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STREAMLINE DESIGN OF A HIGH SPEED INTERCITY BUS FOR FUEL SAVING, REDUCTION OF CARBON-DIOXIDE EMISSION AND BETTER DRIVING STABILITY AT HIGH SPEEDS

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Abstract: The rising of fuel price and strict government regulations make the road transport uneconomical nowadays. Aerodynamically efficient designing of vehicles plays a vital role to achieve reduction in fuel consumption, have less carbon dioxide emission and to get more convenient driving stability on a high way. However, at present, the external body shape of a long-distance, high-speed buses manufactured around the world are in a rectangular shaped blunt body. With this conventional body configuration, it is not possible to minimize aerodynamic drag. In this study, a streamline design concept was applied to the front-side of a long-distance intercity bus to see its effect on the reduction in aerodynamic pressure drag. Additionally, the effect of attaching a spoiler at the rear side was investigated. For this purpose, an existing intercity bus was taken as a reference and analyzed. Then streamline design concept was applied on the frontal area of the bus by splitting the windshield angle into two steps (θ_1 and θ_2). For this purpose, four different model buses were developed and analyzed. In all cases the modified vehicles were streamline designed on the frontal area with different exterior body styling. Computational fluid dynamics (CFD) method was used to analyze the variation of aerodynamic drag with variation of the vehicle speed for all bus models. The results showed that the maximum reduction rate of drag coefficient (16.3%) was obtained by model 2 when compared to the original model bus (Model 0) at a speed of 60Km/hr.

Keywords: **Aerodynamics, Computational Fluid Dynamics, Drag reduction, Fuel consumption**

I. INTRODUCTION

The depletion of fossil fuel is one of the most critical dilemmas which the world will face in the imminent decades. Petroleum products account to about 40% of the total amount of fossil fuels among which diesel and gasoline are the vital products, which are being disintegrated from day to day due to their no renewability nature. Out of the total petroleum products consumed by various sectors, about 66% of it is consumed for transportation. Nowadays, buses are major means of mass transportation in the world. Therefore, it has become very important to engender buses with better fuel efficiency [11].

Streamline designing plays a vital role to reduce the drag force. Nowadays, the bus body manufacturers concentrated mostly on the aesthetic sense and they give least importance to aerodynamics and its effect in fuel consumption and CO_2 emission. In a moving vehicle, the engine power is used to overcome tractive resistance, which is the combination of rolling and aerodynamic resistance. The rolling resistance will be dominant over the aerodynamic resistance at lower vehicle speeds. But as the speed of the vehicle increases, the aerodynamic resistance dominates the rolling resistance. Thus, reducing the aerodynamic resistance at high speed reduces the pressure drag which in turn reduces the load on the engine and hence boosts the fuel efficiency of the bus [10].

Most of the previous researches focused on the race car, sedan aerodynamics rather than the heavy vehicles. This is mainly due to market forces and consumer preferences. However, there were few researches, which focused on the aerodynamic design area.

Sachin et al., 2011 conducted a research on Computational Analysis of Inter-City Bus with Improved Aesthetics and Aerodynamic Performance on Indian Roads and with the new model, they managed to reduce the drag force by 30% [1].

Edwin et al.,1999 carried out assessment research on Heavy-Duty Truck Aerodynamic Design Features on Reducing the Drag of Trucks and Buses. From the experiment results, they concluded that the aerodynamic resistance highly depends on the frontal geometry of vehicles [4].

Thomas et al.,2012 conducted a research on Reducing Aerodynamic Drag and Rolling Resistance from Heavy-Duty Trucks on Chinese Trucks. This report summarizes the commercial technologies available that can be used to improve the fuel efficiency of heavy freight trucks by reducing aerodynamic drag and rolling resistance, and evaluates their applicability to Chinese heavy trucks. These methods include roof and side fairings, vortex generators and air dams for trucks. For trailers, these methods include: gap reducers, nose cones, side skirts, under body fairings, and boat tails/end fairings. Wind tunnel test indicates that individual aerodynamic aids can reduce distance-specific fuel use (l/100km) from trucks by 1% to 15%; packages of several different types of devices together can reduce fuel use up to 25%. From the test results, it has also been demonstrated that low rolling resistance tires can reduce fuel use from trucks by approximately 3% while the use of single-wide tires of traditional dual tire sets on truck rear axles and trailer axles can reduce fuel use up to 9%. Automatic tire inflation systems have been shown to reduce fuel use by 0.5% to 1.2% [3].

G. Buresti et al., 2007 carried out a research on Methods for the drag reduction of bluff bodies and their application to heavy road- vehicles in which they stated that in order to reduce the bluff body drag, boat- tailing has been applied & this reduced the base drag by 5% up to 10%. Further to reduce the drag force Tractor – Trailer gap was occupied by a device so that both drag reduction devices and the trailer can turn easily around the turns without any clashing. Also fairings and flow-deflection devices have been provided in the pressure drag on the axle and the trailer base. This paper also points out the wheels of the road vehicles are, in general, a source of considerable aerodynamic drag [5].

Panu et al.,2007 conducted a research on aerodynamic possibilities for heavy vehicles and they came out with a conclusion that boat tail approach is known to be a good solution in terms of aerodynamic drag reduction [6].

In this study, a streamline design concept was applied to the front side of an intercity bus to minimize the aerodynamic resistance. In addition to this, the effect of putting or not putting a spoiler at the rear side and also the effect of the roof air conditioning system placement was studied. For this purpose, an existing inter-city bus was taken and investigated. Then, its surface structure was modified with the streamline design concept. The frontal configuration of the model bus was modified to reduce the stagnation pressure drag and the roof air conditioning system was placed at different positions (at the front and center) and also the rear spoiler was designed and attached to minimize the induced drag at the rear side of the bus. Four models of the streamline designed buses were developed with the combination of the modified frontal area and the rear spoiler. The roof air conditioning system was placed at the front and at the middle/center and its effect was studied and the results are compared with the baseline model bus.

II. METHODOLOGY

In this study, numerical simulations of different bus configurations were performed. Starting with evaluating the results of the baseline model (model 0), a streamline design concept was applied to the frontal area of the vehicle. As a result, four different bus models were introduced. In all cases the modified vehicles were streamline designed on the frontal area by splitting the windshield angle into two steps (θ_1 and θ_2). In addition to this, a spoiler was designed and the effect of putting the spoiler and not putting the spoiler on vehicles was investigated. Also the effect of placing the roof air conditioning unit at the front or center of the roof was incorporated into the study and the results were compared with the original model vehicle. For each configuration, computational fluid dynamics (CFD) method was used to analyze the variation of aerodynamic effect on the model buses.

The 3D model of the baseline model bus (Model 0) is shown in figure 1 below.

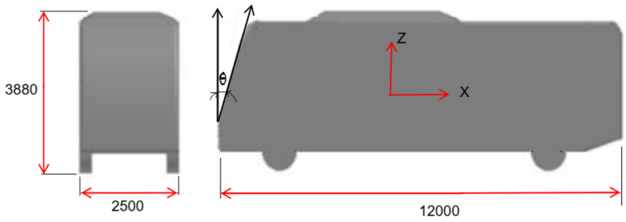


Figure.1: Geometrical configuration of the original model bus (Model 0).

The windshield angle(θ) for the original model bus is 16 degrees from the vertical and the length dimensions are in millimeters. Vehicle specification of the baseline model is given below.

Table I: Vehicle specification of the baseline model.

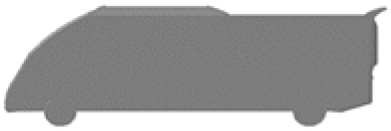
Parameters	Dimension
Overall length	12000 mm
Overall width	2500 mm
Overall height	3880 mm
Clearance	400 mm
Gross weight	30000Kg
Windshield angle	16 Degrees

The side views of the geometry of the modified model buses are shown in figure 2 below.

Model 1

Model 2

Model 3



Model 4

Figure.2: The side views of the modified bus models (Model 1 – Model 4)

Model 1 was streamline designed on its frontal area, there is no spoiler on the rear side and the roof air conditioning unit was placed at the front.

In model 2, the roof air conditioning unit was placed at the center and the other parameters remain the same as model 1.

In model 3, a spoiler was attached at the rear side, the roof air conditioning unit was placed at the front and the remaining parameters remain the same as model 2.

In model 4, the rear guide vane was added to the rear side of the vehicle and the other remaining parameters remain the same as model 3.

All of the modified Models were streamline designed on their frontal area. The windshield angle was divided into two steps (θ_1 and θ_2) to minimize the stagnation pressure. θ_1 was 60 degrees and θ_2 was 22 degrees for all the modified models. The general design concepts made are shown in the figure 3 below and the length dimensions are in millimeters.

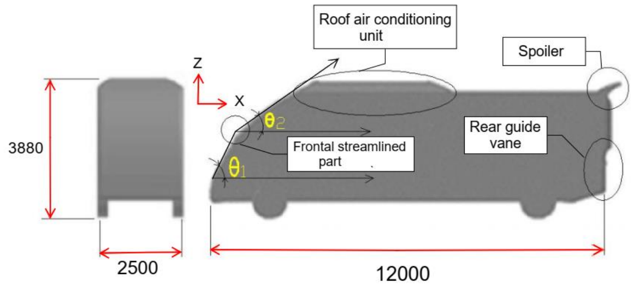


Figure.3: Streamline design concept used.

Figure 3 shows the general design concepts used in this paper to reduce the aerodynamic drag.

III. Boundary Conditions and Numerical Grid Generation

The orthogonal grids were used for the numerical grid generation in the physical domain in this study. First, a 3D geometry of the model bus was developed by CATIAV5R20, 3-dimensional CAD software and the model was imported into to the numerical domain(PHOENICS-VR) to generate the numerical grid in the rectangular coordinate system to perform the numerical calculations. Atypical grid used for simulation purpose is shown in the figure below.

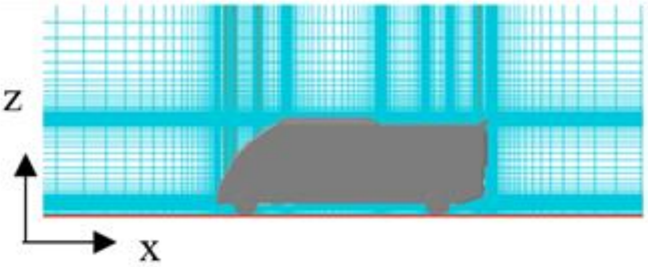


Figure. 4: A typical grid of model 4 bus

Figure 4 shows a typical numerical grid of the physical domain with the modified model bus with a rear-spoiler incorporated for the numerical investigation. The optimum grid size of the 3D model was decided to be (161 X 82 X 84) from the previous numerical grid validation test.

While performing the simulation, the following initial conditions were applied.

- Only straight wind condition was considered at different inlet velocities from 60Km/hr. up to 120 Km/hr.
- A Constant inlet velocity condition was applied at the inlet boundary condition and constant pressure (zero-gauge pressure) was applied at the outlet boundary condition.
- At the surface of the moving bus, no slip condition was assumed.
- A moving boundary condition on the ground surface was applied.
- On the remaining boundary conditions (on the open surface of the control volume; east and west sides and top surface), potential flow condition was assumed.

IV. RESULT AND DISCUSSION

In this study, aerodynamic performance of a high-speed intercity bus was examined to see the effect of streamline designing on aerodynamic drag reduction. Figure 5 shows the variation of the aerodynamic drag coefficient of each bus model with the change in vehicle speed.

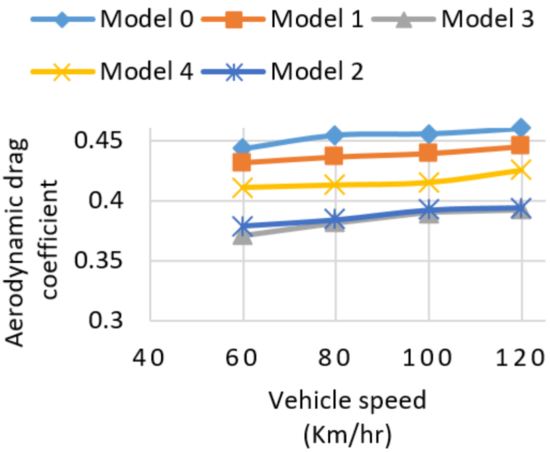


Figure 5: Variation of drag coefficient and drag forces of all models with vehicle velocity.

The drag coefficient increases with an increase in vehicle speed and it does not change much for all models with the change in the vehicle velocity.

The baseline model showed the highest drag coefficient. On the other hand, Model 3, the streamline designed model which has the roof air conditioning unit placed at the front and a spoiler attached at the rear side showed the minimum drag coefficient at the lower vehicle velocity and achieved the same drag with model 2, the streamline designed model with no spoiler, at higher vehicle velocity. The placement of the roof air conditioning unit has no significant difference on the drag coefficient [13]. This means that the decrease in drag coefficient which is observed with model 3 is due to the attachment of the spoiler at the rear side of the bus.

Model 4, which has the same structure with model 3 except the addition of the rear guide vane, showed higher drag coefficient than model 3 which has no rear guide vane. This means that the addition of the rear guide vane increased the drag coefficient of the vehicle.

The drag force(F_D) in the longitudinal direction can be calculated by the following formula [9].

$$F_D = \frac{1}{2} C_D * \rho * A * U^2 \ldots\ldots\ldots\ldots(1)$$

Where, C_D is the drag coefficient, ρ is the incoming air density, A is the frontal area and U is the vehicle velocity.

At any vehicle velocity, the reduction rate of the drag coefficient for each modified models can be calculated as [9].

$$\frac{C_{D_{Model-o}} - C_{D_{Model-i}}}{C_{D_{Model-o}}} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where, $C_{D_{Model-o}}$ is the drag coefficient of the baseline mode(Model 0) and $C_{D_{Model-i}}$ is the drag coefficient of the modified model vehicle.

Variation of the drag coefficient reduction rate for all models with vehicle velocity variation is shown below.

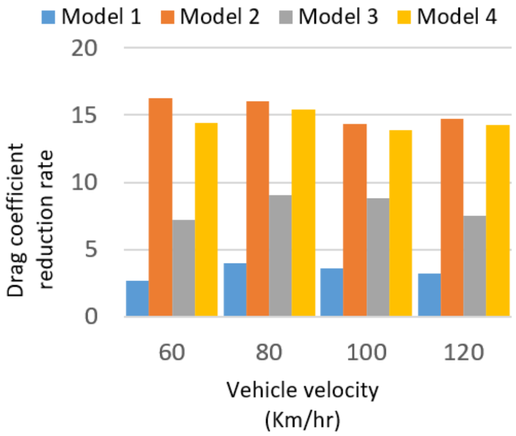


Figure 6: Variation of drag coefficient reduction rate for all models with vehicle velocity variation.

At each vehicle velocity, the highest reduction rate in drag coefficient is achieved with model 2 (which is streamline designed, has no spoiler and the roof air conditioning unit placed at the center). For model 1, the drag reduction rate increased on the front half and then remained almost stable at higher vehicle speeds. For Model 2, the drag reduction rate is almost constant at each vehicle velocity. For Model 3, the drag reduction rate increased with vehicle velocity on the first half and then declined at higher vehicle velocity. For model 4, the drag reduction rate increased with an increase in vehicle velocity around the lower vehicle velocity, then it started to decline around the medium vehicle velocity and again started to rise at higher vehicle velocity.

The surface pressure contour of the baseline model and the streamline designed model buses are shown in figure 7 below.

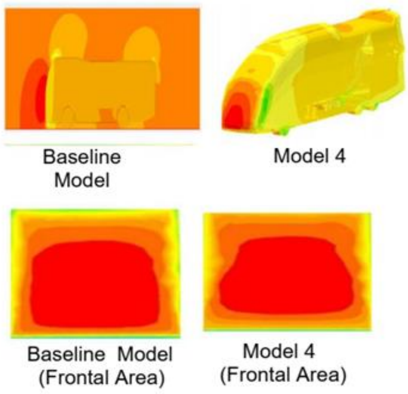

Baseline Model
Model 4
Baseline Model (Frontal Area)
Model 4 (Frontal Area)

Figure 7: Comparison of surface pressure contour of the conventional bus model and the streamline designed bus (model 4) at 100Km/hr.

By dividing the windshield angle in to two steps (θ_1 and θ_2), it has been possible to reduce the stagnation pressure area on the frontal area of the buses with the streamline designed models.

V. CONCLUSION

The test results revealed that, streamline designed vehicles acquired improved performance than the original model bus in aerodynamic drag reduction at higher vehicle speeds. It was observed that the drag coefficient largely depends on the frontal geometry of the vehicle. In addition to this, attachment of the spoiler on the rear side of the vehicle showed further reduction of the drag coefficient when compared with the same vehicle without spoiler. On the other hand, inclusion of the rear guide vane at the rear side of the buses persevered the aerodynamic drag.

Generally, the following concluding points can be drawn from the test results.

- ➢ Streamline designing a vehicle on its frontal side greatly reduces the aerodynamic drag that the vehicle encounters at higher speeds.
- ➢ Adding a rear guide vane at the rear side of buses slightly increases the aerodynamic drag.
- ➢ Attaching a spoiler at the rear side of buses marginally enhances the reduction rate of the drag coefficient.
- ➢ The placement of the roof air conditioning unit either at the front side or at the center of the roof of buses has no significant effect on the aerodynamic performance of buses.
- ➢ The maximum reduction rate of drag coefficient was obtained by model 2, streamline designed vehicle with the roof air conditioning unit placed at the center at a vehicle speed of 60Km/hr.

VI. ACKNOWLEDGMENT

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