25	321.52	477.21	301.29	403.45	376.42	351.49
198 km/hr	48.03	133.98	217.72	301.51	389.10	543.75	567.65	566.12	515.62	495.19

Table 2: Values of drag-force in Newtons(N)

As we can see, at a particular angle of the spoiler, the values of drag-force and downforce increase with increasing velocity. As this data is obtained, it was evaluated with analytical data calculated. For example, a comparison of simulation results and analytical results for the spoiler at an angle of 8 degrees with increasing velocity is shown below.

Velocities	Simulation results	Analytical results
126 km/hr	201.29	200.74
144 km/hr	271.82	270.65
162 km/hr	336.27	334.52
180 km/hr	376.42	373.34
198 km/hr	515.62	511.71

Table 3: Comparison of downforce in Newtons(N)

Velocities	Simulation results	Analytical results
126 km/hr	74.06	74.47
144 km/hr	101.97	101.49
162 km/hr	124.09	123.10
180 km/hr	148.15	148.67
198 km/hr	195.38	195.89

Table 4: Comparison of drag-force in Newtons(N)

The comparison shows very small difference with minimum 0.5N to maximum 3.91N difference for downforce at different speeds and minimum 0.41N to maximum 0.99N for drag-force at different speeds.

The analytical data is calculated using the formulas given below.
$F_D = C_D.(0.5).\rho.v^2.A$
&
$F_L = C_L.(0.5).\rho.v^2.A$

Where,
F_D= Drag force in Newtons
F_L= Lift Force which is equal and opposite to downforce in Newtons
C_D= Drag coefficient
C_L= Lift coefficient
ρ = density of the fluid, here air is used hence = 1.196 kg/m^3
V = velocity of the fluid in m/s
A = Body area in m^2, here A = 0.221 m^2
At different speeds, different drag coefficients and lift coefficients are obtained and are represented below in Table 5.

Velocities	Lift Coefficient ($\boldsymbol{C_L}$)	Drag Coefficient ($\boldsymbol{C_D}$)
126 km/hr	-1.24	0.46
144 km/hr	-1.28	0.48
162 km/hr	-1.25	0.46
180 km/hr	-1.13	0.45
198 km/hr	-1.28	0.49

Table 5

Solution:

1) For the spoiler at 8 degrees and velocity 126 km/hr that is 35 m/s,
Downforce:
$F_L = C_L.(0.5).\rho.v^2.A$
= (-1.24)(0.5).(1.196)$(35)^2$(0.221)
= -200.74 N
Hence downforce = 200.74 N

Drag-force:
$F_D = C_D.(0.5).\rho.v^2.A$
= (0.46)(0.5)(1.196)$(35)^2$(0.221)
= 74.47 N

2) For the spoiler at 8 degrees and velocity 144 km/hr that is 40 m/s,
Downforce:
$F_L = C_L.(0.5).\rho.v^2.A$
= (-1.28)(0.5)(1.196)$(40)^2$(0.221)
= -270.65 N
Hence downforce = 270.65 N

Drag-force:
$F_D = C_D.(0.5).\rho.v^2.A$
= (0.48)(0.5)(1.196)$(40)^2$(0.221)
= 101.49 N

3) For the spoiler at 8 degrees and velocity 162 km/hr that is 45 m/s,
Downforce:
$F_L = C_L.(0.5).\rho.v^2.A$
= (-1.25)(0.5)(1.196)$(45)^2$(0.221)
= -334.52 N
Hence downforce = 334.52 N

Drag-force:
$F_D = C_D.(0.5).\rho.v^2.A$
= (0.46)(0.5)(1.196)$(45)^2$(0.221)
= 123.10 N

4) For the spoiler at 8 degrees and velocity 180 km/hr that is 50 m/s,
Downforce:
$F_L = C_L.(0.5).\rho.v^2.A$
= (-1.13)(0.5)(1.196)$(50)^2$(0.221)
= -373.34 N
Hence downforce = 373.34 N

Drag-force:
$F_D = C_D.(0.5).\rho.v^2.A$
= (0.45)(0.5)(1.196)$(50)^2$(0.221)
= 148.67 N

5) For the spoiler at 8 degrees and velocity 126 km/hr that is 55 m/s,
Downforce:
$F_L = C_L.(0.5).\rho.v^2.A$
= (-1.28)(0.5).(1.196)$(55)^2$(0.221)
= -511.71 N
Hence downforce = 511.71 N

Drag-force:
$F_D = C_D.(0.5).\rho.v^2.A$
= (0.49)(0.5)(1.196)$(55)^2$(0.221)
= 195.89 N

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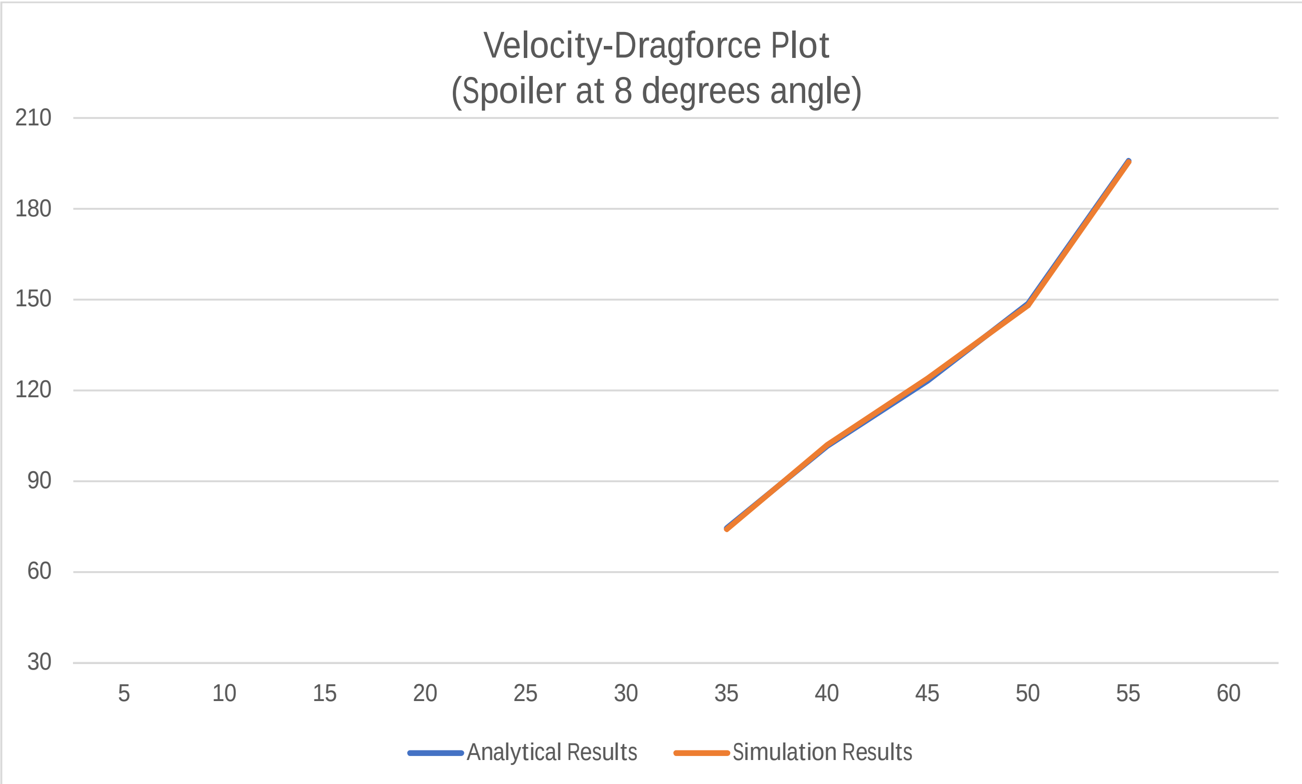
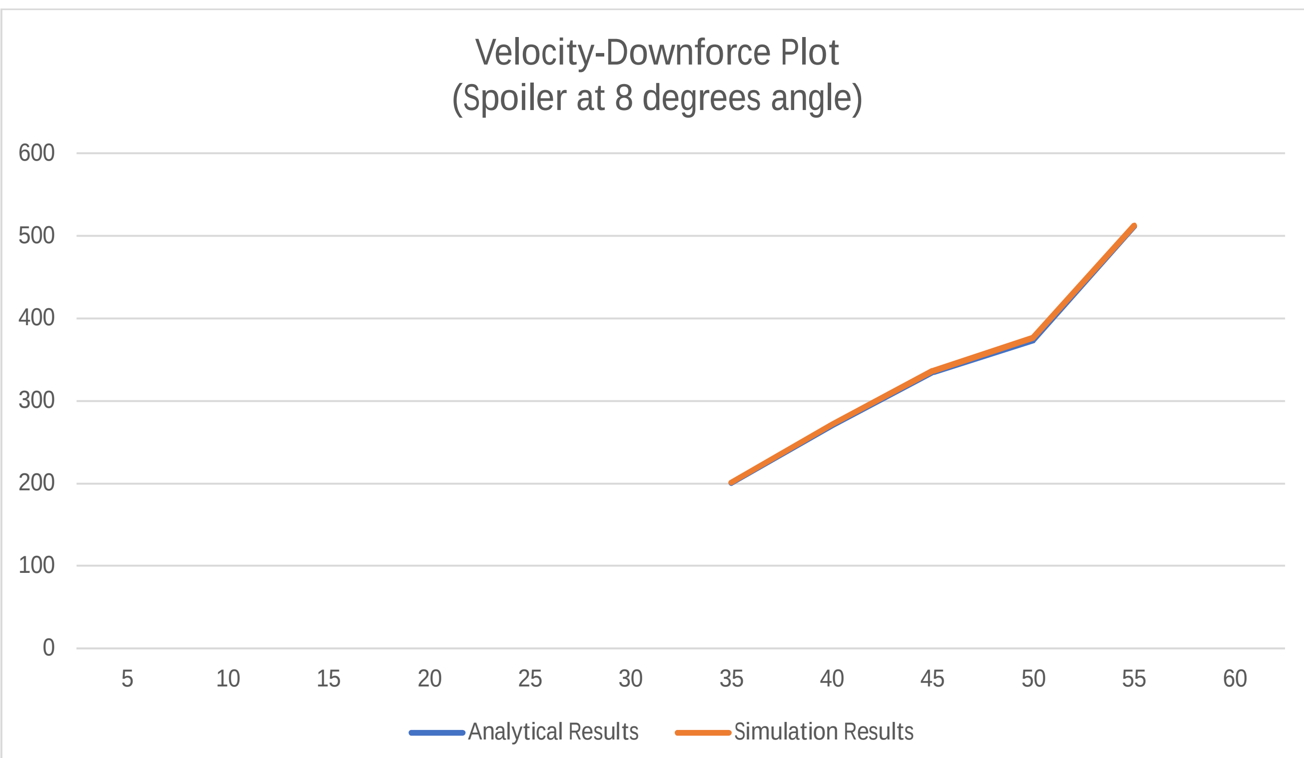
The comparison of these results of downforce and drag-force can be shown with the help of X-Y plot as represented below.





The difference in the values of the results is much less that causes the graphs to almost overlap each other.

VI. RESULT & CONCLUSION

A. The comparison of analytical and simulation data shows minimal difference.
B. For the spoiler inclined at 8 degrees angle, the minimum downforce obtained was 200.74 N at the velocity of 126 km/hr and maximum downforce obtained was 511.71 N at the velocity of 198 km/hr.
C. The values of downforce increase with increasing velocity and does not show any sudden fluctuation.

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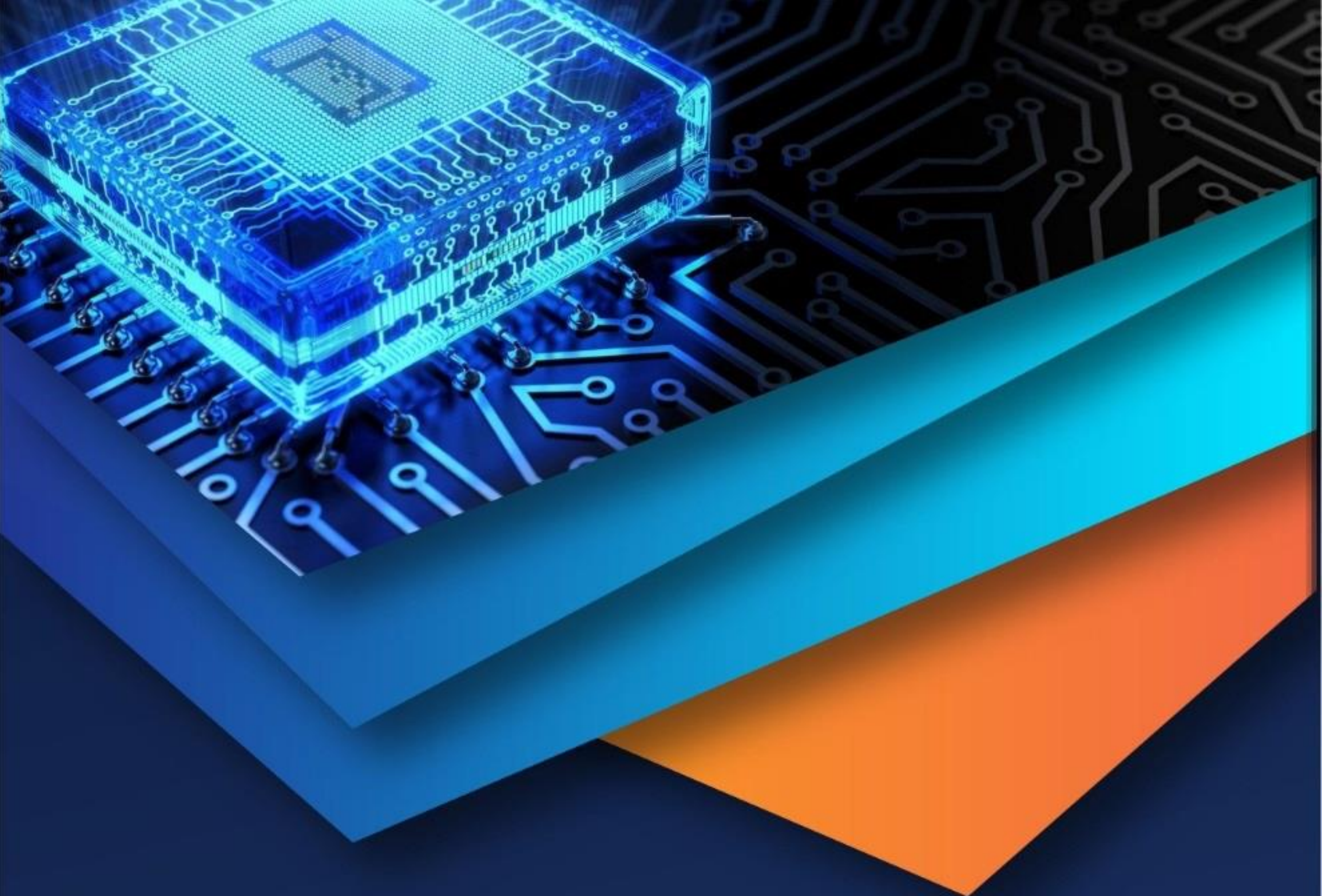

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