Design of a Custom Vortex generator
Optimization of Vehicle Drag and Lift Characteristics

Naveen. S¹, Vipin Prakkash², Sukanth Kannan³

¹, ², ³ Senior Engineer, Sharda Motor Industries Limited – R&D, Chennai, Tamil Nadu-603002, India

Abstract— It is now history when people just wanted a vehicle for transportation. Now the need has changed and desires had made the engineers to develop more technicalities that increase the performance of the vehicle. From the initial need of fuel efficiency the needs varies as the requirement of high speeds, quicker pick up, higher torque, sporty looks, and more such desires have now become a primary need for the people to choose their vehicle. This builds competition between the designers to compete in the market.

The paper shall discuss the implementation and the importance of vortex generators mainly used for, drag and lift characteristics optimization depending upon the needs and situations. A quantitative analysis will be discussed with simulation proofs worked on CFD software-CHAM PHOENICS. This assignment is a comparison of the performance of a definite sedan model’s behaviour with a vortex generator and without a vortex generator.

1. Introduction

The study of air travel over the surface of a solid is called aerodynamics. When an automotive moves in a certain velocity the air flow over the car induces drag which is very undesirable for its performance. An automotive requires more power to overcome this drag force. When the aerodynamic property of the automotive is furnished to overcome this air resistance, the vehicle can travel faster, longer and could be more fuel efficient. The vehicle could gain more down force thereby providing greater grip between the car and the road. The down force enables the vehicle to corner at high speeds. However there exists a trade off for high speed because of the increased resistance. The aerodynamic property of the automotive can be changed by installing a vortex generator at the rear of the vehicle.

2. Literature Review

Study of aerodynamic property of a car is very critical and is very significant to alter the aerodynamic property to improve the performance of the vehicle. The factors that affect the aerodynamic property of a car are drag, lift, down force and flow separation.

2.1 Drag

The resistance offered by air over a solid surface relative to the motion of the fluid is termed drag. When drag acts...
over the car, it limits the car’s ability to cut through the air and travel easily, thereby reducing its performance.

2.2 Lift
A force acting perpendicular to the flow of air is termed lift. Often a fast moving car experiences lift at the rear. When a car moves faster there might be a pressure difference at the top and bottom end of the car due to drag and flow separation effects and this causes lift at the bottom rear of the vehicle. Lift is undesirable as it reduces down force and makes the car lose its traction with the road.

2.3 Down Force
This is termed the Bernoulli Effect, which states that the object is forced towards the faster moving fluid. So when the car is moving faster, the faster moving air should be channeled to the bottom of the car so that the car will be pulled towards the ground creating more down force. Down force is a force that creates more traction with the ground that assists in cornering.

2.4 Flow Separation
When the boundary layer of the air breaks from the object at a certain point when it is travelling through air is called flow separation. When there is a flow separation the velocity reduces and it results in drag. In order to overcome this flow separation we use a vortex generator which helps the air to flow over the surface of the car without any separation by reducing the turbulence.

3. Aerodynamic Upgrades:
There are number of ways to optimize the aerodynamic forces that affects the performance of the car. Some of them are;
- Front Wing
- Rear Diffuser
- Spoiler
- Drag Reduction System(DRS)
- Vortex Generators

4. Vortex generators
A vortex generator is mainly used to delay flow separation. Flow separation creates eddies and vortexes and results in increased drag characteristics. The vortex generators reduce the drag and increases down force. As the speed of the vehicle increases, the effect that the vortex generator creates will increase, increasing the vehicle’s performance in terms of speed.
A vortex generator is to reduce drag and to increase the down force of a car. These functional parameters are checked in this analysis at different speeds and the results are compared between AUDI-A4 with and without the vortex generators.

4.1 Design
A vortex generator has to perform its above mentioned functions in an effective manner so an optimal design is directly proportional to increased performance. The height of the vortex generator is selected by assuming that it is equal to the boundary layer thickness formed at the surface of the vehicle. The rear angle of the wind shield where the vehicle slopes is assumed to be approximately 27°. This angle is used for the vertex of the vortex generator where it starts at the rear end. The vortex generator is then placed at a distance of 100mm from the rear. Eight vortex generators are used in this model and the simulation is run at varying speeds.
7. **Solver:**

- KENCHEN model is used to solve the problem and the number of iterations is set to 150. When the solver was solving the model the graphs shown were observed and it is found that the error values tend to converge but finally all error values formed a straight line.

- The error values should converge and fall down to a minimal value but it does not happen in this case. This is because of the complications and assumptions in the 3D model used and the error values are not converging to a minimal level and the results obtained are quite accurate. If we expect more accurate results then the simulations have to be done for higher number of iterations.

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5. **Simulation:**

AUDI-A4 model is first simulated in PHOENICS without vortex generators. The track of the car is 1.2m.

6. **Pre-processor:**

- The model is imported and placed at a distance of 4m from the inlet
- The outlet is placed 9m away from the rear end of the car
- A plate is placed at the bottom of the car to prevent air from escaping
- The simulation is done for three different speeds – 30m/h, 50 m/h and 70 m/h.
- The meshing is then refined so that the surface of the car has finer meshes where the detailing of the results are required.
- The domain fluid is set as air and the values are set to PHOENICS assumptions.
8. Post Processor:
The solution obtained is then viewed. The pressure and velocity values are observed and studied. The pressure and velocity distribution of the model at three different speeds are shown below:

8.1 At 30 m/h:

![Figure 8. Pressure graph @ 13.4112 m/s](image)

![Figure 9. Boundary layer separation](image)

We could see the boundary layer separation at the rear end of the car. This effect is undesirable as it creates a low pressure region at the rear top end of the car thereby creating drag. The drag value obtained for this simulation is 140N and the lift obtained is 1372N. Here the lift value is very high and the car does not produce enough down force so a vortex generator should be installed and the results are checked again.

![Figure 10. Velocity distribution showing drag at the rear end](image)

8.2 At 50 m/h:

![Figure 11. Pressure distribution](image)

![Figure 12. Velocity distribution](image)

8.3 At 70 m/h:

![Figure 13. Pressure distribution](image)

![Figure 14. Velocity distribution](image)

It is very much evident from the above results that the drag force increases with increase in velocity of the vehicle. The drag at 70 m/s is 244 N and the lift is 790 N. the drag is more at 70 m/h but lift is more at 30 m/h. We need a compromise between both values and the down force should be increased so a vortex generator is installed to see if the drag force can be reduced.
9. Modified simulation with vortex generators:
The vortex generators are installed at the rear end of the car at a distance of 100 mm from the top end of the rear wind shield. There are 8 vortex generators placed at a distance of 137 mm from each other and are perpendicular to the flow of the air.

10. Pre-processor:
The same procedure is repeated to import the model into the simulator. Now the designed vortex generator is imported and placed at the right position. The mesh has to be refined again because of the introduction of new objects.

11. Solver:
KENCHEN model is used to solve the model and 150m iterations are done.

Post Processor:
The obtained pressure and velocity graphs are studied and compared with the previous results.

11.1 At 30 m/h:

11.2 At 50 m/h:

11.3 At 70 m/h:

With installation of the vortex generators, the expected results are achieved and the experimentation is repeated for different speeds.
At 70m/s the model without the vortex generator had a drag of 244 N but after the installation of the vortex generators the drag obtained is 53 N. Thus the drag seemed to have reduced greatly with the installation of the vortex generators.

12. Result Comparison:

12.1 Pressure Comparison

From the plots above it is evident that the model without the vortex generators develop a low pressure area at the bottom rear of the car. The boundary layer separation is vary large at the rear end.

When the vortex generators are installed, the bottom of the car develops a low pressure region thereby increasing the velocity at the bottom of the car to increase which results in more downforce. The car now has greater grip on the track and the handling and cornering ability of the car will be greater.

12.2 Velocity Comparison

Figure 19 shows that the drag at the rear of the car is very high. The screen shot is from 70 m/h and the drag obtained without the vortex generators is 244 N. The drag force reduces the performance of the vehicle.

Figure 20 shows the screen shot of the model with vortex generators at the speed of 70m/h. The velocity distribution plot show that the velocity has increased at the rear end of the vehicle thereby reducing the drag drastically. The drag force obtained for this simulation with the vortex generators is 53 N. The reduction in drag greatly reduces the air resistance on the car and results in higher top speed and power required in greatly reduced. This also has a direct impact in increased fuel economy.

13. Results and Conclusion

From the simulations performed we can conclude that the designed vortex generators have satisfied their purpose by reducing the drag, increasing the downforce and reducing the boundary layer separation. By observing the pressure over and under the car the coefficient of pressure can be found for both the models (with the vortex generators and without the vortex generators) and compared using the formula,
Where,
P – Pressure at the probe position (Pa)
\( P_i \) – Ambient pressure (Pa)
\( P \) – Density of air (1.189 Kg/m³)
\( V_i \) – Inlet Velocity (m/s²)

The coefficient of pressure is calculated for the run at 70 mil/hr and the graph is drawn between the distance and the coefficient of pressure. This calculation is done for the model without the vortex generators.

![Figure 25. Coefficient of pressure without vortex at 70 mil/h](image)

![Figure 26. Coefficient of pressure with vortex at 70 mil/h](image)

It is observed from both the cases that the \( C_p \) value is very random in the first case where there is no vortex generator. But in the model with the vortex generators the pressure coefficient keeps on decreasing from the front of the car to the rear and the pressure coefficient at the lower part of the car is always less than that at the top. This phenomenon helps in the increase in velocity at the rear exit of the vehicle thereby reducing drag and increasing the downforce due to Bernoulli effect.

References


1Naveen.S, born in Coimbatore District, Tamil Nadu, India, completed his Mechanical Engineering in Amrita University in 2010. He is working as a Senior Engineer in Sharda Motor Industries limited, R&D, Chennai. He is a research and target oriented engineer with skill and global exposure to automobile exhaust product development. He has rich understanding and diversified exposure in the field of product lifecycle management. Having completed his Masters in Automotive Engineering from Staffordshire University, UK (2013), he has strong knowledge in DMAIC methodology to handle projects from concept definition, to manufacturing. He has an eye for intricate details to optimize vehicle emissions, CO₂ control and fuel efficient vehicle design.

2Vipin Prakkash completed his Bachelors in Electrical and Electrical Engineering and Master of Science in Electrical Engineering from Staffordshire University, UK and is currently working as a Senior Engineer, R&D in Sharda Motor Industries Ltd.

3Sukanth Kannan, having completed his bachelors degree in Mechanical Engineering is now pursuing his masters in “Computer Integrated Manufacturing” in par with his ardent support for Sharda Motor Industries Limited as a program manager.