DEVELOPMENT OF A BUDGET ROOF FAIRING USING A CFD ANALYSIS OF DIFFERENT ROOF FAIRING SHAPES

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Abstract - Semi-trailer trucks are commonly used in Sri Lanka for long distance transportation. These trucks are subjected to an unfavourable high drag which makes a huge impact in fuel consumption. In order to reduce this drag, semi-trailer truck cabins are implemented with a roof fairing which provides a perfect air flow over the entire vehicle. Purpose of this research was to evaluate the efficiency in drag reduction of different roof fairing shapes by conducting a computational fluid dynamics (CFD) analysis. Simulations were done on a 1:1 scaled semi-trailer truck model which was modelled using the blueprint of a commonly used truck model in Sri Lanka. Initial simulation was done without the roof fairing and results were compared with the values of coefficient of drag provided by the manufacturer to improve the accuracy of the research. Different roof fairing shapes were then modelled and attached to above mentioned cabin model and CFD simulations were performed. Subsequent simulations were done using three truck speeds which were 30, 60 and 100 kilometres per hour. The efficiency of each roof fairing was analysed during the post-processing phase after the estimation of the coefficient of drag values. Effect of other coefficients such as coefficient of lift and moment were also considered during the analysis. Results which were achieved through the simulations illustrated a drag reduction excess of 10-25% due to the impact of the geometry and the deflection angles of the roof fairing. Based on the analysis, an effective roof fairing shape was proposed which can be manufactured at a lower cost compared to the roof fairing shapes that are available in Sri Lanka. Final outcomes of this research will be helpful for designers to design more effective roof fairings for semi-trailer trucks with improved drag reduction.

Keywords - CFD, Drag Reduction, Wind Shield

I. INTRODUCTION

Semi-trailer truck configuration was modeled as a 1:1 scaled model based on the most common prime mover which is commercially using in Sri Lanka and simulations were performed. Blueprints provided by the manufacturer were used for solid modeling of the truck and initial simulations were done using only the tractor and trailer configuration without attaching the modeled roof fairing shapes. In tractor-trailer configuration, aerodynamic drag occurs mainly due to the shape of the cabin, transition gap between the tractor, underbody of the truck and rear edge of the trailer (Curry et al., 2012). After confirming the accuracy of the simulated coefficient of drag values with the values provided by the truck manufacturer, the modeled roof fairing shapes were attached, and simulations were done. Simulations were performed for three different inlet velocities using *OpenFOAM* computational fluid dynamics software and the inlet velocities were selected considering the speed ranges in Sri Lanka. The efficiency of the different roof fairings was analyzed in the post-processing based on the parameters such as coefficient of drag, the percentage of drag reduction relative to the truck without the fairing, horizontal deflection angle and vertical deflection angle of the roof fairing. Other parameters such as coefficient of lift and moment were also considered in the analysis phase, for that Navier-Stokes equations were used. A percentage reduction between 10 – 30% was obtained for the different roof fairing shapes and It was found out that vertical deflection angle of a particular roof fairing provides a higher impact to the drag reduction as well as efficiency. Results obtained from the analysis was used to develop a low-cost roof fairing shape which is more compatible with the Sri Lankan road conditions and the economy. The most prominent parameters highlighted in the analysis such as vertical deflection angle was considered for the development of the new design. It was focused more to keep the curvy surfaces lower as much as possible in order to reduce the cost of machining and tried to keep the machining techniques and material used as simple as possible. The new budget roof fairing design is developed to manufacture using the aluminum material with basic welding techniques and fabrication techniques which are commonly available in Sri Lanka and a cost estimation was also done based on the rates of local manufacturers and suppliers. The design outcome of this research will be helpful in manufacturing a low cost and affordable roof fairing shape for the local market which is more efficient in reduction of drag, other related problems of fuel consumption and economic factors in Sri Lanka.

II. METHODOLOGY AND APPROACH

Performance assessment of the truck with different shapes of roof fairing was done by using following tools:

- Solid modeling
- Mesh generation
- Computational Fluid Dynamics

The blueprints of the cabin of truck were obtained by the manufactures, the 3-D model of the truck and the different shapes of roof fairings were created using *SOLIDWORKS* 2015 and then generated meshes using *OpenFOAM* “snappy hex” tool. Meshes were generated for each roof fairing shape. With the available computational power grid negligence procedure was conducted to find the best mesh that could be used to perform the CFD analysis without interruption. The Mesh generated for the basic truck without roof fairing is shown in figure 1.

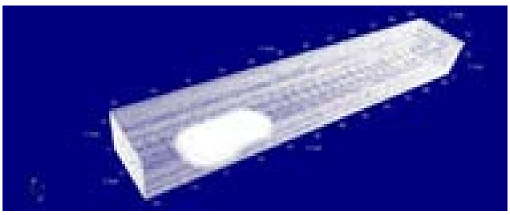

Figure 1. 3. D Mesh created by OpenFOAM snappy hex tool

The quality of mesh was a factor for the improve the accuracy of the solution and the computational time. Considering that fine mesh was generated, and inflation layers were added to the near surface of the truck to capture boundary layer interactions accurately. Cell volume details of generated computational domains are given in Table 1.

Table 1. Cell volumes of computational domains

	Basic Truck	DAF SE1643	Volvo FM12	Renault 420 DCI
Cell Volumes	2,572,217	5,961,439	5,428,264	5,779,100

After generating the mesh *OpenFOAM* CFD tool used to run the analysis. K-Omega SST model which is two-equation turbulence model which became more recommending because of its analytical capabilities in ordinary aerodynamic streams. Simulations were run on hired server 8 core 3.0 GHz computer with 32GB RAM, up to 10000 iterations and the solutions converged around 4500 iterations. The process was repeated for each model to all three velocities.

III. RESULTS AND DISCUSSION

In the post processing phase, final results were observed and compared through an analysis of the flow properties. For the analysis, the *Para View* (5.5 version) post processing tool was used since it has the capability of handling multi-platform data and large-scale data which is important in this analysis. Results obtained through basic long truck without the roof fairing was used to compare coefficient of drag values with each roof fairing. It is important to have a reference value to compare since we used a moderated model for the simulations. (Table 2)

From the simulations it was understood that the vortices which are generated due to flow separation when the flow leaves the rear end of the trailer causes a severe pressure to drop behind the long truck. Due to that a large wake region builds behind the trailer of the long truck.

Long truck is a blunt body which generally creates a high pressure in the front face due to the crashing air molecules in the front face of the cabin due to the movement of the long truck. The trailer which generally has a larger face than the cabin also influences in creating a high-pressure force in the frontal area. These crashing air molecules tend to move up or down or sideways along the front face and

Table 2. Reference values of models

Roof Fairing Shape	Horizontal Deflection Angle (°)	Vertical Deflection Angle (°)	Base Area (m^2)	Perimeter of Base (m)	Coefficient of Drag		
					30kmph	60kmph	100kmph
Without fairing	0	0	3.558	7.695	0.3724	0.3775	0.3766
DAF SE1643	19.77	35.68	2.318	6.021	0.2799	0.2786	0.2778
Volvo FM12	8.66	37.76	2.99	7.012	0.2952	0.2943	0.2933
Renault 420DCI	20.71	15.62	2.709	6.807	0.3296	0.3283	0.328

join other molecules of streamlines which moves along the surfaces of the truck. This accelerates the flow speed along the surfaces which creates the flow separation at the rear end. Simulations were done in three different velocities but the coefficient of drag values remained relatively same even at larger velocities showing that the impact of the velocity is minimum.

Roof fairings are used to reduce the flow separation due to above phenomena. Roof fairings help these crashing molecules to move smoothly over the surfaces of the long truck by reducing its turbulence impact on the streamlines around it. roof fairing with higher horizontal deflection angle sends most of these molecules along the side surfaces of the truck. But from any simulation, a significant effect on drag reduction couldn't be identified due to the high horizontal deflection angle.

Vertical deflection angle sends these molecules above the long truck. When the vertical deflection angle is high it prevents air particles crashing on the top of the trailer (Figure 2). This prevents the probable reverse flow that occurs in the gap between the cabin and the trailer which happens in long trucks without the roof fairing. Roof fairing with a lower vertical deflection angle showed relatively a smaller drag reduction compared to other roof fairings because of the above mentioned reverse flow. Through the simulations, it is understood that the higher the vertical deflection angle higher the drag reduction will be.

Roof fairings which were built with a curvature in the top surface have shown a better drag reduction compared to the other roof fairings. It is also understood that the roof fairings which were built with several layers allow air to be flown in different levels which reduces the air molecules mixing with other streamlines (Figure 3). This reduces the turbulent behavior of the streamlines which leaves the rear of the trailer. From all three roof fairings, the most drag reduction was reported in the roof fairing which has a curvy geometry and a higher vertical deflection angle.

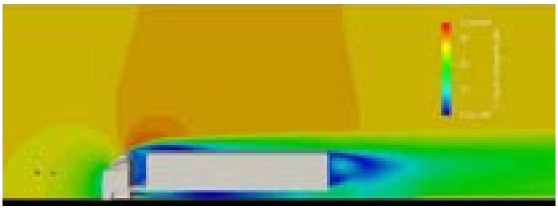

Figure 2. Velocity profile

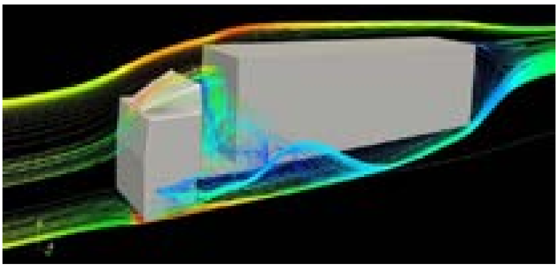

Figure 3. Flow visualization using streamlines

III. CONCLUSION

the analysis, it was understood that the effect of velocity on aerodynamic drag is minimum. Hence velocity doesn't affect at all for the performance of the roof fairing in drag reduction. Researchers also identified that the reverse flow in between the cabin and the trailer also affects the resultant drag force. It was understood that the vertical deflection angle makes an impact in increasing the efficiency of roof fairings, but the impact of horizontal deflection angle is low. As for the results, the geometry or the shape of the roof fairing made the highest contribution in drag reduction by allowing streamlines to flow smoothly over and in the sides of the long truck. As for the recommendations, researchers are willing to introduce two budget roof fairing designs in near future based on the analytical data obtained through the process.

Researchers propose first roof fairing design (Figure 4) as a budget roof fairing with a higher aerodynamic efficiency that can be afforded by any entrepreneur. In this design, effect of horizontal planes was considered as negligible. This design was prepared by removing the side panels of the roof fairing. A curvy top surface in a vertical angle of 35.68˚ is the prime part of the design which is the same vertical deflection angle of the roof fairing that showed the highest drag reduction.

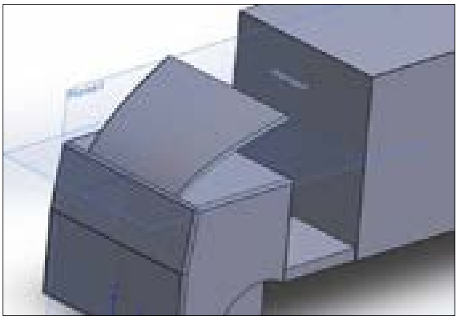

Figure 4. Roof fairing design 1

Design 2(figure 5) was made by taking all the conclusions into consideration. Vertical angle hasn't changed from the earlier one (35.68˚) and the horizontal angle was decided by allowing flow to be deflected just enough to flow along the side surfaces of the trailer. Side panels are designed using a surface arc producing a very smooth deviation of the flow in side panels of the roof fairing. This fairing will be designed using lesser number of sheet materials compared to any other roof fairing that is in the current market. As for the connecting of surfaces researchers propose to use TIG welding method. This welding will allow to use thinner sheet material and it also allows a perfect finish on the surface which will not interrupt the smooth flow over the roof fairing.

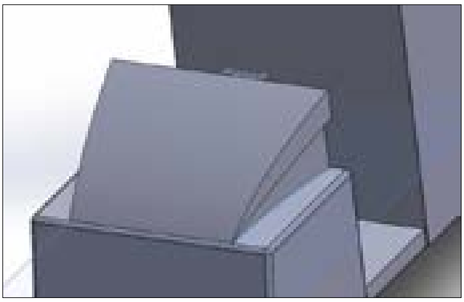

Figure 5. Roof fairing design 2

Performance analysis of the new designs using CFD simulations are ongoing and researchers also plan to develop prototypes and compare the results in future.

IV. REFERENCES

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