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Numerical Investigation of the effect of different Aerofoil profile of a spoiler in a car

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ABSTRACT

With the speed changes, aerodynamic vehicles experience issues such as instability, drag and lift increasement, and so on. A great amount of lift force is created at the back end of the vehicle when a person drives a vehicle at a high speed, which can be reduced by attaching a spoiler at the rear side of the car. This paper shows the influence of the rear spoiler in an aerodynamic vehicle and the changes that occur when a rear spoiler is mounted. The right height of the rear spoiler from the rear trunk at a constant high speed and constant angle of attack is being investigated here. To obtain those results, 2 symmetric and 1 cambered type NACA Aerofoil is being analyzed as a rear spoiler with the help of CFD. CFD (Computational Fluid Dynamics) is a set of numerical algorithms used to estimate the solution of fluid dynamics and heat transport issues." A BMW 3 series car model is used here which is being modeled in solidworks19 and then imported in ANSYS Fluent (2020R2). The k-omega SST turbulence model was chosen. A new rear spoiler is utilized as a consequence of an examination of the simulation results, which demonstrates a slight reduction of the vehicle aerodynamics lift force with the optimization of lift and drag force. Among the three types of naca profile, it can be seen that NACA 0012 provides more downforce (38%) than the other two types NACA 0012 (37.8%) and NACA 2412 (32.5%) when they are used as a rear spoiler in a car at Reynolds number 2.68. Even though spoilers are often attached to a vehicle to minimize lift force, they increase drag force in this case, as seen in this research. From a safety standpoint, reducing aerodynamic lift is more critical than reducing aerodynamic drag. The best height of the spoiler from the rear tank is 0.4 times than distance between the rear trunk and the upper surface of the car body in which more amount of downforce is generated.

Key Words: Spoiler, CFD Analysis, NACA profile, Down force

1. Introduction

The aerodynamic performance of a car is very critical to car modeling engineers. For the marketing strategy, efficient and faster cars are given always the priority. When an automobile travels through the air at high speed, the lift and drag forces on the car have a substantial impact on the car's aerodynamic performance. As a result, the aerodynamic performance of a car has long been a top priority for car designers. External attachments are applied to a car by improving its performance relates to aerodynamics. In this paper, a two-dimensional flow field analysis has been performed to understand the airflow characteristic around a car profile which creates aerodynamic forces. This illustrates the need for aerodynamic wing with a spoiler that causes a controlled stall over the wing section behind the spoiler, essentially by lowering the lift of that wing section. Spoilers are meant to minimize lift while also increasing drag significantly [3]. Because of its ability to reduce aerodynamic lift, the spoiler's invention was unavoidable; in terms of safety, this feature is more significant than aerodynamic drag, which affects the car's performance as well as its economic side. Fig.1 shows the flow pattern of air over a car when there is no spoiler attached on the rear portion of the car that shows a rear wake region at the back side of the car. Kim,Rho[3] has given the numerical analysis based on stationary and oscillating type spoiler in which 3 different spoiler deflection was taken. The effects of frequency and amplification were examined in this study.

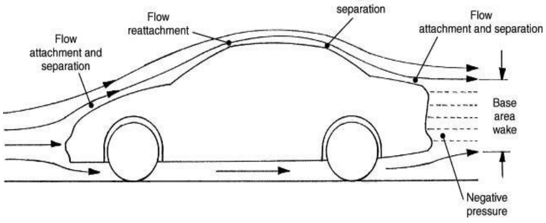

Fig.1 Flow nature over a car body without spoiler [1]

. T Sai et al[4] investigated aero acoustic analysis of a passenger car by adding spoiler. Here the effect of wind velocities on passenger cars with and without spoiler were investigated. Daryakenari et al. [5] has shown that there is a possibility to reduce the 75% lift coefficient for a passenger car model by doing the right inclination angleof its flat plate type spoiler. .Xu-Xia, Wong [6] did their study on the effect of rear spoilers in passenger vehicles. They analyzed the flowaround a high-speed passenger automobile with a rear spoiler and the flow around a high-speed passenger carwithout a rear spoiler using two distinct types of simulations. Cakir [7] studies the aerodynamic effect of a Passenger car by adding a rear wing spoiler. The numerical result shows that with

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a wing-type rearspoiler 17% drag reduction occurs and also increasesnegative lift by reducing lift force by an amount of 7%[7].The influence of the rear spoiler and the angular effectof the spoiler on the aerodynamics of a vehicle is investigated by Singh, Anuj, and Shubham [8]. Here, various angles of attack position have been analyzed.

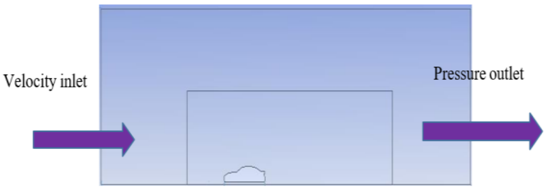

Fig.2 Fluid Domain

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The top and bottom side of the domain is named symmetry and road respectively. Air will enter the domain in velocity inlet and exit through pressure outlet. Fig.2 shows the direction of air flow through a computational domain in which velocity entrance is in the left side and outer portion is right side of the domain.

2. Methodology

2.1 Governing Equation

Continuity equation for 2D, incompressible, steady state flow

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

For 2D, incompressible, steady state flow the Navier Stokes [10] equation is

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\rho g_x \tag{2}$$

$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\rho g_y \tag{3}$$

Transport equation of SST K-ω model [11]

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_{ij}}(\rho k u_i)=\frac{\partial}{\partial x_j}\left(\Gamma_K\frac{\partial k}{\partial x_j}\right)+G_k-Y_k+S_k \tag{4}$$

$$\frac{\partial}{\partial t}(\rho w)+\frac{\partial}{\partial x_{ij}}(\rho w u_j)=\frac{\partial}{\partial x_j}(\left(\Gamma_w\frac{\partial w}{\partial x_j}\right)+G_w-Y_w+S_w \tag{5}$$

In Eq. (4), the term G_k represents the production of turbulence kinetic energy. In Eq. (5) G_ω represents the generation of ω. Γ_k *and* Γ_ω *represent* the effective diffusivity of k and ω respectively. Y_K And Y_ω represents the dissipation of k and ω due to turbulence. D_ω Represents the cross diffusion term. S_K & S_W are user defined source term. In Eq.(1) and (2) u & v denotes the velocity in a specified direction.

2.2 Numerical Methodology

In this region model validation, geometry creation, meshing, numerical set up has been discussed.

2.2.1 Mesh Dependency Test

At first in the mesh dependency test, Reynolds number is taken as Number= 37952.75, a k-omega turbulencemodel is selected, and Residual is taken as 0 .001. Here it is shown that up to 693558 elements coefficient of drag changes rapidly. From elements 693558 the valueof coefficient of drag becomes nearly constant. After this, by increasing element drag coefficient changes very small in amount

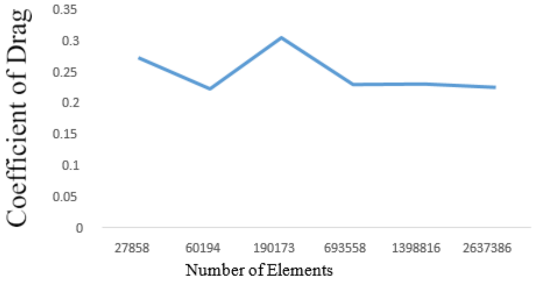


Fig.3 Result of Mesh Dependency Test

2.2.3 Validation of Drag coefficient of a conference paper

In order to check the accuracy of the present analysis, at first Kushwaha, Vikash, Races, "Investigation of Aerodynamic forces on vehicle using CFD" [12] a conference paper is studied and validated the result of drag coefficient.

Table 1 Results of drag coefficient validation

Velocity (m/s)	Result of conference paper	Result of my simulation	Deviation (%)
22.22	0.243702	0.24254291	0.476
27.77	0.241598	0.24183054	0.09

2.3 Geometry Creation

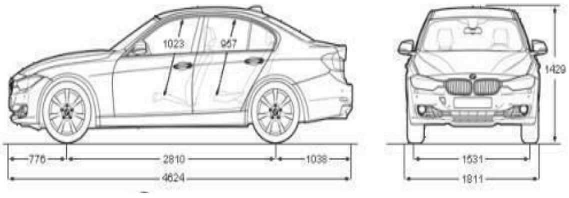
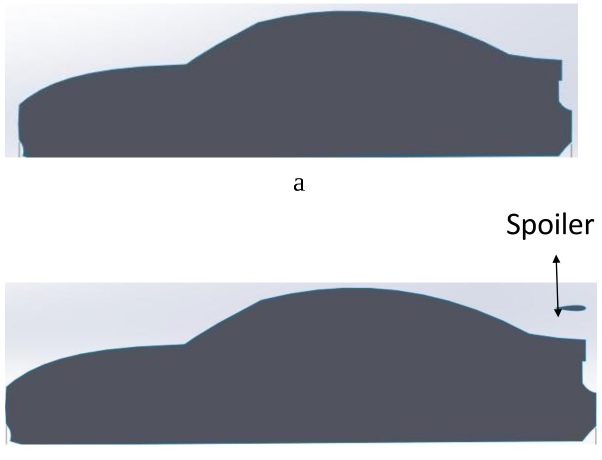


Fig. 4 BMW 316i E Series car model [13]

A BMW 316i E Series car model is used in this analysis
Length Scaled: 100mm Original: 4624mm
Height Scaled: 26.67mm Original: 1429mm

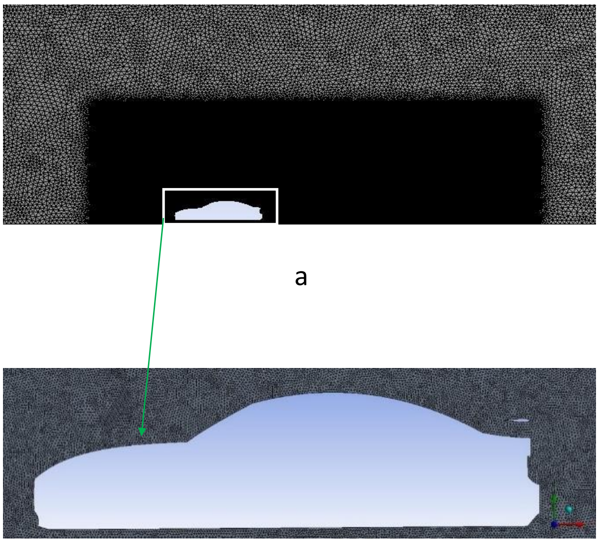


a

b

Fig.5 2D Car Profile (a) without spoiler **(**b) Without spoiler

Fig. 4 shows the original car profile but in the analysis scaling is done. Scaled dimension is given and Fig.5 shows the scaled dimension car profile without spoiler which is modeled in Solidworks 16 and Triangular meshing is done in this analysis which is shown in the Fig.7 (a) and meshing near the car profile is shown in the Fig.7 (b). Inflation layer is used to make smooth air flow over the car.



a

b

Fig.6 Triangular meshing (a) Meshing all in the domain (b) Meshing near the car body.

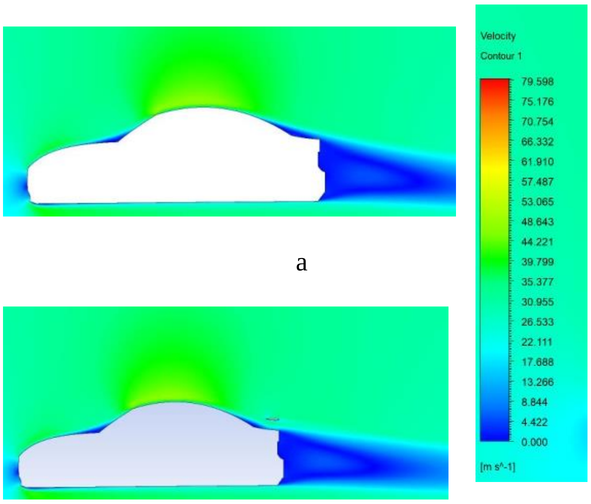
2.4 Solver Settings

Table 2 Solver setting in the ANSYS

Solver	Fluent
Time	Steady
Velocity	Absolute
Turbulence	k-omega(2 equation)
Velocity inlet	7,15,30,45,60
Inlet turbulent	1%
Initial pressure	0 pa
Fluid type	Air
Residual	0.0001
K-Omega model	SST

3. Result and Discussion

3.1 Discussion of Various Contour

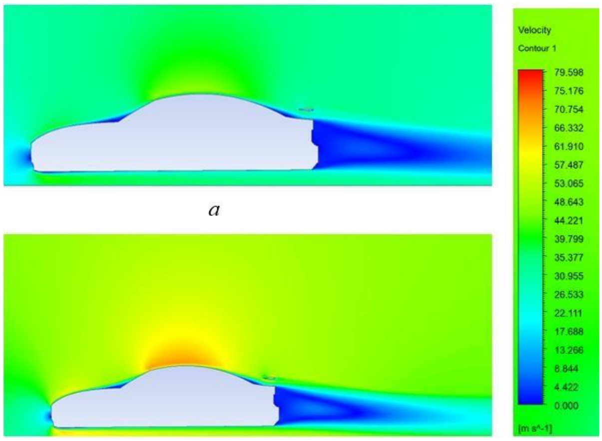


a

b

Fig.7 Velocity Contour at Reynolds number Re=2.01× 10^6 (a) Without spoiler (b) with spoiler(NACA 0018)

The fig.7 gives the information on velocity distribution over a car body with and without attaching the rear spoiler at a fixed Reynolds number 2.01 × 10^6. The dissimilarities are shown in the rear part of the car. When a spoiler is added at the rare sideof the car, air moves slowly over the spoiler surface and moves quickly at the lower side portion of a spoiler. This velocity dissimilarities of lower part and upper part of spoiler creates a down force that reduceslift when a car moves at a high speed.

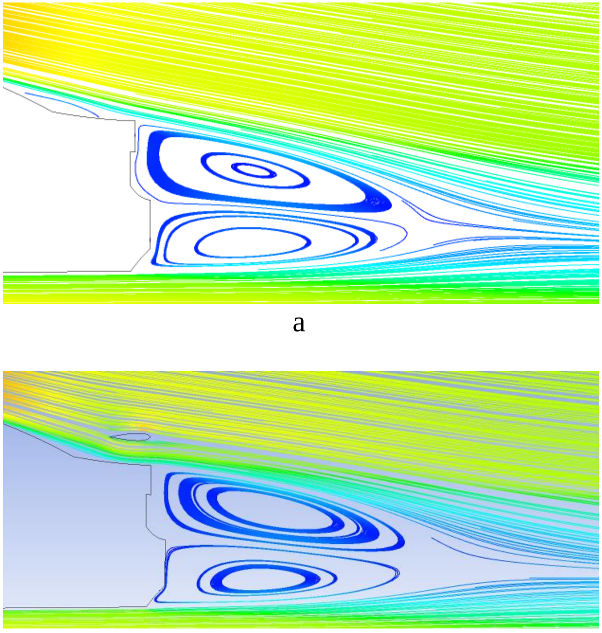


a

b

Fig.8 Velocity contour at Reynolds number a) 1.34× 10^6 (b) 2.01× 10^6

The above fig.8 gives the information on the velocity distribution of a car at various Reynolds number. The dissimilarities are shown in the rear part of the car. When a spoiler is added at the rear side of the car there creates a high pressure region over the spoiler that acts downward direction. This high pressure due to the spoiler reduces lift force but slightly increased drag force. The velocity streamline of an automobile with and without attaching a spoiler is shown Fig.9.

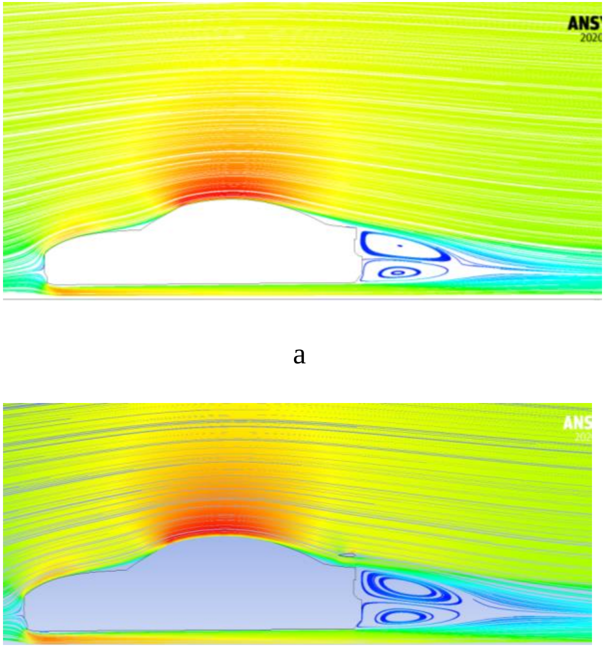


a

b

Fig.9 Vortex region at the rear portion of the car (a) Without spoiler (b) With spoiler

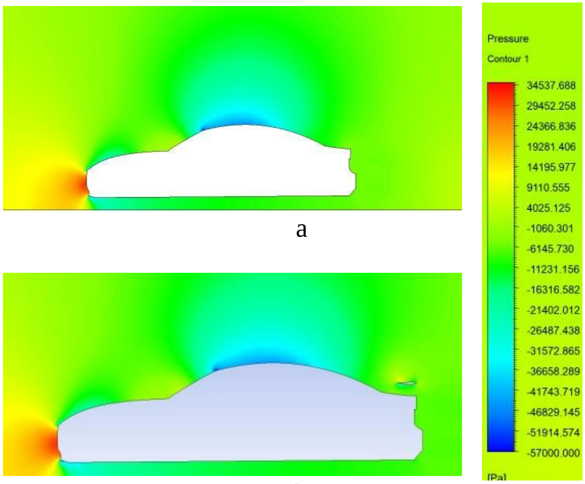
The velocity Streamline of an automobile with and without attaching a spoiler is shown in fig.9. The air flow is readily divided from the rear of the automobile that results a wake region when no spoiler is placed on the rear portion of the automobile. The streamlined smooth airflow is disrupted when spoiler is added on the rear side .This disruption makes airflow slower and boosting the air pressure of upper surface .This increasement of upper surface pressure produces negative lift the gives driving stability at high speed.



a

b

Fig.10 Velocity Stream line (a) without spoiler (b) with spoiler



a

b

Fig 11: Pressure contour at Reynolds Number 1.34 × 10^6 (*a*) Without spoiler (*b*) with spoiler (NACA 2412)

The fig.11 shows the pressure distribution of a car with and without a spoiler at a fixed Reynolds number. In both cases maximum pressure acts on the front part of the vehicle and lowest amount of pressure is acted on the roof surface of a car. The dissimilarities are shown in the rear part of the car. When a spoiler is added at the rare side of the car there creates a high-pressure region over the spoiler that acts downward direction. This high pressure due to the spoiler reduces lift force but slightly increased drag force. There is no high pressure zone on the back side of a car when no spoiler is attached. Down force is crucially needed when a car moving with very high speed.

3.2 Graphical Representation of obtained result

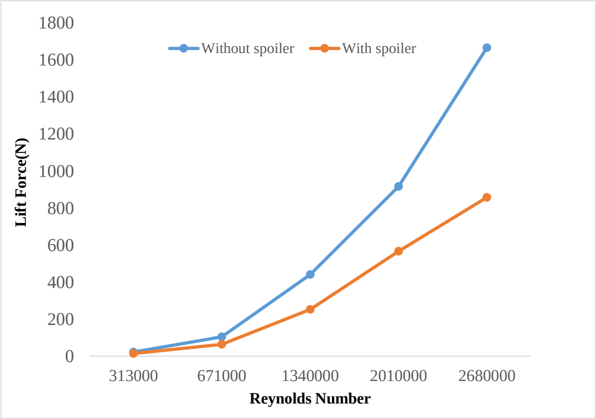


Fig.12 Lift Force variation with Reynolds number

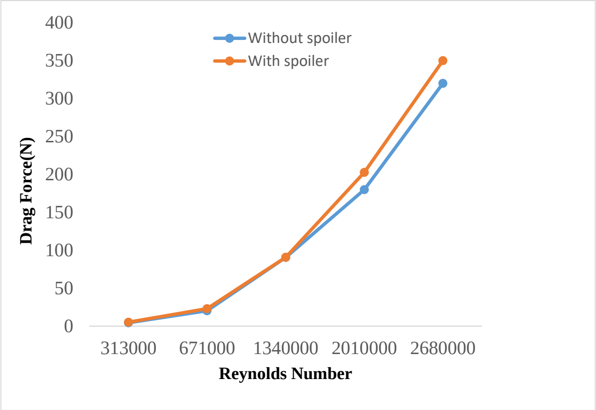


Fig.13 Drag force variation with Reynolds number

Fig.13 gives the information how drag forces vary with Reynolds number. By the increasement of Reynolds number Drag force also increases in both cases. At Reynolds number 3.13×10^5, drag force without spoiler is 4.478 N and with attaching rear spoiler the obtained drag force value is 5.1362. Here it can be seen that at Reynolds number 3.13×10^5, 14% of drag force is increased by attaching rear spoiler. . At Reynolds number 6.71×10^5 the value of drag increasement is 13.72%, at Reynolds number 1.34×10^6, the value of drag force increasement is 12.5%, At Reynolds number 2.01×10^5. Here we can see that by increasing Reynolds number indicates the decreasing nature of drag force increasement by attaching spoiler on the rear side of the car. It is happened because a fixed rear side spoiler may increases drag force at lower velocity. Because of occurring little amount of airflow over spoiler at the rear portion of the car little improvement of vehicle stability is done Spoilers are mainly designed to increase down force but sometimes it may increase the drag force.

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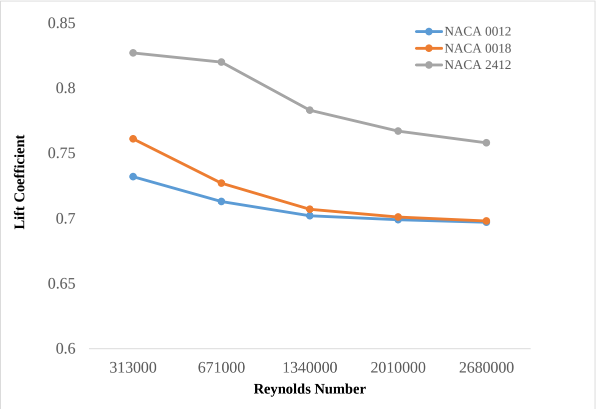

Fig.14 Lift coefficient variation with spoiler at various NACA profile

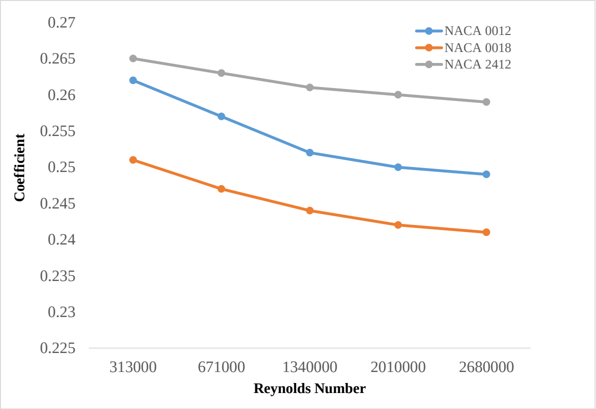

Fig.15 Drag coefficient variation with spoiler at various NACA profile

The fig.14 gives the information at which NACA profile we can generate better downforce at a fixed Reynolds number and fixed height from rear trunk .Reynolds number 3.13×10^5 *and* 6.71×10^5. At Reynolds number 3.13×10^5 , by using NACA0012 as a rear spoiler the generated liftcoefficient value is 0.73195 and for NACA 0018 and NACA 2412 gives the lift coefficient0.7613and 0.82673 respectively. AtReynolds number 6.71×10^5, by using NACA 0012 as a rear spoiler the generated liftcoefficient value is 0.71323 and for NACA 0018 and NACA 2412 gives the lift coefficient 0.72697 and 0.8244 respectively. Here lift-coefficient of car by attaching NACA 0012 as arear spoiler is smaller than others. So, it can besaid that

NACA 0012 spoiler produces more down force than NACA 0018 and NACA 2412.

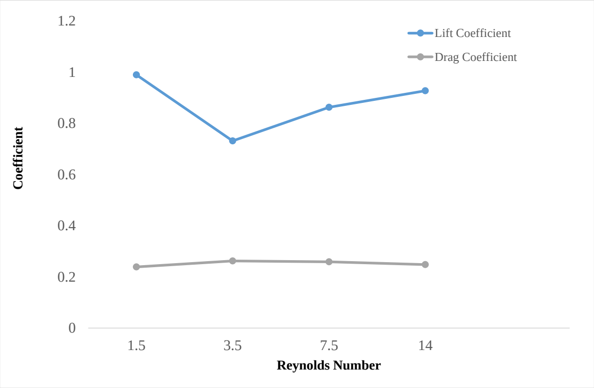

Fig.16 Lift and Drag coefficient variationwith spoiler height from rear trunk

From Fig.16 the variation of lift and dragcoefficient at various spoiler height from reartrunk of a car is shown. It is shown from thegraph that initially lift reduces and reaching itsminimum position at a height of 3.5mm from therear trunk.

6 Conclusion

The use of a spoiler at the rear side of automobile results in a considerable change in the coefficient of drag and lift of the modeled car profile, according to the research. Adding a spoiler at the rear side creates the down force which gives some driving stability at high speed car which has been investigated here. Among the three types of naca profile, it can be seen that NACA0012 provides more down force than other two types NACA 0018 and NACA 2412 when they are used as a rear spoiler in a car. Despite the fact that spoilers are often attached to a vehicle to minimize lift force, they actually increase drag force in this case, as seen in this research. From a safety standpoint, reducing aerodynamic lift is more critical than reducing aerodynamic drag. The best height of the spoiler from the reartank is 0.4 times than distance between the rear trunk and the upper surface of the car body in which more amount down force is generated.

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NOMENCLATURE

C_D : Coefficient of drag

C_L : Coefficient of Lift

ρ : Density (kg/m^3)

F_D : Drag Force (N)

F_L : Lift force (N)