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The Influence of an Active Rear Spoiler on Vehicle Aerodynamic

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A B S T R A C T

computational studies were performed to study the drag forces and the downforce of a scale model Skoda Octavia A4 at increasing yaw angle. A 3d models of a car were performed without and with fixed and with slanted rear spoiler at ANSYS software. In the numerical study, three-dimensional, incompressible, and steady governing equations were solved by the software with realizable k-ε, 2-eqn model with non-equilibrium wall function. Numerical C_d and $C_l$values were found in good agreement for considered yaw angles. Maximum downforce-to-drag ratio and drag-to-downforce ratio were obtained at yaw angle of (4:12) degree for numerical calculations.

Keywords: drag force, spoiler, downforce, yaw angle.

1. Introduction

Because of rising oil pricing, the automobile industry shifted its priority from enhancing car power to optimizing fuel economy[1]. As a result, aerodynamic resistance is regarded as an important aspect of car design. Aerodynamic drag contributes for approximately 65% of total resistance in a medium-sized automobile travelling at 100 km/hr. As a result, minimising drag helps greatly to a car's fuel economy[2].

In general, the aerodynamic coefficients vary continually as the relative wind direction changes (i.e. yaw angle)[3]. However, certain vehicles exhibit a significant shift in aerodynamics at a specific yaw angle because the structure of their wake flow changes abruptly at that yaw angle[4]. Around such a crucial yaw angle, the vehicle's aerodynamics frequently exhibit bi-stability, which means that the two wake structures before and after the shift are both stable[5]. Furthermore, in such a circumstance, once one stable state develops, it may persist for some time, resulting in a type of hysteresis.

Various experimental and numerical investigations on drag optimizations have been undertaken in the past literatures, such as shape, style, and wake controls using vortex generator applications and active control techniques[6].

Various experimental and numerical investigations on drag optimizations have been undertaken in the past literatures, such as shape, style, and wake controls using vortex generator applications and active control techniques[7].

However, aerodynamic research on production automobiles have lately been published in a number of technical publications and papers. When a side wind approaches, the coefficients of resistance of both passenger automobiles and commercial trucks increase significantly[8]. If the geometric center, center of gravity, and stagnation point are all aligned, the vehicle is more stable. However, in the presence of a crosswind, the flow becomes asymmetric, and the stagnation point changes toward the direction of the crosswind, affecting the vehicle's stability[9]. When the yaw angle "b" reaches a particular level, the drag coefficient "Cd" and the lift coefficient "Cl" increase to a specific level. Several prior research has focused on the aerodynamic properties of the vehicle in crosswind[10].

Howell et al. discusses how vehicle design influences aerodynamic characteristics in yawing angle change. The most important yaw angle, where the drag force coefficient is greatest, was determined in the literature research to be between 20 and 35 degrees. Furthermore, at a critical yaw angle, the drag coefficient is no longer responsive to changes in yaw angle[9].

2. Methodology

The aim of this study is to investigate the aerodynamic forces on the model without and with rear spoiler at increasing yaw angle. The model of SKODA OCTAVIA A4 was tested for yaw angles of 4, 8, 10, and12 degree by using ANSYS Fluent program[11].

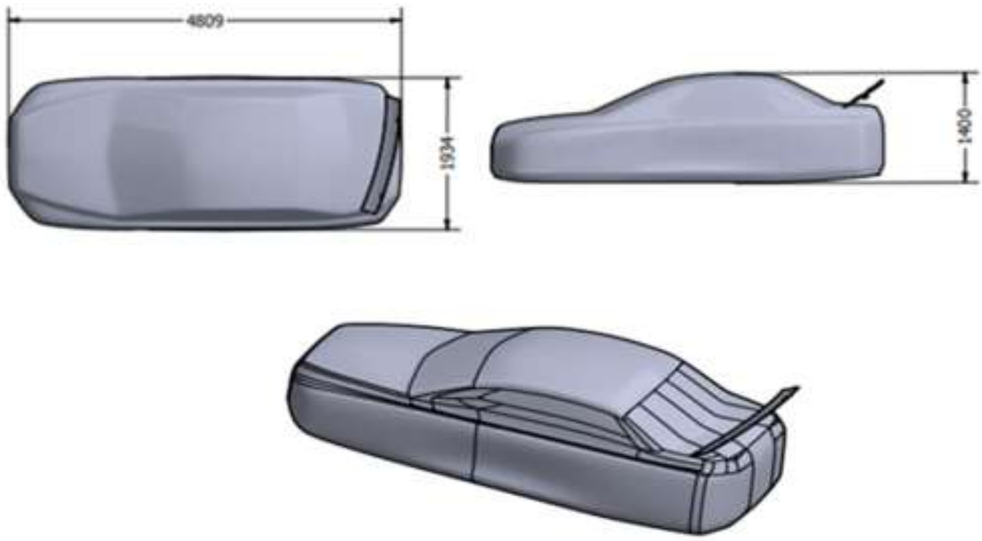

Figure. Error! No text of specified style in document..1 Skoda Octavia model

2.1 Meshing

An inflation layers was set near the walls to capture the change of the properties in the boundary layer according to the required Y+ of the turbulence model used (k-epsilon) 30 < Y+ < 300. Then two boxes of influence were made around the vehicle to have small mesh size around it then transition from small element to large ones in the rest of the domain. Also, Proximity and curvature with different size function was made for every curvature of the vehicle to capture the curvatures accurately. Table 1. Shows the mesh properties.

Table 1 Mesh properties

Element shape	Terahedral mesh
No. of cells	10,717,120
Y^+	35
Enclosure dimensions	(14 × 3.2 × 3.3) [m] (Length × Width × Height)
Max. skewness	0.48
Min. orthogonal quality	0.35

2.2 CFD Model Setup

The simulation done with the car taking a left turn at (170 km/h) inlet velocity for three different car configurations, then simulating the car when taking a right turn with tilted spoiler:

1. The car without the spoiler.
2. Horizontal spoiler.
3. Tilted spoiler in the positive direction.
4. Tilted spoiler in the negative direction.

And every configuration has four different yaw angles respectively (4 – 8 – 10 – 12) degree.

Table 2 CFD Setup

Turbulence model	k-epsilon
Boundary conditions	Inlet velocity = 170 [km/h]. Pressure outlet = zero [gauge]. Stationary walls with no slip condition at the car walls
Pressure-velocity coupling scheme	Coupled scheme
Spatial discretization	2nd order upwind
Gradient	Least Squares Cell-Based

3. Post Processing

3.1 The car without the spoiler

The velocity magnitude vectors at the back of the car without rear spoiler and also at the front of that are shown. The free stream velocity for simulation is 47.2 m/s. The velocity magnitude is 77.8 m/s.

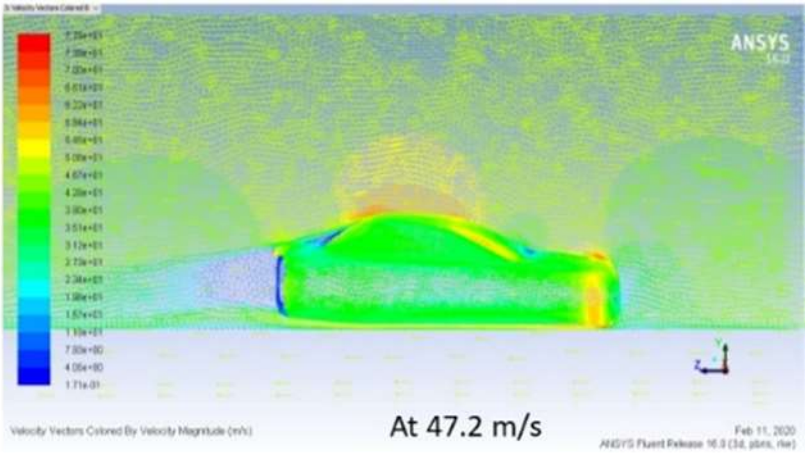

Figure Error! No text of specified style in document.**.2 velocity magnitude of the car without spoiler**

3.2 The car with horizontal fixed rear spoiler

The velocity magnitude vectors at the back of the car without rear spoiler and also at the front of that are shown. The free stream velocity for simulation is 47.2 m/s. The velocity magnitude is 77.8 m/s.

The wake region is also shown behind the car model. The region by using b2 spoiler height is divided into two regions with the decrease in backward length.

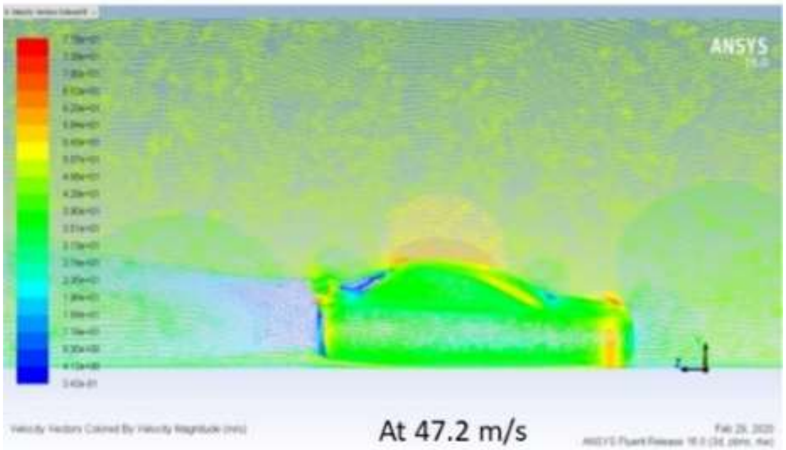

Figure Error! No text of specified style in document.. 3 Velocity magnitude of the car with horizontal fixed rear spoiler

3.3 The Car with tilted rear spoiler

3.3.1 At positive direction

The velocity magnitude vectors at the back of the car with tilted rear spoiler at the positive 4 degree and also at the front of that are shown. The free stream velocity for simulation is 47.2 m/s. The velocity magnitude is 74.34 m/s.

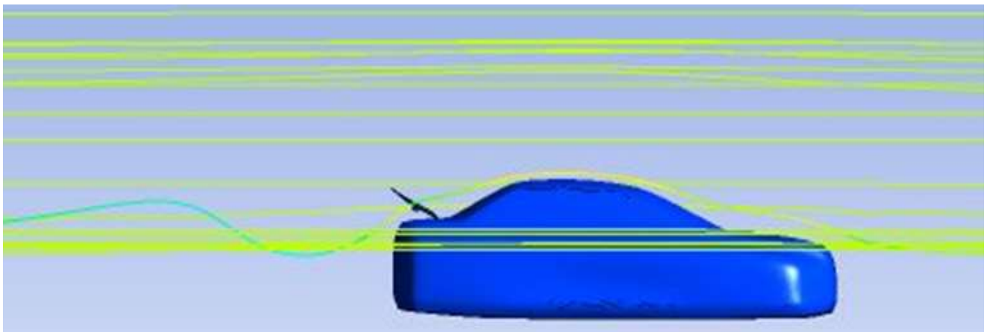

Figure Error! No text of specified style in document..3.Velocity magnitude of the car with tilted rear spoiler at +ve 4 degree direction

3.3.2 At negative direction

The velocity magnitude vectors at the back of the car with tilted rear spoiler at the negative 4 degree and also at the front of that are shown. The free stream velocity for simulation is 47.2 m/s. The velocity magnitude is 74.34 m/s.

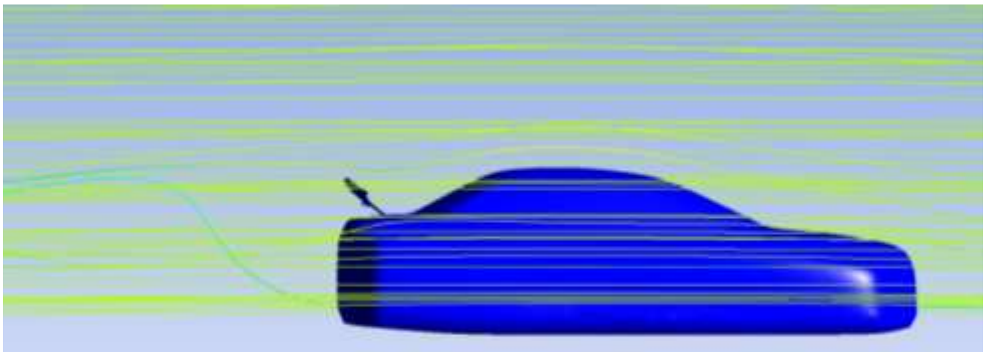

Figure 4 velocity magnitude of the car with tilted rear spoiler at -ve 4 degree direction

4. Discussions

After the simulation was complete, the results were used to plot the drag and lift force. These values are essential for understanding and determining the effect of different yaw angles on the car with and without rear wing and with active rear wing. A fixed velocity at 47.2 m/s is used in all analysis.

Drag and Lift forces are plotted in figures below, figures 6 and 7. The plots are from the analysis relation between car without and with b2 spoiler and tilted spoiler according to yaw angle differences.

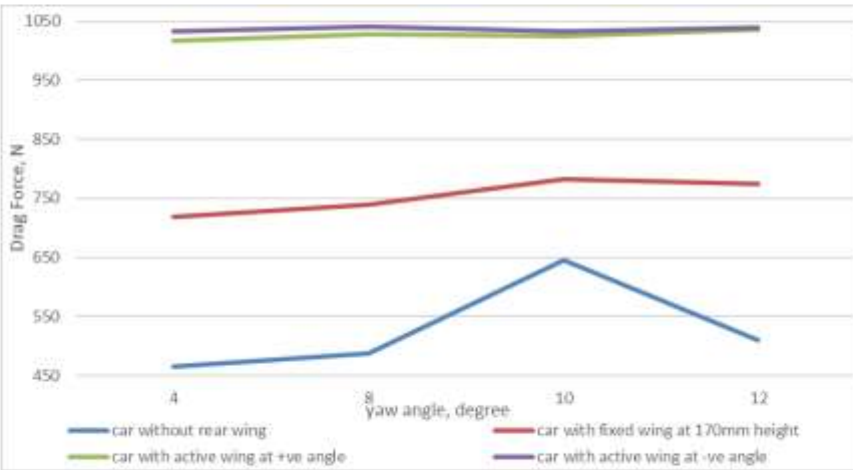

Figure 5 Drag force with different yaw angle

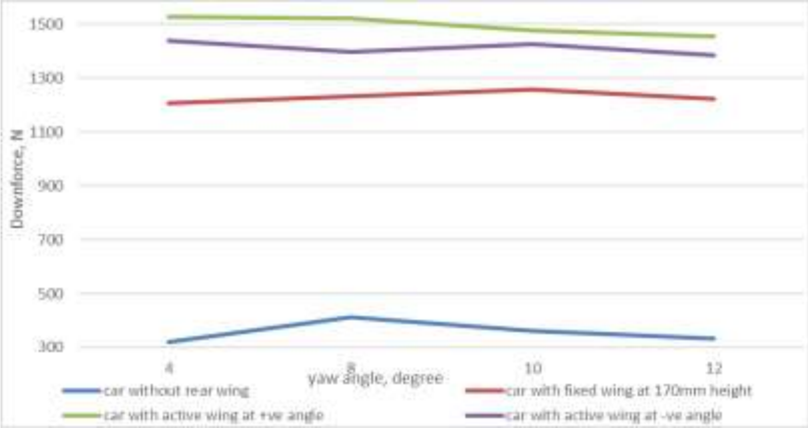

Figure 6 Downforce with different yaw angle

From the graphs above, figure 6 and figure 7, the using rear spoiler in tilt position achieve the optimum values that needs in change in different yaw angle. It achieves the high drag value that uses in decreasing the vehicle speed and also achieve the high downforce that uses in making the vehicle in stable.

Because of the lift-to-drag ratio is the most important consideration in designing spoiler, a graph of downforce-to-drag ratio is showed, figure 8 and 9.

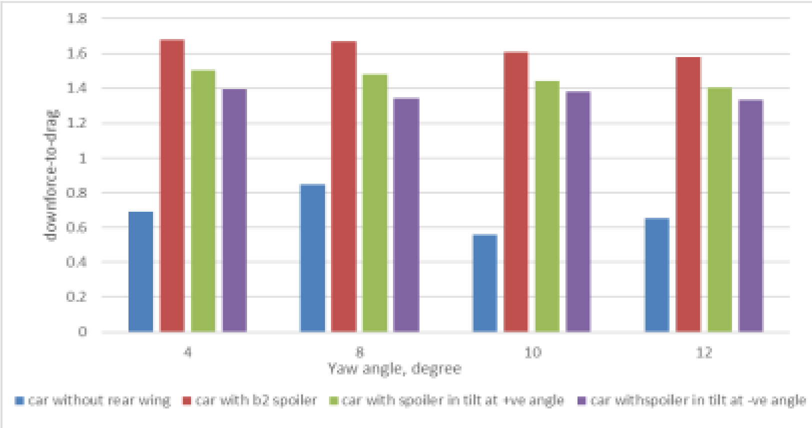

Figure 8 Downforce-to-drag ratio according to yaw angle

From the graph, the usage of the b2 spoiler has the highest value in it. And the car without rear spoiler is the least. To make more validation, the next graph is showed the drag-to-lift ratio.

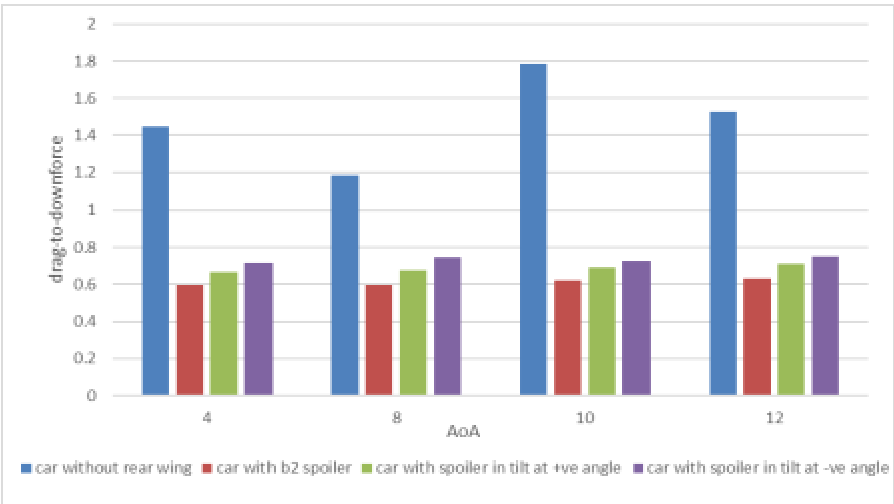

Figure 9 Drag-to-downforce ratio according to yaw angle

From the graph, , the usage of the b2 spoiler has the least value in it. And the car without rear spoiler is the highest.

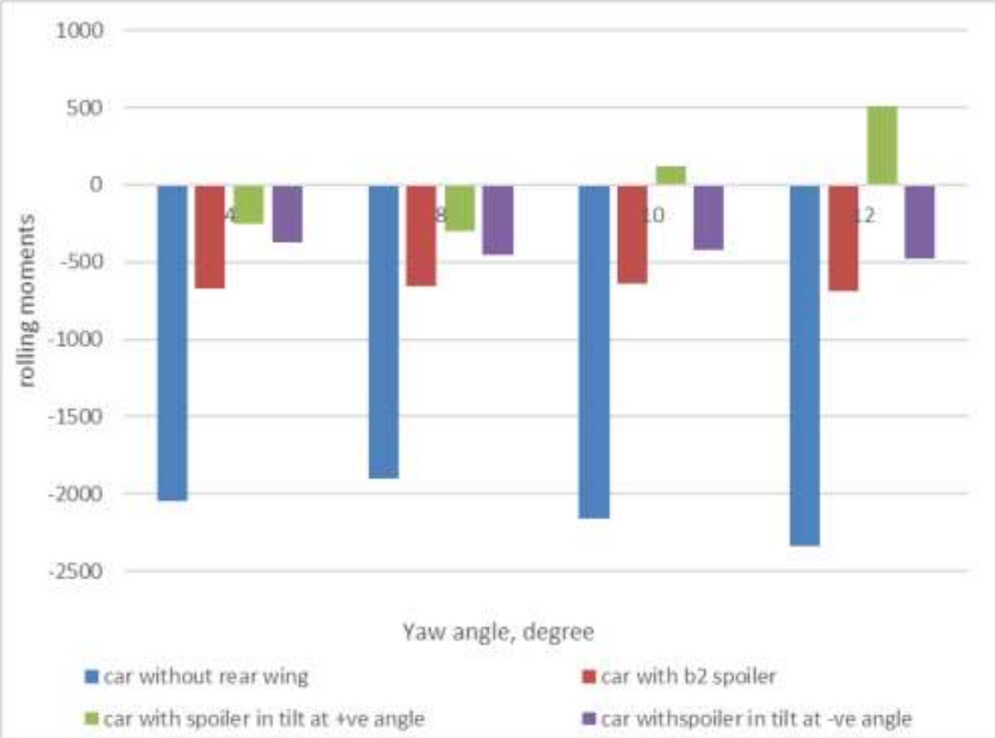

Figure 10 Rolling moments with yaw angle

Then we see the effect of using spoiler with fixed horizontal and tilted position and without them on the rolling moments of the car at the next graph, Figure 10.

5. Conclusion

In this paper, a Skoda Octavia Model A4 was studied in a case of high-speed different yaw angle at a speed of 47.2 m/s (170 km/h). An active aerodynamic spoiler was then added, and its performance was studied and contrasted against the base model. The base model cornering case had a 57.64% increase in drag over a straight-line case, and adding the surface resulted in a 649.25% increase in yaw moment, from -81.825 Nm to 449.427 Nm, for a 12.54% increase in drag. The surface had significant direct and indirect effects on yaw moment while cornering and an overall increase in yaw moment was observed. An active aerodynamic surface such as this can be retrofitted to a car with sufficient rear overhang, and can be actuated by electro-mechanical or pneumatic actuators. Future studies could be performed on the effects of active aerodynamics on stability of the vehicle, and repurposing such surfaces to increase their functionality.

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