Investigation on Dimple inspired Mitigation of Aerodynamic Drag of Intercity Bus

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**Abstract.** The aim of this paper is to reduce aerodynamic drag of an intercity bus in order to achieve lower fuel consumption through dimples implementation on the intercity bus. The importance of a redesign is to reduce the aerodynamic drag on an intercity bus, which comprised of 70% pressure drag and on rear-side which affects 30% induced drag by vortex. Scaled down bus models (with and without dimples) are tested in a subsonic wind tunnel. Also, numerical simulation for both cases are completed in which the design of a bus is modelled by CATIA and the pre and post processing works are carried out in ANSYS Workbench 16.2. Drag forces are validated, which confirmed dimples plays vital role in the intercity bus’s lower fuel consumption, when it travels above 60 km/hr.

***Keywords*:** Drag, Dimple, Fuel consumption, intercity bus

1. **INTRODUCTION**

Public transport sector are the most important form of urban and rural passenger transport around the world. Bus-based public transport, which is typically not a profit-making business but it depends solely on revenue earned from ticket sales. Increase in population, shifting mobility patterns and a greater focus on environmental issues are changing the face of public transport. Buses and coaches account for 55 percent of public transport in Europe, over 45 percent of all passenger transport in Turkey, and 751 million passenger trips annually in the USA. More than 21 million people work directly in public transport sector in China. In India, there are 1,70,000 buses carrying roughly 70 million people per day. Most bus agencies strive to meet operational costs in other ways, and fuel economy has been recognized as a significant strategy that contributes towards operational efficiency. It leads to saves the corporation, which closes to 9 percent of the total cost of operation. It also has positive implications on the environment due to its reduction in usage of fuel. The amount of fuel used to push a heavy vehicle through the air increases rapidly with speed. Improve engine efficiency, reduce auxiliary loads, reduce rolling resistance, reduce vehicle weight, improve vehicle and trailer aerodynamics, optimize driver behaviour, improve transmission and driven efficiency are the opportunities to reduce fuel consumption of heavy vehicles, in which aerodynamic drag plays vital role. 10 percentage of fuel saving is achieved with the help of aerodynamics modification compared to all other techniques. But the problem is aerodynamic conditions cannot be suitable for all operating condition. For example, if a vehicle with aerodynamic devices operates at the rate of 50 km/hr in speed zone will typically improve the fuel consumption to 1 percent. Simple low-cost measures you can use to improve the aerodynamics when average speeds are greater than 70 km/hr and achieve fuel savings up to 10%. For example, linehaul vehicles can save up to 10% or more of their fuel bill through improved aerodynamics. It also translates to 50,000 litres of fuel saved over the first million km of the life of the vehicle. For a typical heavy vehicle need about 22 horsepower to overcome aerodynamic forces at 50 km/hr with no aerodynamic device. It leads to increases to 126 horsepower at 90 km/hr and over 170 horsepower at 100 km/hr.

1. **PROBLEM IDENTIFICATION AND SOLUTION TECHNIQUES**

Ground vehicles always suffer from wind in the forms of increasing drag, reduction in stability, noise generation and side wind induced accidents. In the case of buses, rolling resistance, climbing resistance and aerodynamic drag are playing major role in their operational efficiency. The significant increase of road transport combined with the increasing environmental issues and fuel prices has renewed the interest in the aerodynamic design of an intercity bus. The profile of the intercity bus is a bluff body, which act as principal object of aerodynamic drags and is governed by the way in which bus disturbs the air stream, so apart from all other prime factors reduction aerodynamic drag, directly impact on the operational efficiency. Nowadays the importance of good aerodynamic parameters in the design of the bus is being increasingly recognized. Especially for a high-speed coach, it has been played very important role in a long-distance transportation system connecting city-to-city and state-to-state. In the case of low speed town buses, are not affect as much as high speed intercity buses because of its high velocity, which directly increases as square of the speed, hence reduction of aerodynamic drag is of prime importance to keep the fuel consumption at minimum. In order to achieve low fuel consumption and secure level, drag reduction technique plays a vital role so this paper suggests that existing bus model modified with dimples in the flow separation regions is the key to reducing the drag. By creating dimples on the front and rear side of the intercity bus, it is found that the drag is reduced, as the drag is reduced the fuel consumed per kilometre is reduced. In general, drag reduction methodologies are lies on the modification of shape without consider the driver stress free environment. This existing reduction methodology does not provide sufficient reduction on the opposing forces in the ground vehicles. The dimple creation is an advanced solution instead of shape angle reduction at the back and front of the bus. Also the dimple creation methodology has capable to provide efficient flow behaviour around the bus. In this paper, Computational Fluid Dynamics and wind tunnel experimentation have been attempted.

1. **RESULT AND DISCUSSION**

**3.1 Design of the Bus**

Drag force due to pressure, plays a dominant role in intercity bus because of its large frontal surface area also has high possibility of flow separation on the front and back side of the bus due to the large wake resulting from the bluntness. Although friction drag occurs along the external surfaces of the intercity buses, particularly along its length. Hence geometry of the bus plays a vital role in order to reduce aerodynamic drag without negatively affecting the usefulness or profitability of the bus design with the help of technologies. Design of a bus is modelled by CATIA and the dimensions of the reference bus have been determined from literatures. The design parameters are height of the bus – 9.5 cm, length – 36.8 cm, and width – 7.5 cm.

**3.2 Numerical Simulation - Without dimple’s results**

CFD plays a vital role to predict the pressure variation and velocity distribution on the both the models, in which a perfect boundary conditions provide acceptable solution. The boundary conditions used are: pressure based solver is used, k-omega with shear-stress transport model selected as turbulence model, and second order numerical approaches are used for good accuracy. Figure 1 implies about the drag force acted on the bus and Figure 2 represents the Co-efficient of drag value of the bus without dimples for the input fluid velocity of 14 m/s. Drag due to pressure is considered as prime evaluating parameter, but the drag dependent results ANSYS are inclusion of pressure drag and skin—friction drag. Figures 3 to 16 show the pressure distribution and velocity variation on the bus for the velocities varies from 14 m/s, 17 m/s, 20 m/s, 22 m/s, 25 m/s, 28 m/s and 35 m/s respectively.

|  |  |
| --- | --- |
| 14 m/s | |
|  |  |
|  |  |
| 1. Drag force | 1. Co-efficient of Drag value |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
| 17 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
| 20 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
| 22 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
| 25 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
| 28 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
| 35 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |

**3.3 Numerical Simulation – With dimple’s results**

Figure 17 and 18 shows about the velocity plot and pressure plot of the bus with dimples at the velocity of 14 m/s, similarly figure 19 and 20 represents velocity and pressure variations at the speed of 17 m/s. Remaining velocities such as 20 m/s, 22 m/s, 25 m/s, 28 m/s and 35 m/s are also analysed, the pressure distribution and velocity variations are plotted and revealed in the figures 21 to 30. Drag force and its relevant parameters are also evaluated, a sample plots are revealed in the figures 31 and 32. Figure 31 represents the drag force acted on the bus with dimples at the velocity of 35 m/s. Figure 32 shows about the Co-efficient of Drag value at the velocity of 35 m/s in bus with dimples.

|  |  |
| --- | --- |
| 14 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
| 17 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
| 20 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
| 22 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
| 25 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
| 28 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
| 35 m/s | |
|  |  |
| 1. Velocity Plot | 1. Pressure plot |
|  |  |
| 1. Drag force | 1. Co-efficient of Drag value |

**3.4 Experimental Results**

Figure 33 and 34 shows the frontal view of the Experimental Set-up without and with specimen. Figure 35 shows the typical view of Bus without dimples, which underwent aerodynamic testing for different velocities which derived from field work on the Indian bus. For the same estimated velocities, the bus modified with dimples also tested, which are revealed in the figure 36.

|  |  |
| --- | --- |
|  |  |
| 1. Typical View of Experimental Set-up without Load | 1. Experimental Set-up with test specimen |
|  |  |
|  |  |
| 1. Typical View of Intercity Bus without dimples | |
|  |  |
|  |  |
| 1. Typical View of Intercity Bus with dimples | |

After the experimentation, both the case results are noted and listed in the table 1. In which the aerodynamic drag values are carefully monitored, when it undergoes the above 20 m/s due to bus nature.

1. Comparison of Drag on a Bus

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Velocity (m/s) | Drag (N) [Without Dimples] | | Drag (N) [With Dimples] | |
| Experimental | Numerical | Experimental | Numerical |
| 14 | 0.26 | 0.2428 | 0.5 | 0.4 |
| 17 | 0.59 | 0.394 | 0.7 | 0.45 |
| 20 | 0.78 | 0.670 | 0.81 | 0.606 |
| 22 | 1.1 | 0.808 | 1.01 | 0.7957 |
| 25 | 1.3 | 1.0940 | 1.15 | 1.073 |
| 28 | 1.37 | 1.2613 | 1.35 | 1.1973 |
| 35 | 1.7 | 1.43 | 1.6 | 1.406 |

1. **Conclusion**

The geometry of the intercity bus with and without dimples is modelled with the help of CATIA, in which the literature review provides the dimensions of both cases. The computational analyses have been carried out using ANSYS Workbench 16.2 for the given boundary conditions, which are determined from the field work. The co-efficient of drag value have been monitored throughout the convergence of iterations, in which it is noted that the co-efficient of drag has been reduced from 0.81 to 0.606 at the velocity of 22 m/s also the drag is initiated to reduce from 22 m/s by creating dimples in the front and rear part of the intercity bus. Subsonic wind-tunnel provided the platform for experimental testing, in which the same numerical conditions are considered as experimentation input. Results are compared, which confirmed that the creation of dimples on the intercity bus is the suitable method for reducing drag.

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