Analysis of External Aerodynamics of Sedan and Hatch Back Car Models Having Same Frontal Area by Experimental Wind Tunnel Method

[1]Sharath Kumar S N, [2]Dr. C. K. Umesh
[1]M.E Scholar, [2]Professor
[1,2]Department of Mechanical Engineering,
[1,2]University Visvesvaraya College of Engineering, Bangalore, India

---

Abstract* - Analysis of vehicle external aerodynamics has a very important role to play in designing aesthetic, safer and fuel efficient vehicles. An aerodynamically efficient vehicle cuts through the air smoothly, has less rolling and yawing forces at high speeds and consumes less gallons of fuel for the distance travelled. The effectiveness of aerodynamics of a particular vehicle is measured by a dimensionless parameter known as Drag- Co-Efficient. The value of Drag Co- Efficient is close to or more than 1 for boxy design vehicles such as passenger bus, truck etc, while its value is close to or less than 0.1 for stream lined vehicles such as race cars, fighter jets etc. The major objective of this work was to perform aerodynamic comparison of Sedan and Sedan derived Hatch Back car models having same frontal area by conventional wind tunnel experimental approach on a 1:30 scaled wooden car models. The experimental analysis was carried out in an open circuit blower type wind tunnel having a test section dimensions 0.3 m wide, 0.3 m high and 1.5 m long. Experimental results suggest that Sedan car is more streamlined and aerodynamically efficient as compared to that of Hatch Back car model. Even though both the car models have the same frontal area, Hatch back model has approximately 13% more Drag Co-Efficient as compared to that of Sedan car model. This can be concluded in the other way; conversion of Hatch Back car into a Sedan car by keeping frontal area same can improve the Drag Co-Efficient by 13%.

***Key Words* - Aerodynamics, Wind Tunnel, Sedan, Hatch Back, Drag-Co-Efficient.**

I. INTRODUCTION

Aerodynamics is a branch of fluid mechanics which deals with the study of motion of air and other fluids when it interacts with solid bodies. In case of vehicle aerodynamics these solid bodies can be space vehicles such as airplanes, rockets, satellites etc; or road vehicles such as cars, buses, trucks, scooters etc; and can be ships, boats, sub marines etc for water vehicles. For the present aerodynamic study; road vehicle, especially Sedan and Hatch back car models are used. The aerodynamic efficiency of the vehicles is measured in terms of a dimensionless parameter Drag Co- Efficient. Drag co-efficient value specifies how well vehicles can cut through the fluid. Drag Co-Efficient value ranges from 0.1 for streamlined vehicles to values close to 1 for boxy design vehicles [1]. The value of drag force acting on the vehicle depends on several parameters such as Drag Co-Efficient of the vehicle, its frontal area, velocity at which the vehicle moves and density of the fluid in which the vehicle operates. Even though drag force depends on several parameters, it's only the value of drag co-efficient times the area that can be controlled.

At lower velocities the value of drag force acting on the vehicle may not be significant but at higher velocities drag force acting on the vehicle plays very important role. This is because drag force is a function of square of velocity and the power required to overcome this drag force is a function of cube of velocity [2]. This means most of the power developed under the hood of the vehicles is used to overcome drag force at higher speed.

With increase in fuel prices and competition, there is constant pressure on aerodynamic design engineers to produce highly efficient and aesthetically pleasing cars. The recent trend in Automotive industry is to convert already successful Hatch back into sedan car or vice versa with minimal changes in geometry i.e. by modifying only the rear part of the car, thereby reducing the cost of designing a all new Sedan or Hatch back car.

Manan Desai et al. (2008) [3] in his work suggested two experimental methods to perform aerodynamic analysis of road vehicles. In the method 1the pitot tube was traversed in the horizontal and vertical directions in order to find the static pressure at different nodes there by covering entire flow field around the car model. While in the method 2 which is adopted in the present work, pressure tapings were instrumented along the centre line of the car model and was tested at different velocities. Further the experimental results obtained by the two methods were compared with the results obtained by computational method. The comparison showed that the pressure distribution and drag force agreed well with both the experimental methods. "Comparative assessment of drag force of Hatch back and Sedan car model by experimental method" carried out by Bhagirath zala et al. (2012) [4] showed that hatch back car model had 42% more drag force as compared to sedan car model and this difference in drag force between the two car models increased with increase in speed.

Most of the road vehicle aerodynamics research work has been concentrated either on Sedan cars or bluff bodies such as passenger bus and only few works has been reported on the aerodynamic analysis of Hatch Back cars. Although there are some works done on the aerodynamic comparison of Sedan and Hatch Back cars [4], there is no work reported on the direct comparison of Sedan and Hatch Back cars having same frontal area. Since each car manufacturing company has its own design language and it's not a good idea to compare two different segments of cars i.e., Sedan and Hatch Back cars of different make (company) to come into a conclusion that which among them is aerodynamically better, unless any of the geometric parameter is kept constant (in present work frontal area is kept constant).

The major objective of this work is to perform aerodynamic comparison of Sedan and Sedan derived Hatch Back car models having same frontal area by conventional wind tunnel experimental approach on a 1:30 scaled wooden car models. The experimental analysis was carried out in an open circuit blower type wind tunnel having test section dimensions 0.3 m wide, 0.3 m high and 1.5 m long.

II. DESCRIPTION OF THE EXPERIMENTS

1. Wind tunnel

Experimental tests were carried out in open circuit blower type wind tunnel having test section dimensions 0.3 m wide, 0.3 m high and 1.5 m long with a transparent glass window meant for visual observation of flow field around the experimental model. The test section is a vented jet i.e. the section is physically closed but vented to atmospheric pressure. A variable speed DC motor employed varies air velocities with a maximum speed of 33m/s.


Figure 1 Blower type wind tunnel set up


Figure 2 Sedan Car model mounted in wind tunnel

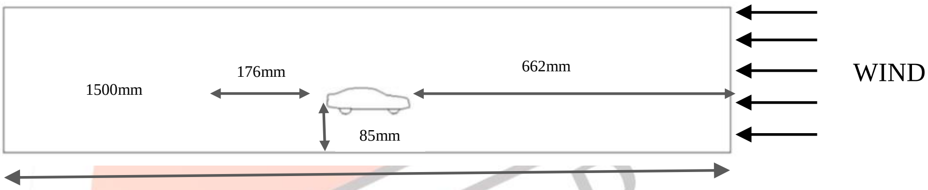


Figure 3 Schematic diagram of wind tunnel

Car model was mounted at the centre of the wind tunnel test section. Since, the maximum flow of air takes place at the centre of the wind tunnel test section and also to eliminate boundary layer effects caused by wind tunnel walls (boundary layer formed between car and actual road condition is quite different as compared to the boundary layer formed between car model and stationary base of the wind tunnel) [5]. Blockage ratio, found out with respect to projected frontal area of the car model in test section was about 3%, which is well below the permissible limit of 7.5% [1].

2. Car models

Experimental Analysis was conducted on two 1:30 scaled down rubber wood car models, out of which one is geometrically similar to commercially available Sedan car and the other model is a Hatch Back which is newly designed by modifying the 2d profile of the same Sedan car model. Both the car models have been fabricated such that they have same frontal area but varies only at the rear portion i.e., one is fabricated as a Sedan car model and other as the Hatch Back car model.

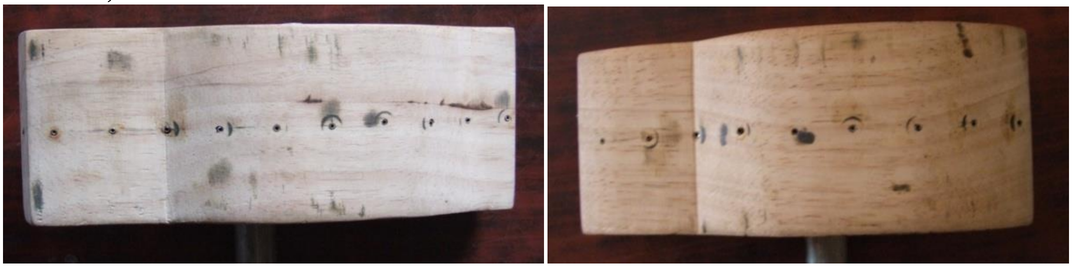
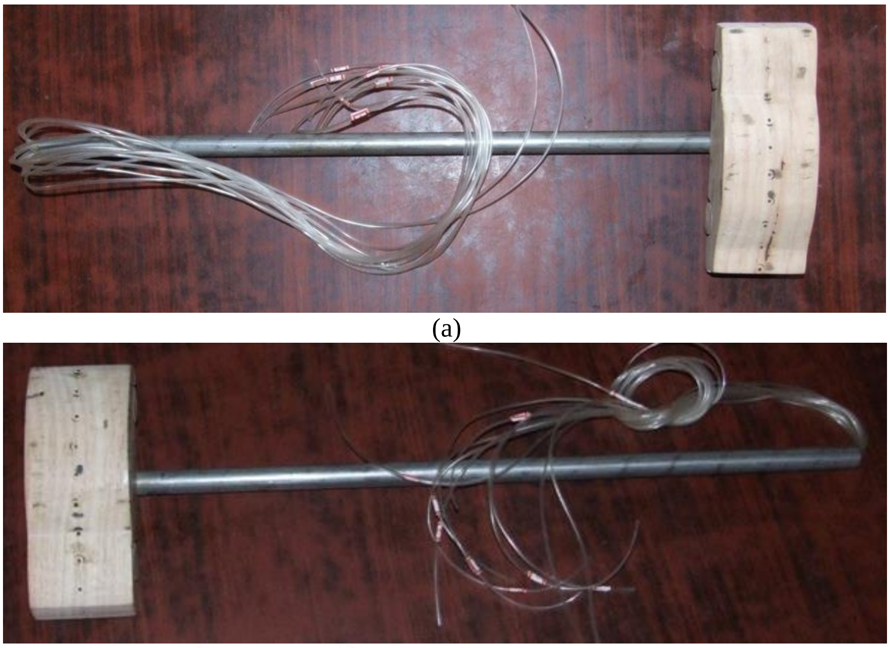

(a) (b)

Fig. 4 Scaled wooden car models: (a) Sedan; (b) Hatch Back



(a)

(b)

Fig. 5 Car models with pressure taps and PVC tubes: (a) Sedan; (b) Hatch Back

3. Experimental Procedure

In order to find out pressure distribution over the car models, pressure tapings were instrumented along the longitudinal center plane of each car model. The velocity of the air inside the wind tunnel was measured using single channel electronic manometer and the pressure at each port on the surface of the car model was measured using 32 channel pressure scanner, which displayed pressure in terms of head of Methyl alcohol. Pressure readings were recorded at 4 different velocities (10m/s, 15m/s, 20m/s, 25m/s). The drag force, drag co-efficient and pressure co-efficient acting on the car models was calculated as follows:

1. Pressure Co-Efficient = $C_P = (P - P_\infty) / (0.5 \times \rho \times U_\infty^2)$
2. Drag Force = $F_d = \sum (P_i \cos\Theta_i) \times A$
3. Drag Co-Efficient = $C_D = F_d / (0.5 \times \rho \times U_\infty^2 \times A)$

Where,

P = Pressure acting at each port = $\rho_m \times g \times H$

ρ_m = Density of Methyl Alcohol

H = Head of Methyl Alcohol

ρ = Density of free stream air

Θ = Angle between direction of relative velocity and normal pressure force

A= Frontal Area of the car model

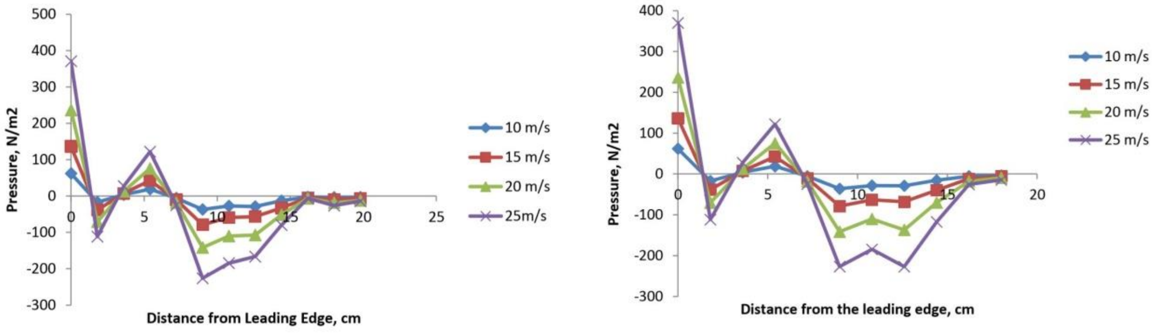
U_∞= Free stream velocity

III. RESULTS AND DISCUSSIONS

In an attempt to understand the external aerodynamics of the car models, experiential analysis was performed in an open circuit blower type wind tunnel having the test section dimensions 0.3 m wide, 0.3 m high and 1.5 m long. 32 channel pressure sensors were used to tap the pressure at each port on the surface of the car models.

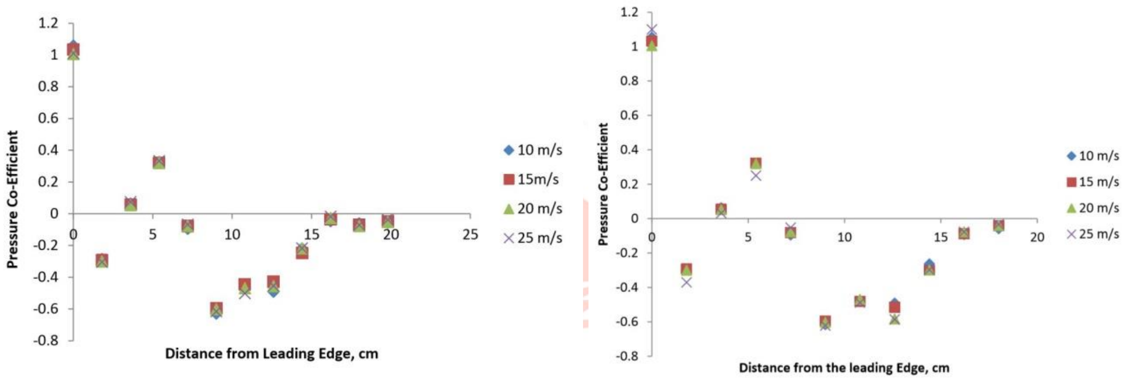
It is evident from the fig 6 (a) and fig 6 (b) that stagnation point is located at the lower part of the front bumper and the pressure in this region increases with increase in velocity, as it is the first region of the car model which comes in contact with the air flow. The front bumper region is a high pressure region while the other regions of the car models will be at low pressure. Due to this pressure difference, some part of the air molecules at the front bumper of the car models cruses to the hood region while the remaining air molecules cruses to the bottom and sides of the car models, causing flow separation at the front bumper. As the air flows from front bumper to the hood, there is a sudden drop in pressure to a negative value. This negative value of pressure changes gradually to a positive value as the air reaches the intersection of the hood and windshield due to the obstruction caused by the front wind shield. This intersection is one of the two high pressure areas of the car models. The mean pressure of the air near the edge of the passenger roof entrance shows a significant drop in pressure to a negative peak value causing high velocity over the roof surface. Flow separation occurs at the mid portion of the windshield due to abrupt change in car geometry and creation of adverse pressure gradient. Due to flow separation, formation of eddies and vortices take place at the rear windshield of both Sedan and Hatch Back car geometry. In case of Sedan car model, at the intersection of rear windshield and boot, pressure increases slightly due to further change in geometry and formation of vortices. It can be seen that pressure decreases slightly due to slight flow reattachment at the boot region. Finally air separates out from the Sedan car model leaving negative pressure area behind the car model. But due to the absence of boot region in case of Hatch back car model there is no flow reattachment and also the negative pressure area left behind the hatch car model is quite more as compared to Sedan car model.

It is clear from the fig 7(a) and fig 7(b) that pressure co-efficient plot trend is same for all the velocity ranges for both the car models. So, it can be concluded that pressure co-efficient variation along the centre line of the car models is independent of velocity [3]. Also it can be seen that variation of pressure co-efficient along the centre line of the car model follows similar trend as that of the pressure, with pressure co-efficient being maximum at the front bumper with a value close to 1.0 and minimum on the roof. Almost identical value of C_P is obtained at every port on the car model for different velocity ranges.



(a) (b)

Fig. 6. Pressure distributions along centre line at different Velocities: (a) Sedan; (b) Hatch Back



(a) (b)

Fig. 7. Variation of C_P along the centre line at different Velocities: (a) Sedan; (b) Hatch Back

As observed in the works of Manan Desai et al. (2008) [3], drag co-efficient slightly decreases with increase in Reynolds number as shown in fig. 8 while drag force increases with increase in velocity as shown in fig. 9 over the entire velocity ranges for both the car models. It can be seen that Hatch Back car model has around 12.7% more drag force and drag co-efficient than the Sedan car model which agrees with the works reported by Bhagirath Zala et al. (2012) [4], even though both the car models has same frontal area. Hatch Back car model experiences more drag force as compared to Sedan car model due to the fact that air flow over the Hatch Back car model detaches much earlier and the negative pressure area left behind the Hatch Back car model due to flow separation is more as compared to that of Sedan car model. It is interesting to note that drag co-efficient decreases with increase in velocity because of delay in flow separation as the speed increases in both the car models. From the above comparison it is clear that geometry change only at the rear end can produce a drag co-efficient variation up to 12.7%. This can be concluded in the other way, conversion of Hatch Back car into a Sedan car can improve the drag co-efficient by 12.7%. Even though the drag improvement is quite small in terms of magnitude, but this small improvement can make huge impact on aerodynamic efficiency of cars. In general this improvement in drag co-efficient of the Sedan car helps in getting the mileage almost equal to that of Hatch Back car even though weight of Sedan car is more as compared to Hatch Back cars.

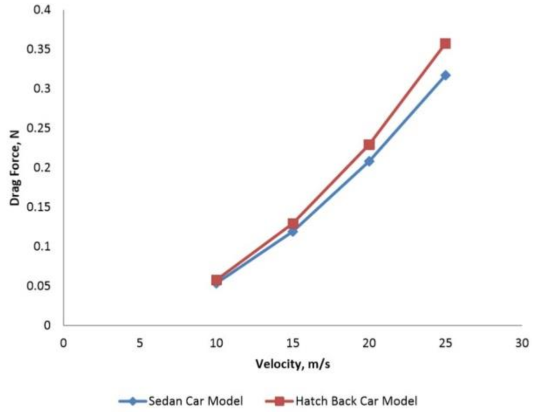


Fig. 8 Variation of F_d with velocity

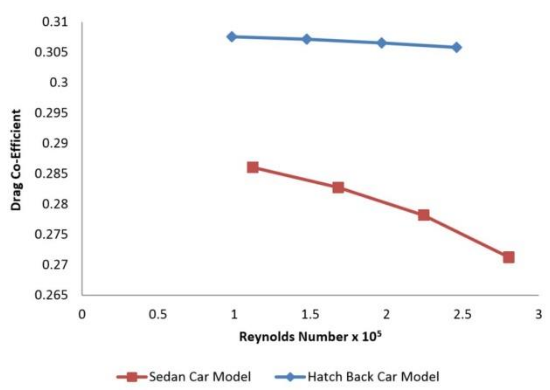


Fig. 9 Variation of C_D with velocity

IV. Conclusion

1. Experimental pressure distribution found out using pressure tapping method is in good agreement with the theoretical understanding which suggests that the results obtained are reliable and is recommended for future experimentation.
2. Experimental Aerodynamic comparative analysis of Sedan and Hatch Back car models suggest that Sedan car model has approximately 13% less drag co-efficient and drag force as compared to that of Hatch Back car model. So, it can be concluded that Sedan car model is more streamlined and aerodynamically efficient compared to Hatch Back car model.
3. Drag force increases with increase in velocity for both Sedan and Hatch Back car models.
4. For both Sedan and Hatch Back car models, drag co-efficient obtained decreases slightly with increase in Reynolds number.
5. Experimental analysis suggests that as the speed increases the difference in drag force between Sedan and Hatch Back car models also increases.

References

[1] Yunus A Cengel, John M Cimbala "Fluid Mechanics Fundamentals and Applications", McGraw-Hill Publications, 2006.

[2] William H. Bettes, " The Aerodynamic Drag of Road Vehicles: Past, Present, and Future", Engineering & Science, January 1982.

[3] Manan Desai, S. A. Channiwala, H. J. Nagarsheth "A comparative assessment of two experimental methods for aerodynamic performance evaluation of a car", Journal of Scientific and Industrial Research, Volume 67, July 2008, pp. 518-522.

[4] Bhagirath Zala, Dr. Pravin P. Rathod, Sorathiya Arvind S, H. I. Joshi, "Comparative assessment of drag force of Hatch Back and Sedan car model by experimental method", International Journal of Advanced Engineering Research and Studies, Volume 1, Issue 3, June 2012, pp. 181-183.

[5] Vehicle Aerodynamics: Hybrid Electric Vehicle Team, College of Engineering, San Diego State University http://kahuna.sdsu.edu/~hev/aerodyn.html (Accessed on 12-01-2015).

[6] K. Selvakumar, Dr. K. M. Parammasivam, "Experimental Analysis of the Pressure Distribution on Different Models of Car body in the Wind tunnel", DOI:10.1007/978-81-322-1007-8-15@Springerindia 2012 pp: 165-184.

[7] Gauravkumar Tandel, Mayur Makwana, Jigar Patel, "Experimental Aerodynamic Analysis of Automobile Vehicle", International Journal of Engineering Development and Research, Volume 2, Issue 2, 2014.

[8] Automotive Power: A Case Study in Energy Relations http://wps.aw.com/wps/media/objects/877/898586/topics/topic02.pdf (Accessed on 03-12-2014).

[9] Bhavini Bijlani, Pravin P. Rathod, Arvind S. Sorthiya, "Experimental Investigation of Aerodynamic Forces on Sedan, Fastback and Square-Back Car by simulation in CFD" Review Study" International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 2, February 2013.

[10] K.Selvakumar, Dr.K.M.Parammasivam, "Experimental investigations on optimization of aerodynamic characteristics in a hatchback model car 3 using vortex generators", The Eighth Asia-Pacific Conference on Wind Engineering, Chennai, India, December 2013.

[11] K Selvakumar, K.M.Parammasivam, "Experimental investigations on aerodynamic characteristics of a hatchback model car using base bleed" National Conference On Recent Trends And Developments In Sustainable Green Technologies, Issue 7, 2015.

[12] Dinesh Dhande, Manoj Bauskar, "Analysis of Aerodynamic Aspects of SUV by Analytical and Experimental Method", International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 7, July 2013.

[13] Sharath Kumar S N " Analysis of external aerodynamics of Sedan and Hatch back car models by Experimental and Computational Methods" M. E Thesis submitted to Department of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore, India, 2015