OPTIMIZATION OF AERODYNAMICS AND THERMAL CHARACTERISTICS OF AUTOMOBILE

[1]Ruhil Shah, [2]Shailja Saraiya, [3]Ravilal Velani, [4]Sagar Vaghamshi
[1]Student, [2]Student, [3]Student, [4]Student
Mechanical Department, Indus University[1,2,3,4,5]
Indus Institute of Technology and Engineering, Rancharda, India
Guided By: Prof. V.K.Manglik[5]

The optimization of air flow on the automobile is necessary to improve fuel economy, reduction in drag force & pollution, control in aerodynamics noise and ease in driving of the vehicle. Drag force is a complex phenomenon which is not only governed by vehicle configurations but also flow characteristics. It is reduced by modifying the existing configuration of the automobile and altering the fluid flow around the vehicle. Such modification should not affect the vehicle stabilization capability. In this paper efforts were made to optimize the flow characteristics of the vehicle by changing its outside configuration by providing external component such as air-dam splitter, spoilers. Several configurations of the vehicle were realized & each one of them was analyzed using ANSYS software to optimize drag force. The study shows encouraging results by providing front and rear air -dam in the vehicle. The front air -dam significantly reduces the flow of air to the lower portion of the vehicle and increases the amount of air flow to the side and front of the vehicle body. CFD analysis and also pressure distribution was studied in various configurations and optimized solution was obtained for drag and lift forces. Though CFD is a good method for developing and optimizing aerodynamic solutions, the results were also validated by physical tests on a car model in subsonic wind tunnel at IIT Gandhinagar.

The air flow is further optimized to use it in the vortex tube refrigeration system where temperature its temperature was reduced and that is used to take thermal load of radiator.

Keywords —Optimization, Aerodynamics, and thermal, air dam, tuning parts, drag force, wind tunnel, vortex tube refrigeration,

I. INTRODUCTION

The optimization of aerodynamics effects of air flow on the automobile is necessary to improve fuel economy, reduction in drag force & pollution, control in aerodynamics noise and ease in driving of the vehicle.

The drag force which is combined effect of pressure drag and skin friction drag is reduced by the flow of air around the vehicle. The air, which is separated at front of the vehicle, travels at different speeds above and below the vehicle body. Hence, they meet at a distant point away from the body. This phenomenon leads to the formation of the wake that further leads to the generation of drag. Vehicle drag is a complex phenomenon which is not only governed by vehicle configurations but also flow characteristics, component shape/size, layout, and driving velocity. These parameters are also affecting the lift force particularly at high speed, and that plays a significant role in stabilization of vehicle. This paper provides a solution of optimization of these forces by providing various arrangements for directing the flow of air.

In this paper, efforts were made to optimize the flow characteristics of the vehicle by changing its outside configuration & providing external component such as air-dam splitter, spoilers. Several configurations of the vehicle were made and each one of them was modeled and optimized based on the observed drag forces and lift forces. The analysis was carried out by using ANSYS software to optimize the aerodynamic effects on the vehicle.

The study shows encouraging results by providing front and rear air -dam in the vehicle. The front air -dam significantly reduces the flow of air to the lower portion of the vehicle. Moreover, it increases the amount of air flow to the side and front of the vehicle body. The effects of flow velocity, the trajectory of fluid particles on static pressure distribution and pressure distribution on body surface were investigated by varying flow velocity and configuration of the air- dam. Several configuration and positions of the air-dam were tried in the front portion of the vehicle. CFD analysis optimized solution was obtained to reduce the drag and lift forces. This also improves the steering and driving performance of the vehicle.

A model of the car was prepared by screen printing based on the optimized result obtained by ANSYS software. The model was prepared in 1:10 scale. Detail experiments were conducted on this model at the Subsonic Wind Tunnel testing facility at IIT Gandhinagar.

Further, a concept is developed to utilize the ramming of air for cooling of vehicle. The compression of air is utilized in the vortex tube refrigeration system to take away some of the heat load generated in the engine and braking system. Authors have not come across in any of several papers which were consulted in the optimization of aerodynamics system. The paper also presents the design results of the vortex tube generator for utilization of compressed air and also the experimental result obtained by the developed vortex tube. Hence, the vortex tube is designed to partially share the thermal load while negligibly adding to the cost of operation.

II. OPTIMIZATION OF DRAG

2.1 VORTEX GENERATORS:

Detail literature survey provided the input for the location of the vortex generator[1] on the car. Several configurations were tried and their analysis was carried out on the ANSYS software. These vortex generators[3] were so placed that it reduces the wake region behind the moving car. They were also helping in reducing the flow separation on the body of the car. The delayed separation minimizes the wake region. The final configuration includes, seven Vortex Generator which was placed in V-shaped pattern and at an equal distance starting from midpoint at the top of the car. It is seen that such a pattern gradually develops streamline airflow[4] over the body of the car.

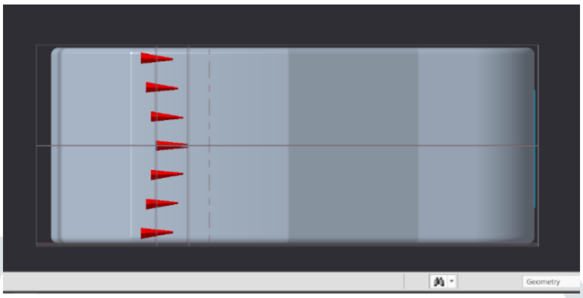

Fig 2.1: Vortex Generator

2.2 AIR DUCT:

The air ducts were provided at the base of the body under the car and also on the bonnet. The primary function served by the lower duct is to collect the air flowing under the body region and eject it at an elevated position, near the rear bumper region. The combined effect of vortex generators and air duct provides us with a very narrow wake region and early meeting of the air streams. Such a configuration has given an early mixing of the air flow in comparison to without modification and also provide narrow wake region to reduce air drag[5]. The air duct provided on the bonnet serves to bleed the excessive air input to the vortex tube refrigerator.

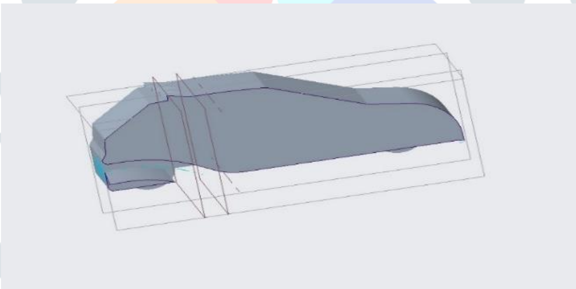

Fig 2.2: Air Duct Rear

2.3 AIR DAM:

The air dams are provided at the front and also rear of the car. It reduces the drag force by reducing the amount of air flowing under the car where several protrusions, cavities are increasing the drag forces. It also increases the down force by reducing the average pressure under the car. They are regulating the flow of air entering the underbody at the front and also rear of the vehicle. The combined effect of air dam and also vortex tube refrigeration system provides improved cooling and reducing the thermal load on the radiator. Such a flow regulation improves the fuel efficiency and better control of the vehicle.

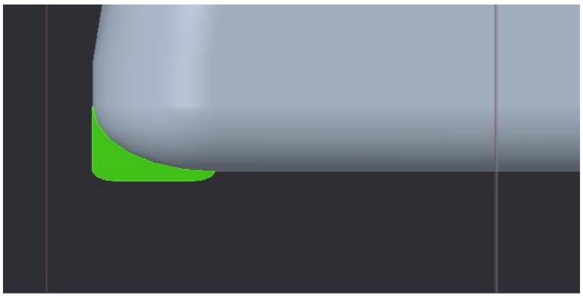

Fig 2.3: Air Dam

1.4 GUIDE VANES:

Guide vanes are used to reduce the drag and also the lift forces which stabilizes the vehicle movement. The guide vanes provided on the base of the car as shown in the figure. The air is directed into the low-pressure wake region in order to enhance pressure recovery and also to the air duct at the back of the car. Air flow into low-pressure region will reduce the form drag and hence the overall reduction in aerodynamic drag. Guide vane cross-section, chord length and angle of attack are varied in order to obtain the optimal configuration for improved aerodynamic performance. Simulations indicate an overall reduction in the aerodynamic drag coefficient[7] with the use of the lateral guide vanes. Moreover, it is found that guide vanes with symmetric airfoil cross-sections result in higher percentage drag reduction as compared to asymmetric cross-sections. The air flow entering from the sides towards the air duct from the guide vanes helps to form quickly the wake region at the back.

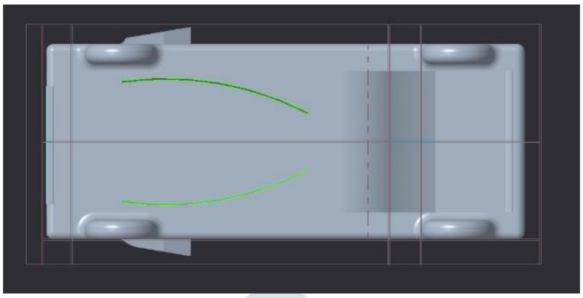

Fig 2.4: Guide Vanes

2.5 FINS:

The fins attached one on each side, helps in streamlining the side flow along with directing the excess air bled from the opening for vortex tube. They are designed in such a manner that the air leaving the duct does not generate lift and the flow is guided to the rear end with minimum wake generation.

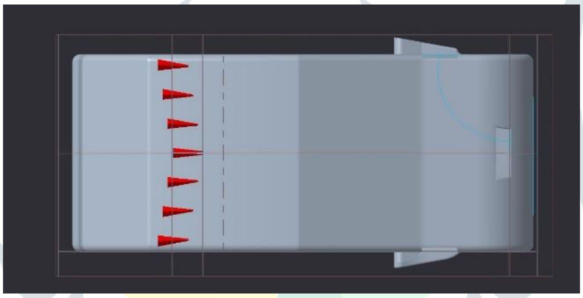

Fig 2.5: Fins

III. WIND TUNNEL TESTING

The computational fluid dynamics (CFD) modeling and analysis by ANSYS software was carried out on various configurations of I10 car. The optimized model which provided minimum drag and negligible lift forces was selected for wind tunnel testing since CFD results are still not completely reliable and therefore, these tests were carried out to verify CFD predictions.

The model was prepared with the help of 3-d printing technology[9] using PLA plastic material in scale 1:10. The physics of proper flow of air to produce actual lift and drag forces were evaluated by the wind tunnel testing. Even in an age of advanced computer simulation, several assumptions and presumptions make it essential to established baseline aerodynamic facts on the model.

The Wind tunnel facility was used at IIT GANDHINAGAR. The wind tunnel has a test section of the dimension of 330x330mm cross-section and 1.2m length. It is capable to produce a wind varying at a speed up to 160 km/h which is sufficient for our car model. The wind speed can be varied by a frequency driven motor and kept at a required speed.

The model was mounted in the wind tunnel on a special platform of the test area. The air flowing around the still model shows the aerodynamics behavior as if the actual car is under test. The aerodynamic forces, moment exerted on model, stability based on different air condition and drag force is measured and visualized during the tests. The test model was instrumented to measure aerodynamic forces, pressure distribution, and other aerodynamic related characteristics. Pressure distributions on a test model was determined by continuously monitoring and also wake region was surveyed and simultaneously air velocity was also monitored. Such monitoring characterized the whole vehicle under test.

IV. VORTEX TUBE REFRIGERATION

Engine cooling[2] system needs to be optimized to improve the vehicle fuel economy and meeting the stringent emission norms apart from maintaining the operating temperature of the engine. The airflow through vehicle subsystems is utilized to reduce the load on the radiator of the automobile vehicle.

The objective is to maximize cooling airflow, reducing the air temperature and also negligible effect on the drag force due to air re-routing under the overall packaging constraints of the vehicle. Thermal load on the radiator of the car is reduced by providing air dams and also vortex tube refrigeration system[6]. The air is routed through the air dam to the engine and also brake and it works like a scoop to grab and direct the cooling air to the engine and also condenser of the air conditioner.

Vortex tube refrigeration system[6] is selected since it is a passive system, not loading the engine and also air routing is necessary for the production of refrigerating effect for cooling purpose.

The rammed air through air duct is supplied through a tangential nozzle into its spin chamber, where a strong rotational flow field is established. The velocity of air near the tube wall due to friction is lower than the velocity at the tube center, as a result, gas in the center region transfers energy to the gas at the tube wall. After energy separation in the vortex tube, the inlet air stream gets separated into two streams, a hot air stream, and a cold air stream. The hot air stream leaves the tube from one end and the cold air stream leaves from another end. This air flows over the engine wall and brakes of the engine to reduce the thermal load on the radiator.

The result of the design of the vortex tube refrigeration system are projected on the table nos 4.1, 4.2, 4.3 and 4.4. The major problem in such a good passive system is a very low coefficient of performance.

TABLE 4.1 Design Considerations for Vortex Tube Refrigeration Calculation

P1	1.013 bar
P2	2.0 bar
ρ	1.225 kg/m3
Ti	29°C
tc	14°C
th	39°C

- **TABLE 4.2 Calculation for Vortex Tube Refrigeration for P2 = 2.0 bar.**

Sr	**V1**	**W (W)**	**Re (W)**	**C.O.P**
1	60	1039	102.05	0.0779
2	80	1745.15	136.09	0.07798
3	90	1963.51	153.01	0.07792
4	100	2181.6	169.59	0.07773
5	110	2399.84	187.18	0.07799
6	120	2618.02	204.20	0.07799
7	130	2836.11	221.21	0.07799

- **TABLE 4.3 Design Considerations for Vortex Tube Refrigeration Calculation**

P1	1.013 bar
P2	3.0 bar
ρ	1.225 kg/m3
Ti	29°C
tc	19°C
th	36°C

- **TABLE 4.4 Calculation for Vortex Tube Refrigeration for P2 = 3.0 bar.**

Sr.	**V1**	**W (W)**	**Re (W)**	**C.O.P**
1	60	890.12	68.068	0.07647
2	80	1186.55	90.732	0.07646
3	90	1335.19	101.79	0.0762
4	100	1483.49	113.06	0.07621
5	110	1638.62	124.79	0.0761
6	120	1780.25	136.13	0.07647
7	130	1928.55	147.47	0.0764

V. MATERIAL

- **TABLE 5.1 Properties of PLA Plastic**

Properties	Pyrolysis Thermal Degradation: 210°C
Flexural Strength: 75.84 MPa (11,000 psi)	Heat Resistance: 110ºC
Melting Temperature: 173 – 178°C	Tensile Strength: 44.81 MPa (Available Range : 25-50MPa)
Elongation at Break: 3-75%	Standard Tolerance: 0.1% With a Minimum of ± 200 µ
Wall Thickness: 1mm-2.5mm	Density : 1.01 - 1.21ρ(Mg/m3)
Shrinkage: 8%	

The material employed for making the model is PLA plastic. It is easy to use with 3D printing technology. The proposed material for use in actual production of the solutions provided in the paper is FRP, which is a composite of plastic and glass fibers. The material is stable in service conditions while being cost-effective at the same time. The vortex tube is fabricated[6] and assembled using aluminum as the material. Aluminum has the inherited property of light weight and high thermal conductivity. It also has sufficient strength to withstand shocks and

VI. ANSYS RESULTS

The different results obtained in ANSYS Software for pressure analysis on vehicle body and vortex tube refrigeration system are as given the figures.

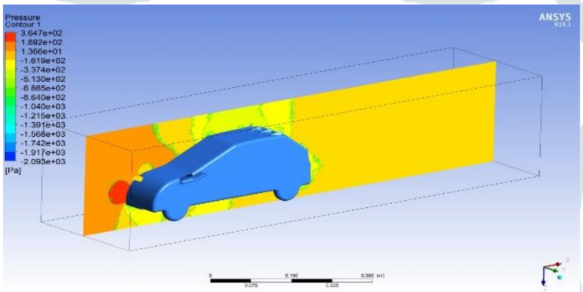

Fig 6.3: Pressure Contour 60km/hr.

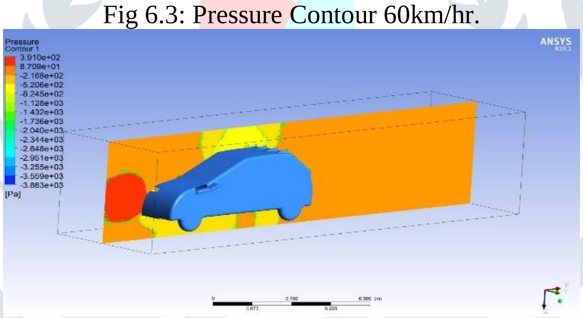

Fig 6.2: Pressure Contour at 80km/hr.

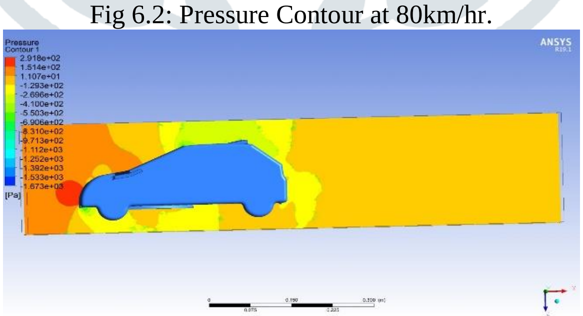

Fig 6.3 Pressure Contour at 100km/hr

VII. CONCLUSION

The theoretical analysis and practical results of testing a model of I10 automobile shows encouraging results. The aerodynamic drag reduction provides better utilization of fuel to improve the efficiency of the vehicle. Improvement is also seen in the lift forces which produce better stability and ease in driving the vehicle, particularly at a higher speed. However such an arrangement of auxiliary components, their design and configuration will not be applicable to all types of the vehicle.

A new concept of utilizing rammed air in vortex tube refrigeration for cooling applications is quite useful but needs further investigations. It requires to generate higher pressure ramming, the effect of the flow of both the streams of air on drag & lift forces and them for useful applications.

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