# Analysis of Flow over Passenger Cars using Computational Fluid Dynamics

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***ABSTRACT:***

*One of the ongoing automotive technological developments is in the area of reduction of aerodynamic drag, because this has direct impact on fuel reduction. The present work consists of mainly determining the flow regime over vehicles and further evaluating the drag force and coefficient of drag using CFD analysis. For this analysis, two modern passenger cars-SEDAN&SUV models were considered.The analysis was carried out for velocities ranging from 30kmph to 120kmph. The analysis was further extended to study the effect of adding a spoiler on both the models.*

*A 3-D model of passenger car was drawn by using a snapshot of the actual vehicle. The snapshot was further developed by using AUTOCAD and CATIA-V5 software's. Further a control volume over the vehicle is also developed using the same software and the total model was imported into ANSYS workbench for CFD analysis.*

*The results obtained in the form of drag force and drag coefficient are compared. It has been observed that the sedan model had lower drag. It was further found from the study that the addition of a spoiler has a minimal effect on the drag induced.*

**Keywords:** *CFD, sedan, SUV, drag force,*

## 1.INTRODUCTION:

Aerodynamic drag is the force opposite to the direction of motion that acts on a body moving through air. Drag force affects the performance and fuel efficiency of aircraft, road vehicles or racing cars as it works opposite to the direction of movement. About 50% to 60% of total fuel energy is lost to overcome the drag force, 30% to 40%to overcome road resistance and about 10% to 20% for operatingelectrical appliances. Thus reduction of aerodynamic drag has become one of the prime concerns in vehicle aerodynamics and great efforts in research have been employed for better fuel economy and performance of aircraft and road vehiclesdue to market competition.

Numerous studies on aerodynamics of vehicles has shown that even 2% reduction in the aerodynamic drag improves the fuel economy by 1%. This is certainly a noteworthy improvement considering the fact of depleting energy resources. Presently, there has been a constant effort to incorporate changes in road vehicles, not just as an aesthetic design feature but transforming their shape whichcontributes to improve vehicles handling and fuel economy.

The objective of aerodynamic research is to minimize the aerodynamic resistance to allow the faster running of vehicles for the same energy consumption or lower fuel consumption for the same speed. The vehicle aerodynamics is best expressed by defining a parameter called co-efficient of drag which directly effects the fuel consumption and engine requirements.

Nomenclature:

$C_d$ : Coefficient of drag force

V : Velocity(m/s)

A : Frontal area($m^2$)

$T_w$: Shear stress($N/m^2$)

ρ: Density of fluid($Kg/m^3$)

## 2. LITERATURE REVIEW:

The following literature was reviewed from the journals. Most of the papers available in the literature reflected upon the subject of flow analysis over passenger cars.

**[1]Toukir Islam et.al.** focused on types or components of aerodynamic drag that are significant for cars, measurement of drag co-efficient and suggestions regarding design considerations to reduce drag.**[2]AbdulGhani** performed aerodynamic shape optimization on a generic notch back model using response surface technique and optimized geometry parameters for minimum drag were obtained in only 18 iterations.**[3]Alaman Altaf et.al.** reviewed techniques used to reduce aerodynamic drag over bluff bodies such as cylinders, spheres, 2D bodies with blunt backs and their application to commercial road vehicles. A new classification of the techniques is introduced and major contributions under them are shown in this paper.**[4]Bhavini Bijlani** has investigated both experimentally and analytically the aerodynamics of sedan and square-back cars, measuring drag coefficient and analysed flow of air over the car body. 1:20 aluminium scale model of popular sedan and square-back cars where used in the experimentscarried on a subsonic wind tunnel having test section of (30cm x 30cm x 100cm).The computational analysis was carried out in ANSYS CFX-13. A comparison of the values that werepredicted by both experimental and computational methods confirms their reliability and recommends for further experimentation. The drag co-efficient which is evaluated for exterior profile of the Sedan and the Square-back is in the order of 0.38 and 0.66 that is acceptable. It was concluded thatthe sedan model is more aerodynamic than square-back model. **[5]C.N.Patil et.al.** in the model work performed aerodynamic flow simulations on a conventional vehicle to demonstrate the possibility for performance improved passengers vehicle reduced drag coefficient which improves the fuel economy. Optimization of drag coefficient is carried out by adding devices like spoilers and panels at rear portion. This assessment shows that the drag can be decreased without altering the internal passenger space with least investment. A simple low cost feature modification at Rear end of the vehicle have been performed. These changes have shown about 20% to 30% of drag reduction.

## 3. PHYSICS OF DRAG:

Fluid flow over solid bodies frequently occurs in practice, and it is responsible for numerous physical phenomena such as drag acting on an automobile, power lines, trees and water pipe lines. Sometimes a fluid moves over stationary bodies and at other times a body moves through a quiescent fluid. These two seemingly different processes are equivalent to each other, what matters is the relative motion between the fluid and the body. Such motions are conveniently analysed by fixing the coordinate system on the body and are referred to as **flow over bodies** or **external flow.** The shape of the body has a profound influence on the flow over the body and the velocity field. The flow over a body is said to be **two-dimensional** when the body is very long and of constant cross section and flow is normal to the body. The wind blowing over a long pipe perpendicular to its axis is an example of two-dimensional flow. Note that the velocity component in the axial direction of pipe is zero in this case, and thus the velocity field is two-dimensional.

### 3.1. Definition of drag:

It is common experience that a body meets some resistance when it is forced to move through a fluid, especially a liquid. Drag is usually an undesirable effect, like friction, and we do our best to minimize it. A dimensionless quantity that is used to quantify drag of an object in a fluid environment is called“**Drag coefficient”.**

**Drag coefficient:** $C_D = F_D / 0.5\ \rho * V^2 * A$

### 3.2. Types of drag: friction &pressure drag:

The part of drag that is due directly to wall shear stress $\tau$ is called the **skin friction drag,** since it is caused by frictional effect, and the part that is due directly to pressure P is called the **pressure drag.** The friction and pressure drag coefficients are defined as

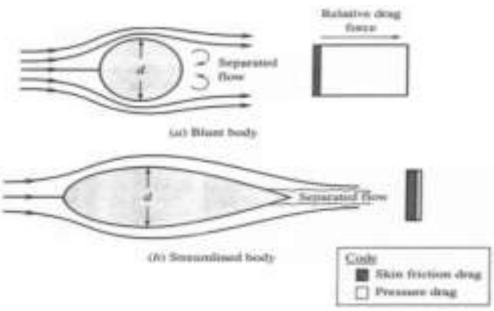



Fig.3.1. Friction and pressure drag

$$C_{D,\ FRICTION} = F_{D,\ FRICTION} / 0.5\ \rho * V^2 * A$$

$$C_{D,\ PRESSURE} = F_{D,\ PRESSURE} / 0.5 \rho * V^2 * A$$

When the friction and pressure drag coefficients or forces are available, the total drag coefficient or drag force can be determined by simply adding them,

$$C_D = C_{D,\ FRICTION} + C_{D,\ PRESSURE}$$

**and**

$$F_D = F_{D,\ FRICTION} + F_{D,\ PRESSUR}$$

### 3.3. Flow separation:

A fluid acts much the same way as a solid body, when forced to flow over a curved surface at high velocities. A fluid climbs the uphill portion of the curved surface with no problem, but it has difficulty remaining attached to the surface on the downhill side. At sufficiently high velocities, the fluid streamdetaches itself from the surface of the body. This is called **flow separation**. When a fluid separates from a body, it forms a separated region between the body and the fluid stream. This low-pressure region behind the body, where recirculation and backflow occurs is called the **separated region**. Pressure drag increases with increase in separated region.

### 4. DEFINITION OF PROBLEM:

The objective of this work is to study the flow over modern passenger cars and determine the drag force exerted over them. The analysis was done at varying vehicle velocities on two types of models;

- sedan car
- sports utility vehicle(SUV)

CFD technique was employed for this study and ANSYS CFX software was employed as a tool. Further the effect of attaching a spoiler at the rear end of the vehicle is also included in the study.

#### 4.1. Specifications of sedan car:

Table.4.1. specifications of sedan model

| Specification | Details |
|---|---|
| Length | 4370 mm |
| Width | 1700 mm |
| Height | 1475 mm |

#### 4.2. Specifications of SUV:

Table.4.2. specifications of SUV model

| Specification | Details |
|---|---|
| Length | 4430 mm |
| Width | 1817 mm |
| Height | 1916 mm |

### 5. SOLUTION METHODOLOGY:

#### 5.1. CFD Analysis

The Analysis is carried out at various speeds ranging from 60kmph to 180kmph in ANSYS-CFX and the results in terms of flow contours, vector plots and streamline plots are represented. The surface pressure contour is also observed in the analysis.The analysis includes process of three steps:

a) **Drawing the outer contour of the vehicle:** The snapshot of the vehicle is taken and its outer contour was obtained by using CAD software. Then part modeling is done in CATIA-V5 software and that file is saved in STP format and then imported to CFX.

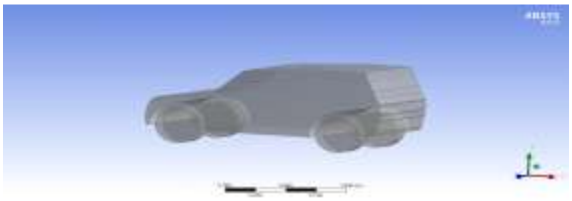


Fig.5.1. SUV geometry model without spoiler

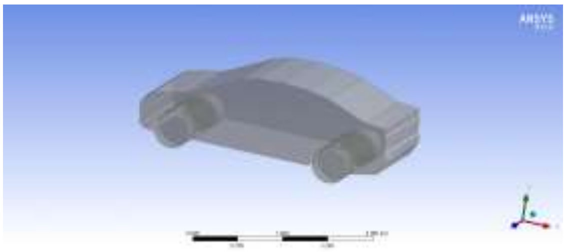


Fig.5.2. Sedan car geometry without spoiler

b) **Meshing:** The imported file geometry is meshed. The physics is then defined on the external domain. A 10 noded tetrahedral element is used for generating the mesh and fine mesh is considered for good results.

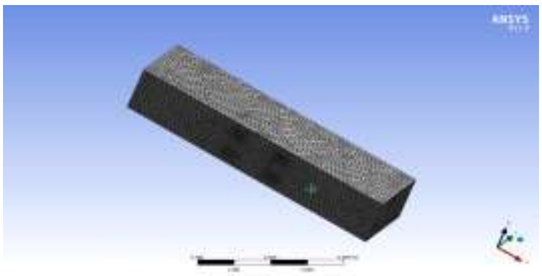


Fig.5.3. Mesh generated on car body by giving control limits

c) **Applying boundary conditions on the model of the vehicle:** The physical properties of air like density and the velocity of the fluid are applied to the domain.

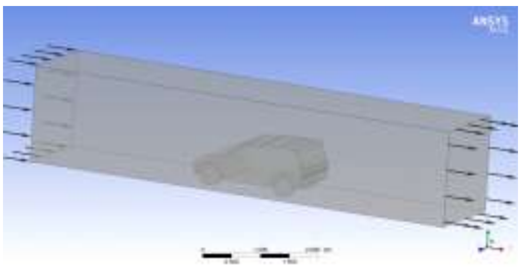


Fig.5.4. SUV without spoiler (enclosed in control volume)

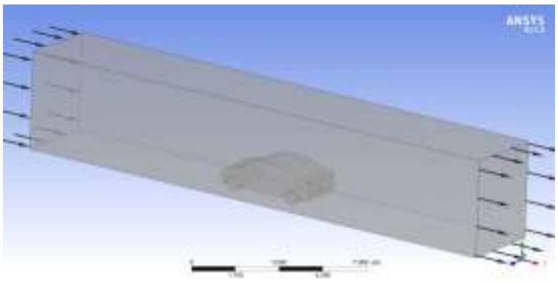


Fig.5.5. Sedan car without spoiler (enclosed in control volume)

**6. RESULTS AND DISCUSSION:**

**6.1: Analysis for various models:**

The meshing details of the four models considered are shown in table 6.1. the comparison of the aerodynamic drag is done for these models and the results are mentioned below.

Table.6.1: details of meshing of various models

| Type of model | Number of elements | Number of nodes |
|---|---|---|
| **SUV without spoiler** | 19424 | 96664 |
| **SUV with spoiler** | 61383 | 333496 |
| **SEDAN without spoiler** | 16415 | 80093 |
| **SEDAN with spoiler** | 89989 | 494176 |

The results of CFD analysis are obtained in the form of pressure distribution, velocity vector plot, velocity stream lines over the vehicles both with and without spoiler. Some of the results in the form of screenshots are shown below for various models.

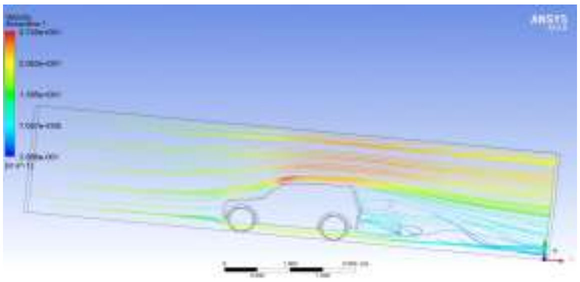


Fig.6.1. Velocity streamlines of SUV (without spoiler) at 60kmph

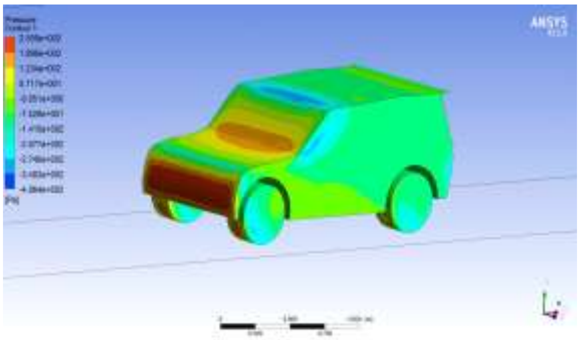


Fig.6.2. Pressure distribution around SUV model with spoiler at 60kmph

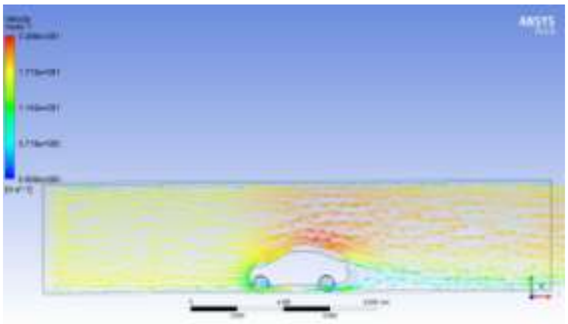


Fig.6.3. Velocity vectors of SEDAN without spoiler at 60kmph

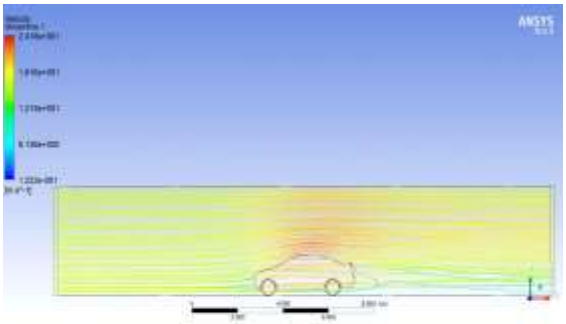


Fig.6.4. Velocity streamlines of SEDAN model with spoiler at 60kmph

**6.2. Velocity distribution**

From the velocity distribution figures (6.1,6.3&6.4), itcan be observed that flow separation occurs on the rear end of the vehicle due to sudden change in the shape. The flow separation produces a low pressure zone and it is also seen that vortices are formed due to recirculation. It can also be inferred that the velocity of flow increases over the vehicle top surface. This can be attributed to the convergence of flow. The high speed air will not follow the outer contour of the vehicles instead it gets separated on the rear end, forming a low pressure zone and inducing pressure drag on the vehicle.

### 6.3. Pressure distribution

The pressure distribution plot (fig.6.2) over a SUV model with spoiler at a speed of 60Kmph is represented.The pressure on the front end of the vehicle reaches a maximum as the fluid flowing towards the vehicle comes to a stagnation state. It can be further observed that the pressure of the fluid over the entire body drops to negative values. The pressure falls further on the rear end due to flow separation. The high pressure difference existing from the front to the rear end of the vehicle leads to a very high "**Pressure Drag**".

The total drag is combination of viscous drag and pressure drag. Since, the fluid is air which has very low viscosity, the friction drag is a very small component of the total drag at low velocities. But with the increase in velocity of vehicle, friction drag also contributes significantly to the total drag.

This phenomena is observed over both the vehicles. With the increase in speed, the flow separation zone where vortices are formed is found to increase in size. This produces even higher pressure drag. The friction drag also increases with increase in velocity. Hence, the total drag at higher speeds is due to both viscous friction and separation.

## 7. COMPARISION:

The drag force induced on the vehicles are shown in the tables 7.1 and 7.2 for both the models without and with spoiler. The drag force increases with speed almost in a parabolic manner as can be observed from the figures 7.1 and 7.2. It can be observed that the drag force on the SUV model is lesser compared to sedan model. The reduction in the drag force varies from 36% to 42% with the increase in speed from 30kmph to 120kmph for models without spoiler.

A similar comparison for both the models with spoiler shows that the drag force variation with speed follows a different trend. The reduction in drag is about 44% at a speed of 30kmph while it is at a lesser value of 35% at a speed of 120kmph.

### 7.1. Drag force for Sedan and SUV models without spoiler:

Table.7.1. Comparison of drag force without spoiler

| S.no | Velocity(km/h) | Drag force (N) | |
|---|---|---|---|
| | | Sedan | SUV |
| 1 | 30 | 27.4 | 17.8 |
| 2 | 40 | 48 | 31.5 |
| 3 | 60 | 105.8 | 69.9 |
| 4 | 80 | 185.4 | 123.1 |
| 5 | 100 | 286.8 | 191.1 |
| 6 | 120 | 409.5 | 237.7 |

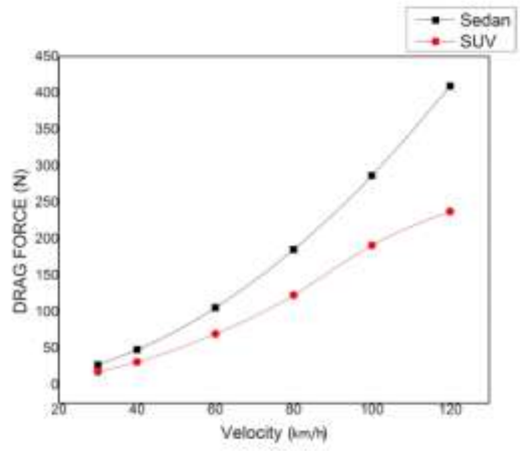



Fig.7.1. Comparison of drag force of sedan and SUV without spoiler

### 7.2.Drag force with spoiler:

Table.7.2. Comparison of drag force with spoiler

| S.no | Velocity(km/h) | Drag force (N) | |
|---|---|---|---|
| | | Sedan | SUV |
| 1 | 30 | 25.8 | 14.7 |
| 2 | 40 | 45.4 | 26.1 |
| 3 | 60 | 100.4 | 58.5 |
| 4 | 80 | 175.4 | 103.5 |
| 5 | 100 | 271.2 | 161.3 |
| 6 | 120 | 359 | 232 |

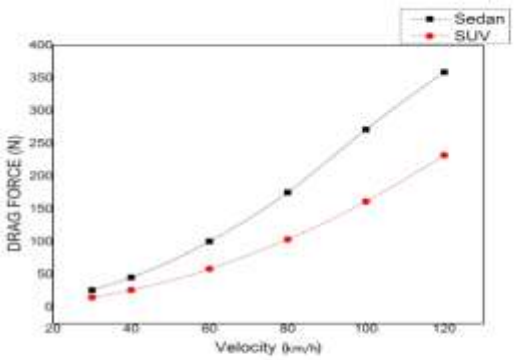



Fig.7.2. Comparison of drag force of sedan and SUV with spoiler

**7.3. Percentage reduction in drag force for Sedan and SUV models with and without spoiler:**

Table.7.3. Comparison of percentage reduction in drag force

| S.no. | Velocity (km/h) | Percentage reduction in drag force (%) | |
|---|---|---|---|
| | | Sedan | SUV |
| 1 | 30 | 16 | 5.83 |
| 2 | 40 | 17.14 | 5.41 |
| 3 | 60 | 16.31 | 5.12 |
| 4 | 80 | 15.92 | 5.39 |
| 5 | 100 | 15.59 | 5.43 |
| 6 | 120 | 2.39 | 12.33 |

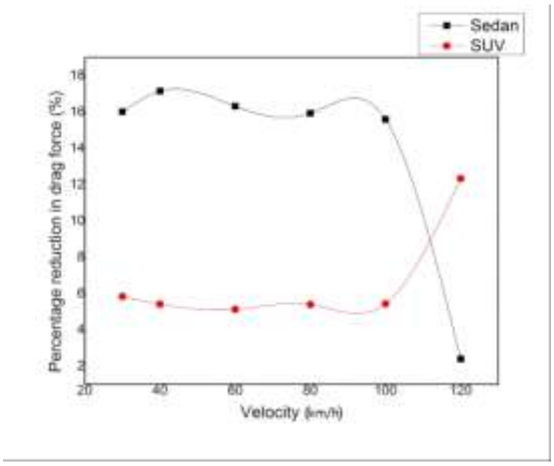



Fig.7.3. Comparison of percentage reduction in drag forcewith and without spoiler

With the addition of spoiler the flow distribution around the vehicle get slightly modified. Though spoilers are generally fixed to the vehicle to reduce the lift force, they are also effective in reducing the drag force as observed from our study. In our investigation, a spoiler was fixed on the rear end of both the vehicles to study its effect on the drag force. It was observed that spoiler has a marginal effect on the induced drag at higher speed than the drag at lower speeds. From the table 7.3 we can infer that drag force reduction on SUV model is lesser compared to sedan model. Hence, it can be inferred that the effect of spoiler in reducing drag is far superior in the sedan model The spoiler is found to delay the separation of flow and reduce the zone of low pressure on the rear end. This effectively reduces the form drag and hence, the total drags.

| S.no | Velocity( km/hr) | Co-efficient of Drag | |
|---|---|---|---|
| | | Without spoiler | With spoiler |
| 1 | 30 | 0.14 | 0.12 |
| 2 | 40 | 0.14 | 0.12 |
| 3 | 60 | 0.14 | 0.12 |
| 4 | 80 | 0.14 | 0.12 |
| 5 | 100 | 0.14 | 0.12 |
| 6 | 120 | 0.14 | 0.12 |

**7.3. Comparison of drag coefficient for Sedan and SUV models:**

Table.7.4. comparison of sedan model with and without spoiler

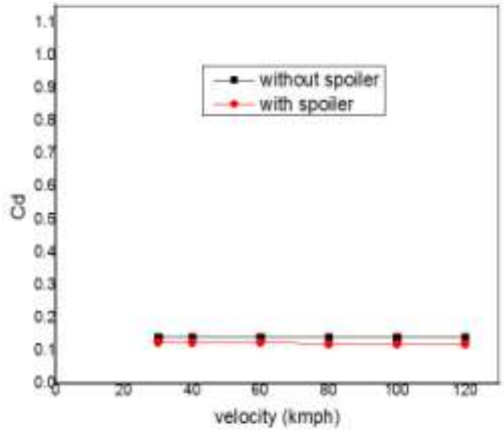
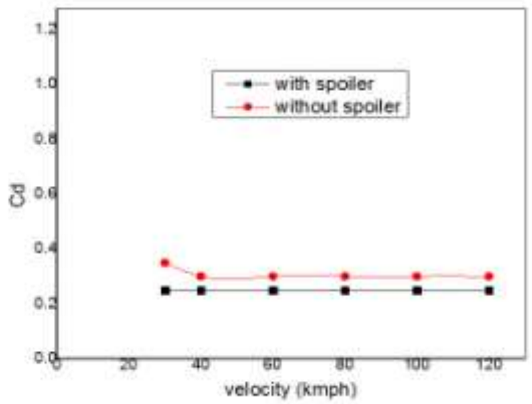



Fig.7.4.comparison of drag coefficient For Sedan model

Table.7.5. comparison of SUV model with and without spoiler

| S.no | Velocity(km/hr) | Co-efficient of drag | |
|---|---|---|---|
| | | Without spoiler | With spoiler |
| 1 | 30 | 0.35 | 0.25 |
| 2 | 40 | 0.3 | 0.25 |
| 3 | 60 | 0.3 | 0.25 |
| 4 | 80 | 0.3 | 0.25 |
| 5 | 100 | 0.3 | 0.25 |
| 6 | 120 | 0.3 | 0.25 |




Graph 7.5.comparison of drag coefficient For SUV model

From the above plots 7.4 and 7.5 it can be observed that though the coefficient of drag is reduced when spoiler is placed.It is found to be invariant with velocity.

**8. CONCLUSIONS:**

From the aerodynamic analysis carried on two different models of passenger vehicles, the following conclusions can be drawn.

The drag force acting on a vehicle varies almost in a parabolic manner with respect to the velocity.The drag acting on the SUV model is found to be lesser when compared to sedan model at a given speed. Hence, it can be stated that SUV model is aerodynamically superior.The analysis was extended further to study the effect of addition of spoiler on the passenger cars.It was observed that the drag force reduces with a spoiler attached to the vehicle. Hence, the fuel economy, stability and overall efficiency will be increased.There is an average of 15% reduction of drag force observed in sedan car when spoiler is placed. Whilst there is an average of 5% reduction of drag force observed in SUV model.

The coefficient of drag exhibits negligible variation with respect to velocity, while it has a considerable variation with the change in the shape of the body. Average drag coefficient of SUV model without spoiler is 0.3 and with spoiler is 0.25 andaverage drag coefficient of Sedan without spoiler is 0.14 and with spoiler is 0.12.

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