EXPERIMENTAL SURVEY OF THE EFFECT OF SPOILER HEIGHT AND DIFFUSER ON AERODYNAMIC COEFFICIENTS OF A GENERIC CAR

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ABSTRACT
In recent years, aerodynamic analysis of automobiles has became one of the most important issue which affect the competition of the companies present in the world markets. Therefore it can be considered as one of the most important factor in aerodynamic design of the vehicles. This paper investigates the effect of aerodynamic devices on how to reduce the aerodynamic forces in the rear of a car model. The study was conducted experimentally at speeds of 0 to 60 m/s and a constant speed of 60 m/s. In these experiments aerodynamic forces, lift and drag coefficients were measured and the effect of the spoiler with three different heights along with diffuser were compared. The most important result of these experiments was the effective reduction of lift and drag coefficients with the presence of a spoiler and diffuser on the model.

KEYWORDS: Aerodynamics, Spoiler, Diffuser, Lift, Drag

INTRODUCTION
Aerodynamics is a science that examines the flow of air around bodies. Research methods in this science have been developed in the three theoretical, numerical and experimental branches. Aerodynamic designing of automobile body and its continuous improvement have been always of interest to researchers and automakers, and extensive research has been done in this area. The reason for this is the significant impact of a good aerodynamic design on the efficiency and performance of a car. In fact, any success in designing the aerodynamics of the body of a car can be considered as a contribution to reducing its fuel consumption during its use.

The aerodynamic analysis of a car in view of the rapid progress of the automotive industry in the present era is one of the important parameters in design for presence in the competition scene of this industry. Starting a move to optimize the body of cars and reduce their fuel consumption, since 1975 was followed by a growing increase in fuel consumption of cars produced from the 1960 to 1970. In the cars of this generation, suddenly the consumption of gasoline showed a dramatic increase that was because of manufacturing cars with a wide front vertical surface and cut rear section. In these cars, due to the presence of a separation point in the end part of body, a very high drag force was created.

Up to now much investigation have been done in order to change the rear form of riding cars and a lot of them have reached to production step that common point of many of them is maximum reduction of the amount of vortices formed behind the car and reduction of drag force in this section and preserving stability of the car in different speeds. One of these ideas is installing a piece called spoiler in the rear of the car. The main task of Spoiler's is controlling the air surrounding the car, particularly its rear. Spoiler can neutralize the force produced in moving that makes a car to exit from its path. In fact, spoiler prevents creation of unbalanced air flow in behind of the car and cause that the car also in the high speed would be in a stable position. Installing this part on a car can have a good impact on the aerodynamic position of a car that these effects mainly are increase of downward force in order to reinforce the balance and stability of the car and also lowering the drag force to reduce fuel consumption.

Another idea that can be effective on the rate of aerodynamic forces of a car rear section is placing diffuser under the rear section of a car. This will guide the air flow in the lower part of the car to reduce as much as possible the high pressure area under the car.

Ahmed et al [1] in 1984 presented an accurate and reference model that created an evolution in the aerodynamic of car and became the subject of many researchers investigation. Ahmed et al following an invention in the body examined a type of current passing from car’s body. Ahmed’s body was designed mostly with the aim to study the effects of rear part of cars on the drag force and current structure. In the Ahmed’s body the angle of the end part of the body was variable and they examined the current formed around the body in different angles.

In 2003 Linhart et al [2] examined Ahmed’s body during an experiment with more details in the two end angles of 25 and 35 degree in the speed 40 m/s by two LDA anemometer devices. They showed in this experiment that the vortex shape and the place of current insertion in the rear of the model are different from various end angles of the model.

Matthews Romance et al [3] in 2008 in a study by help of numerical methods through controlling separation on the rear part of Ahmed’s model in different states studied the reduction of drag and indicated that reduces by controlling current in the rear part of the car to 17% of drag force that this is equivalent to lowering fuel consumption and reduction of pollution and transportation costs.

Mitra [4] using laboratory equipments examined the effects of adding components such as front and back spoiler on the simplified model of Sedan car. They observed that adding back spoiler has a positive effect on the increase of aerodynamic stability of the car.

Sonanda et al [5] in 2013 through a numerical study indicated that a major part of the downward force is created from pressure difference that is applied between the higher and lower surface of spoiler.

Lidya Joveci [6] in 2013 studied diffuser experimentally and showed that setting diffuser in the end part of car and under it results in more sustainability of the car in high speeds. In this experiment by increase of speed in different times can observe that the more speed increase, the more increase downward force in the car rear and consequently result in more sustainability of car.

Tessa and colleagues [7] using numerical methods studied sustainability of a car resulted from the rear spoiler. They concluded that installing spoiler reduces the lift coefficient that results in providing better conditions for driving with high speed and vertical stability of driving.

Samir Kamat et al [8] in 2014 with the aim of improving the aerodynamic performance of hatchback cars installed different forms of spoilers in the rear part of a car model and found that installing spoiler in the most of cases has a significant reduction drag coefficient.

Shame and Ram Bancel [9] in 2014, applying spoiler and vortex generators simultaneously on a simple car roof sought to understand their effect on the rear aerodynamic forces that observed 4.35% reduction in the drag coefficient and 18.83% increase in the negative lift force.

Ahmadi and Abbas Alizadeh [10] by study of the effects of the spoiler's angle and height in the aerodynamic condition of the vehicle obtained an optimum height and angle for the rear spoiler of the Samand car that should be adjusted by a system controller dependent on the speed of the vehicle.

THE STUDIES EQUIPMENTS AND MODEL

These experiments have been conducted in the infrasound wind tunnel of Mechanics Research Center of the Spatial Institution of Iran located at Shiraz.'Figure 1' shows the infrasound wind tunnel. This tunnel has an experiment section with dimensions of 80 cm widths, 80 cm height and 200 cm length. The maximum turbulence intensity in this tunnel is about 0.13 that in 'figure 2' the rate of the turbulence intensity is observable. Controlling the speed of air is using fan circle in range of 0 to 100 m/s. in this experiment to calculate forces and moments the external balance was used and signals given from balance has been calculated by Lab view software in the form of force and moment.

EXTERNAL BALANCE HAS THE FOLLOWING CHARACTERISTICS:

- Lift force 700 Newton
- Drag force 500 Newton
- Lateral force 500 Newton
- Moments 50 Newton meter

And a digital anemometer device has the following characteristics:

- 32 channels of differential pressure 10 mbar with measurement accuracy of 0.05 mbar and speed of 1 kHz
- 64 channels of differential pressure 60 mbar with measurement accuracy of 0.03 mbar and speed of 1 kHz

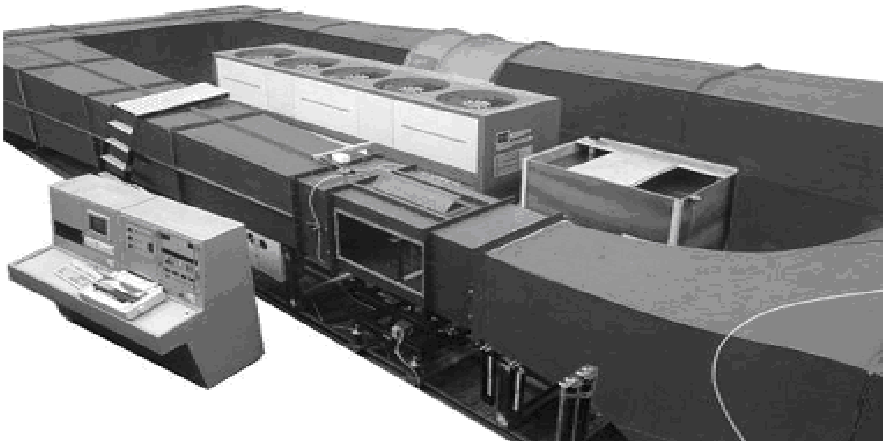

Figure 1: Subsonic wind tunnel of Aerospace Research Institution, Shiraz

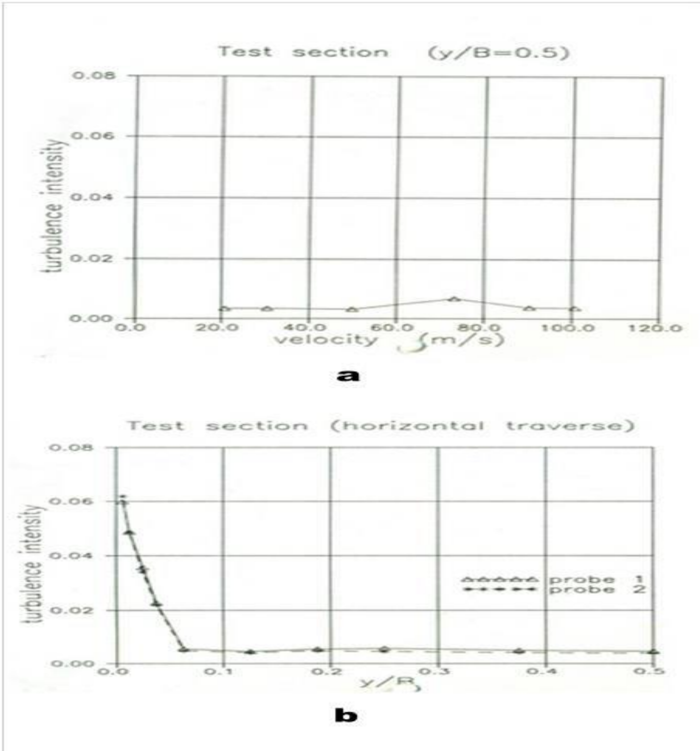

Figure 2: Changes of turbulence intensity in relation to the average speed in the center of the experiment section (a) and in relation to the distance from wall in the experiment section (b)

The studied model in this research is the model suggested by Ahmed with end angle of 35 degree. Other characteristics and dimensions of the model have been shown in 'figure 3' that we have implemented this experiment with half dimensions of the main size of the model of the related experiments.

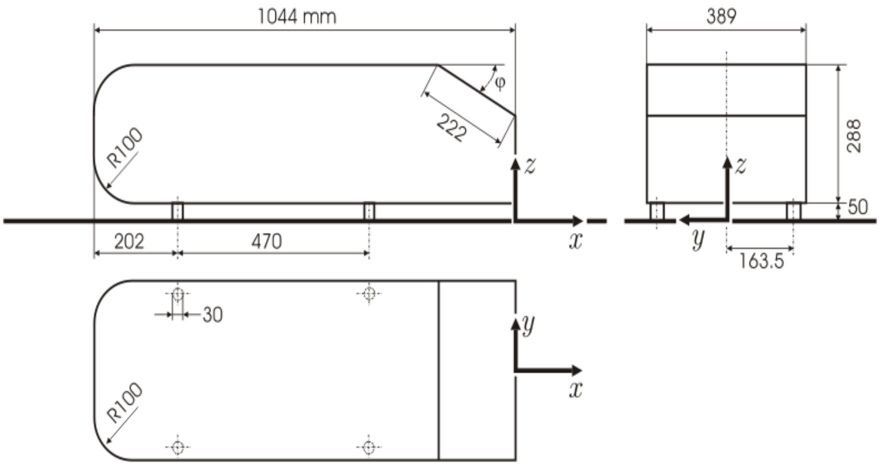

Figure 3: Characteristics and dimensions of Ahmed's model

A schematic of three dimensional view of the Ahmed's base model is presented in 'figure 4'.

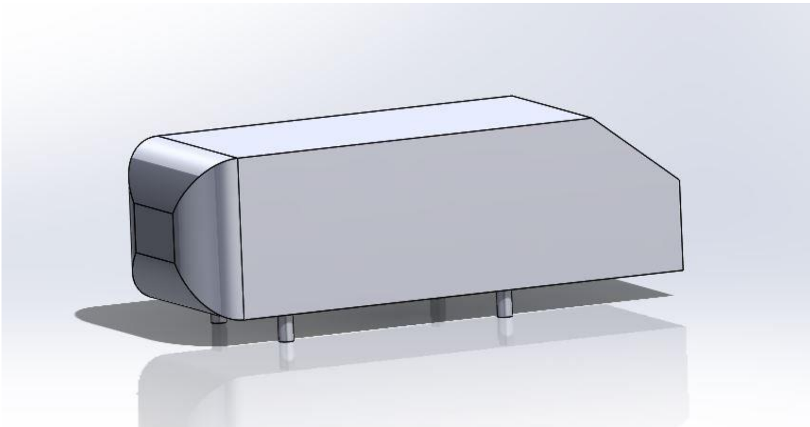

Figure 4: A schematic of the three-dimensional view of Ahmed's base model

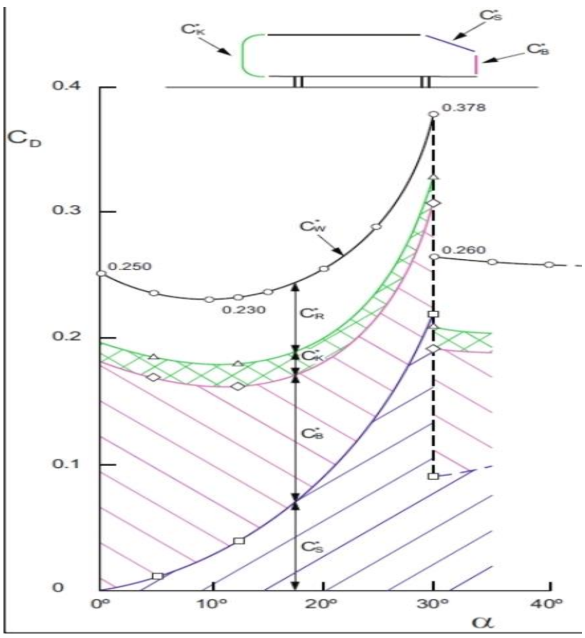

Figure 5: Diagram of the drag coefficient of Ahmed's base model

'Figure 5' shows the diagram of the drag coefficient of Ahmad's base model.

In this research the model was experimented in the speed ranges of 0 to 60 m/s in simple way and by presence of aerodynamic parts such as spoiler and diffuser in the end of the model in four different states 'Table 1'.

Table 1: Aerodynamic parts positioning at the end of the model

row	State	Subject title
1	Simple model without aerodynamic parts	Simple
2	Model with spoiler with height of 1 cm and diffuser	With spoiler 1 & diffuser
3	Model with spoiler with height of 2 cm and diffuser	With spoiler 2 & diffuser
4	Model with spoiler with height of 3 cm and diffuser	With spoiler 3 & diffuser

The studied model in this experiment has been developed from wood and aerodynamic parts (spoiler and diffuser) by three-dimensional printing technology and from PLA [11]. Also a schematic of the spoiler and diffuser model used in this experiment and its dimensional characteristics has been presented in 'figure 6'. Designing these parts has been carried out in CATIA software that is observed in 'figure 7'.

Figure 6: Schematic of spoiler's in different heights

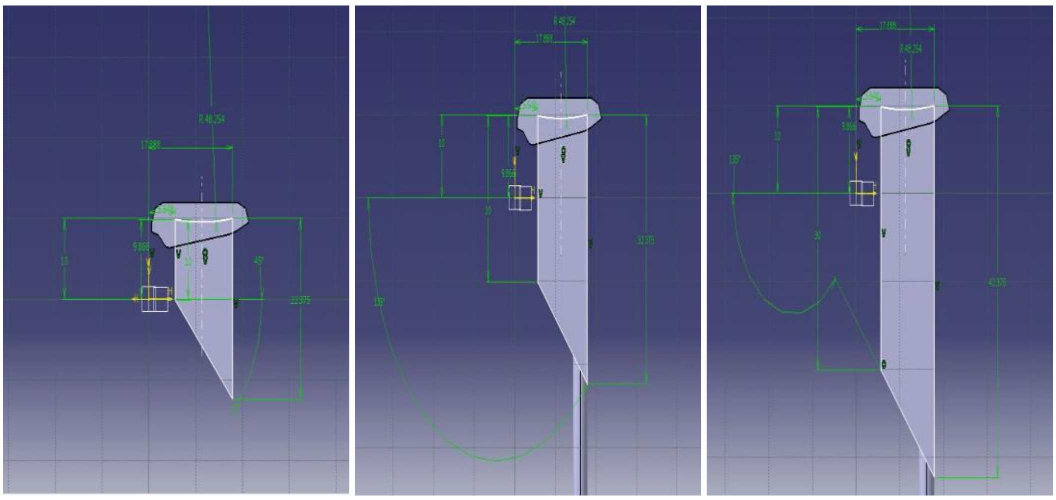

Figure 7: Dimensional characteristics of spoiler models in CATIA software

Figure 8, 9 and 10 show the test model installed on the base plate in the experiment chamber of wind tunnel. Setting up the base plate due to the positioning the test model in a fully uniform current area and away from wall turbulences in the test chamber.

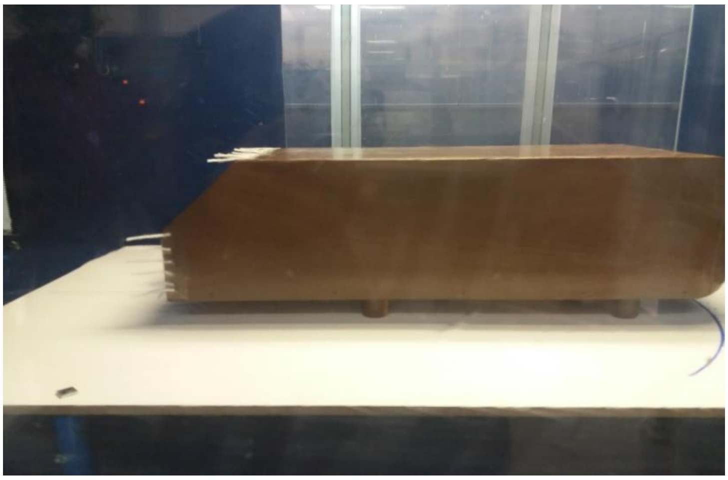

Figure 8: Test model installed on the base plate in the experiment chamber

Figure 9: How the spoiler positions on the test model

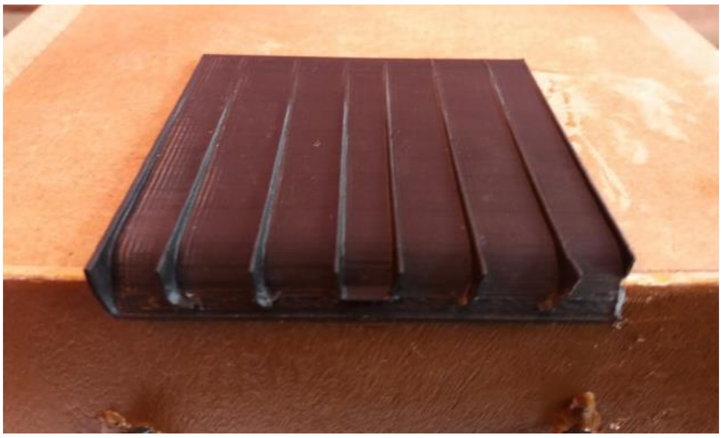

Figure 10: How the diffuser positions on the test model

DETERMINING STANDARD DEVIATION

Among the most important factors influencing on the analysis of the results of this experiment is sufficient information about the accuracy of the test and the error incurred on the test. Then to examine the test precisely, first the possible source of error in the test process of experiment have to be determined and necessary modifications are perfumed on the data obtained from the test. Then the level of accuracy of the obtained data can be understood. In the following the possible source of error in this test are addressed.

As explained, applying any measurement strongly is dependent on the evaluation of its precision in some logical methods and exact evaluation of any measurement is difficult. Then it is needed that all aspects of a particular experiment are examined and analyzed. In this section in order to evaluate the precision of the conducted tests the diagram of aerodynamic coefficients with the standard deviation level in the all tested states have been shown.

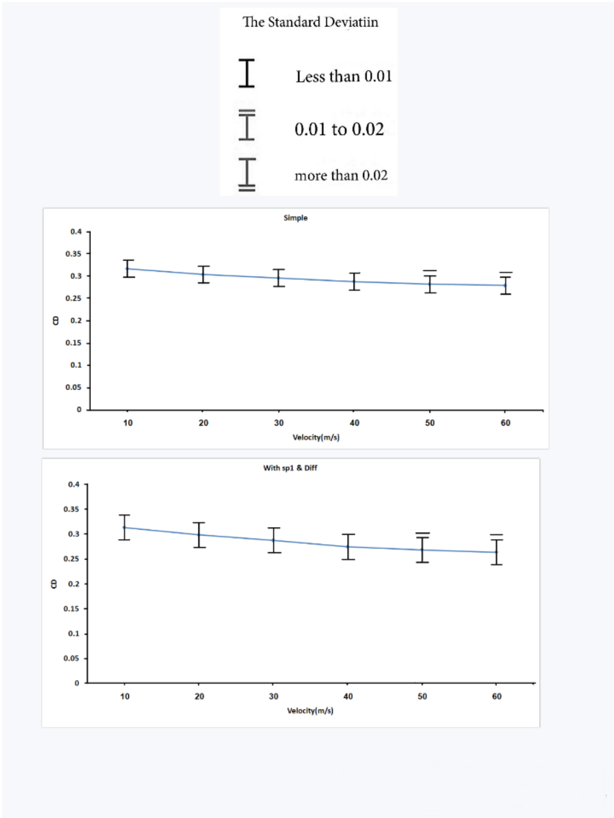

Figure 11: Diagram of determining the standard deviation of drag coefficient

Diagrams of figure 11 show the drag coefficients with the level of standard deviation in the all tested states. As it is observed the standard deviation in the most of points is less than 0.02.

RESULTS AND DISCUSSION

To examine the effect of the spoiler and diffuser on the aerodynamic coefficients experimentally, according 'figure 3', Ahmed’s model has been developed with certain dimensions. It has to be mentioned that due to the relatively smallness of experiment section in the wind tunnel, in this study Ahmed’s model has been developed with slope angle of 35 degree in a half one scale until as much as possible the blockage effects are prevented. Experiments on the Ahmed’s model up to now have been conducted in the speed of 30 to 40 m/s. therefore, to reach the Reynolds’s number consistent with the previous experiments; the uniform flow speed has to reach to 60 to 80 m/s[1].

In this research we have focused on the aerodynamic coefficients and tested the model in the different states mentioned in table 1 in the speed ranges 0 to 60 m/s. 'Figure 12' shows the changes of lift force of the tested model in the all states. According the figure, with increase of speed, left force reduces as well that in turn results in the increase of downward force and the more stability in the car and from the diagrams it is found that generally addition of aerodynamic parts on the model cause reduction of lift force (increase of downward force) and the best effect in the reduction of lift force is related to the 'state 4' that the least lift force in this state was obtained in the speed of 60 m/s and equal to -16.73 .

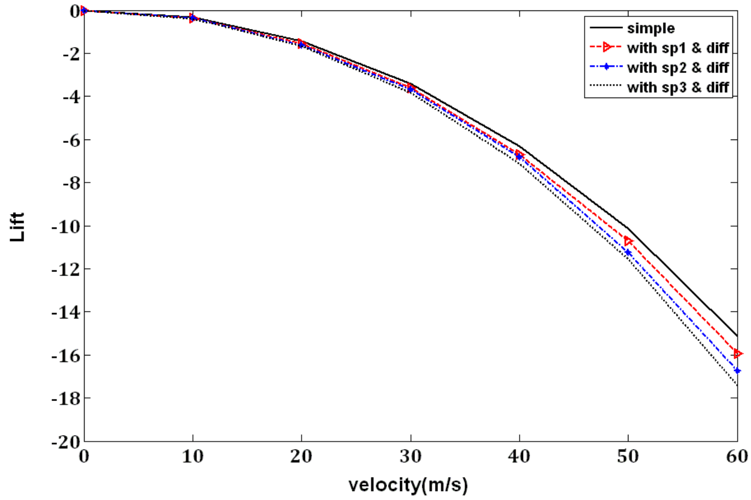

Figure 12: Changes of lift force relative to speed

'Figure 13' shows the changes of drag force of the tested model in the all states. According the figure with the increase of speed, drag force increases, too. 'Figure 13' shows that the highest amount of drag force is related to the speed range of 50 to 60 m/s. As it is observed the least amount of drag force is in 'state 4'. According the situation of the diagrams illustrated in this figure, it can be concluded that presence of spoiler and diffuser in the 'state 4' results in the reduction of vortices of the end of the model and makes air flows more regular and these effects causes falling the drag force in the end of the model.

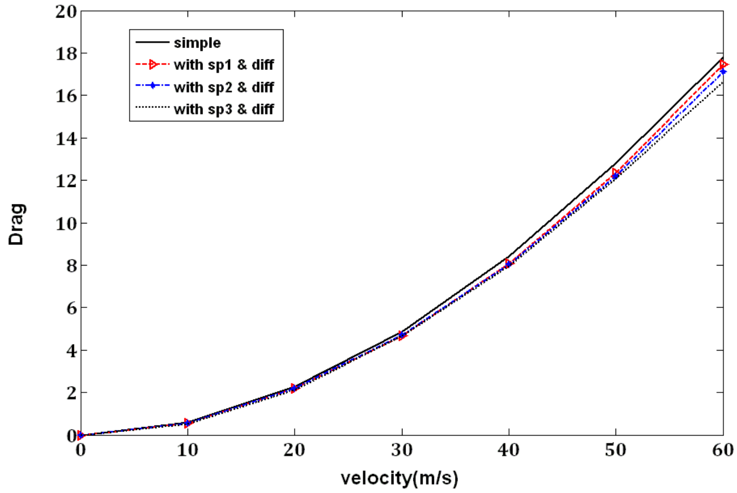

Figure 13: Changes of drag force in relation to speed

'Figures 14 and 15' show the changes of loft and drag coefficients of the tested model in the all states. Figure 14 shows that generally all aerodynamic parts have resulted in the reduction of the lift coefficient in the high speeds. As it is observed in figure 14 the best effect in the reduction of lift coefficient in different speeds is in state 4 that the least lift coefficient has been obtained in the speed of 60 m/s and equal to -0.253, that this fall of lift coefficient is due to the impact of spoiler in generation of downwards forces in the end of the model and as a result reduction of the lift coefficient.

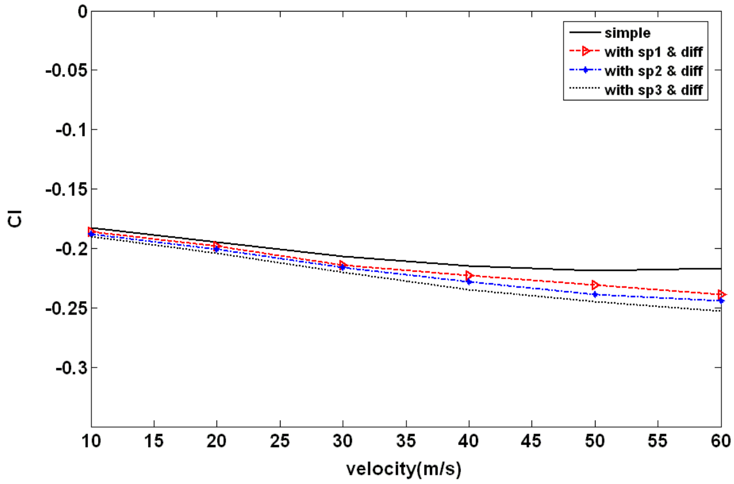

Figure 14: Changes of lift coefficients relative to speed

'Figure 15' shows that in presence of the aerodynamic parts the drag coefficient in the low speeds has remained almost constant compared to the base model (state 1) and by gradual increase of speed the drag coefficient has been reduced. In view of the diagrams depicted in this figure, it can be concluded that the presence of spoiler and diffuser in the states 2, 3 and 4 has resulted in that vortices and irregular currents of the end of the model reduce due to existing of spoiler and become regular and also diffuser helps to the flows under the car to reduce the pressure under the car and becomes equal to the atmosphere pressure in the end of the model. In view of the results of the resource [1], higher drag coefficient has been generated in the simple state that these changes are due to precision in the development of the model and errors of wind tunnel.

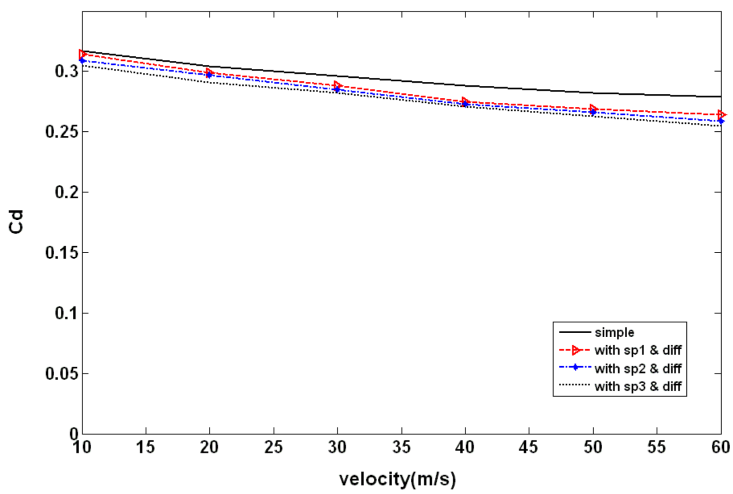

Figure 15: Changes in the drag coefficient relative to speed

'Table 2' shows the values of the aerodynamic coefficients of the car in the speed of 60 m/s for the simple state without spoiler and with diffuser in several different heights. Analysis of results indicates that by adding spoiler and diffuser the drag coefficient decreases but the negative lift coefficient increases. The negative sign of the lift coefficient is due to that it is toward the ground. The more the lift coefficient toward the ground, the car stability is more in the higher speeds.

By increase of the height of spoiler the value of the drag and lift coefficients decreases as well. Therefore, increase of the height of spoiler to 3 cm is suitable to reduce the drag and lift coefficients. Increase of the spoiler height to 3 cm in this model of car reduces the drag coefficient by 6.3%. Also it results in the reduction of the lift coefficient by 12.4 percent. In the following the value of the drag and lift coefficient of

the car model in the speed of 60 m/s in the simple state and simultaneous use of spoiler in different heights and diffuser has been calculated. Figure 16 shows the value of the drag coefficient for different states.
In this figure it is known that positioning spoiler and diffuser has a good effect on the reduction of drag coefficient. Also 'state 4' reduces the value of the rear aerodynamic drag coefficient by 4.54 percent that this amount of the reduction of drag coefficient is higher than simple state and therefore is cost-effective economically due to lowering the fuel consumption.

Table 2: Comparison of the aerodynamic coefficients of the car model in different states

1	simple	-0.217	0.269	-
2	With spoiler and diffuser	-0.239	0.264	1
3	With spoiler and diffuser	-0.244	0.259	2
4	With spoiler and diffuser	-0.253	0.252	3

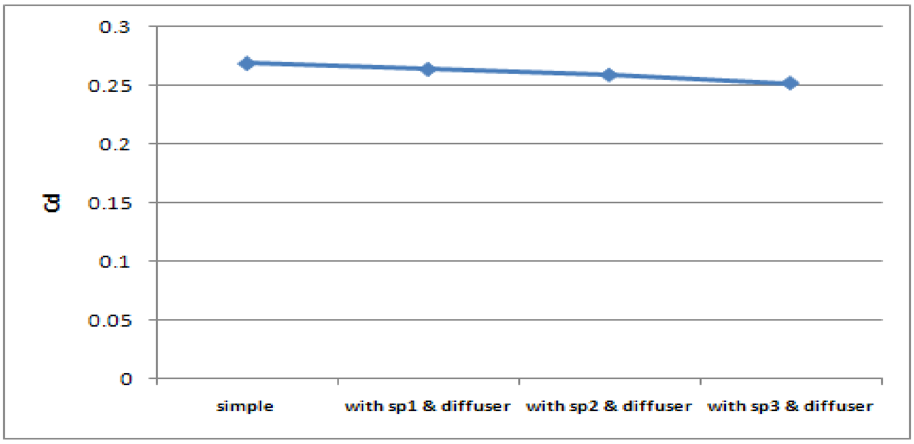

Figure 16: General comparison of the drag coefficients

'Figure 17' also shows the amounts of the lift coefficients and also its changes compared to the other models. Lift coefficient reduces by 12.4 percent. This amount of reduction is suitable for stability of the car particularly in the high speeds. According the 'figure 17' it can be concluded that the highest reduction of the lift coefficient is in the state 4 that it explains the generation of more negative lift force by spoiler.

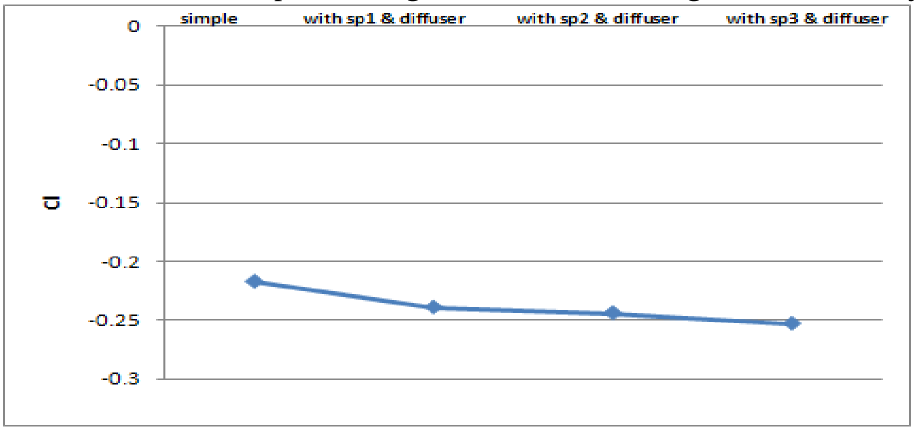

Figure 17: General comparison of the lift coefficients

CONCLUSION

In this article the effect of aerodynamic parts on the aerodynamic performance of the base model of one car was examined. This study was experimentally conducted and in a speed range of 0 to 60 m/s and also constant speed of 60 m/s. In these tests the lift and drag coefficients were measured and the effect of different states of diffuser and spoiler in different heights was compared with each other. Significant results of aerodynamic coefficients were obtained through examination of different models of the car that are summarized in the following:

Comparing the aerodynamic coefficients obtained for the two simple and with spoiler and diffuser states of the car model, it can be concluded that installing this model of spoiler reduces the amount of the rear aerodynamic drag coefficient by 6.3% and results in the decline of the lift coefficient by 12.4%, that cause the stability of the car particularly in the higher speeds. By increase of the height of the spoiler the amount of the drag and lift coefficient decreases as well.

Finally, it has to be stated that the more use of aerodynamic tool and the better designing of a car resulted in reduction of aerodynamic coefficients in the car and increase the stability of cars and saved fuel consumption.

REFERENCES

[1]S. R. Ahmed, G. Ramm, G. Faltin, Some salient features of the timeaveraged ground vehicle wake, SAE International Journal of Passenger Cars - Mechanical Systems, Vol. 1, No. 840300, 1984.

[2]H. Lienhart, S. Becker, Flow and Turbulence Structures in the Wake of a Simplified CarModel (Ahmed Model), 2003-01-0656. Reprinted from: Vehicle Aerodynamics 2003 (SP-1786), 2003 SAE World Congress, Detroit, Michigan, March 3-6, 2003

[3]R. Mathieu, G. Patrick, K. Azeddine, Drag reduction by flow separation control on a car after body, International Journal For Numerical Methods in Fluids, Vpl. 60, pp. 1222-1240, 2009.

[4]D. Mitra , Effect of relative wind on notch back car with add-on parts, International Journal of Engineering Science and Technology, Vol. 2, No. 4, pp. 472-476, 2010

[5]A. Sunanda, M. S. Nayak, Analysis of NACA 2412 for automobile rear spoiler using composite material, International Journal of Emerging Technology and Advanced Engineering, Vol. 3, No. 1, pp. 230-238, 2013

[6]Cooper, K. R.; Bertenyi, T.; Dutil, G.; Syms, J. and Sovran, G., "SAE 980030 - The Aerodynamic Performance of Automotive Underbody Diffusers", SAE International, 1998.

[7]C. Tsai, L. Fu, C. Tai, Y. Huang, J. Leong, Computational aero-acoustic analysis of a passenger car with a rear spoiler Applied Mathematical Modeling, Vol. 33, No. 9, pp. 3661-3673, 2009,

[8]P. Dileep Menon, G. Samir Kamat, S. Yagnavalkya Mukkamala, S. Prakash Kulkarni, To improve the aerodynamic performance of a model hatchback car with the addition of a rear roof spoiler, 16th Annual CFD Symposium, Bangalore, India, August 11-12, 2014

[9]R. B. Sharma, R. Bansal, Aerodynamic drag reduction of a passenger car using spoiler with VGs, International Journal of Engineering Research and Applications, Vol. 1, No. 2248, pp. 256–263, 2014

[10]H. Ahmadi, M. Abbasalizadeh, Investigating the effects of angle and height of the spoiler on the aerodynamic condition of the vehicle, Proceedings of The National Mechanical Engineering Conference, Ahvaz, Iran, December17-18,2014. (in Persian فارسی)

[11]https://www.google.com/amp/xprinter3d.com