International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 22 (2018) pp. 15456-15464

Numerical and Experimental Investigation of Aerodynamics of a Solar Panel Mounted Mini Bus

Mohammad Rafiq B. Agrewale[1], R. S. Maurya[2]

[1,2]Mechanical Engineering Department, Sardar Patel College of Engineering, Mumbai-400058, India,

Abstract

The flow structure emerging around a moving vehicle play a key role in deciding its overall performance. The lift and drag effect is significantly altered by introducing any abrupt change in the exterior of the vehicle body. Increasing environmental concern and depletion of conventional fuel forced researchers to think about environment friendly alternatives. Using rooftop solar panel is an easy and convenient way to address this issue up to a certain extent. The work deals with numerical study to access the effect of different parameters of vehicle performance in context to a mini bus model fitted with rooftop solar panel. Numerical work includes the assessment of possible geometry of solar panels- flat, triangular and arc shape panels on vehicle performance and its stability. Based on numerical investigation, the mini bus model with flat solar panel configuration is selected and scaled prototype model is tested in a wind tunnel for validation of data. The result shows the close agreement between experimental data and numerical analysis. The further numerical investigation is carried out to assess the impact of different parameters such as solar panel mounting height from vehicle rooftop from100 to 300 mm, speed of vehicle from 60 to 120 kmph and yaw angle from 6 to 18 degree. Investigation concludes with interesting results of vehicle performance which may help designers to select a particular configuration of the solar panel.

Keywords: Mini bus, Solar panel, Vortex, Coefficient of drag and lift, Yaw angle

INTRODUCTION

Increasing international concern to environmental issues and depleting reserve of fossil fuels in last two decades, have compelled researched to explore potential of favourable alternative energy sources. Slowly maturing technologies to tap sun power as a source of energy have created hope to get rid of such problems. The automotive sector being a significant contributor to environmental issues, attracted researchers. Recent years PV cell mounted vehicle on rooftop has become very popular because of easy and convenient installation of solar panels. Rooftop mounting of solar panels alters the aerodynamic design of the vehicle which finally leads to performance deterioration. The performance can be depicted through the coefficient of drag (C_D) and coefficient of lift (C_L). An assessment of these parameters are customized which can be done either through experimentation or numerical investigation.

Literature shows that many of the early investigation were on a highly simplified model of a vehicle known as Ahmed Body which was proposed by Ahmed et al. [1]. He investigated the effect of rear slant angle from 0^0 to 30^0 on evolving wake flow structure behind Ahmed body. Vino et al. [2] investigated near end and far end wake formation around Ahmed body. He observed sensitivity of drag coefficient with Reynolds number. To find an optimum turbulence model for numerical study of aerodynamics around road vehicles, Hobeika and Zaya [3] simulated different cases with available turbulence model and came out with conclusion that k-ε models is most appropriate among all. Agrewale and Maurya [4] performed numerical investigation of evolving flow structure around Ahmed body mounted with solar panel of different configuration which shows that shape and mounting of solar panel on ground vehicle play significant role to improve fuel economy and vehicle performance. Also they have discussed the effect on vehicle performance with change in rear slant angle and vehicle speed [5].

The aerodynamic analysis of mini bus by Rodrigues et al. [6] shows that small changes in vehicle geometry has been possible to achieve a reduction of almost 20% of drag coefficient which results in fuel saving of about 10%. Mohamed et al. [7] investigated different cases of bus design with consideration of front and rear curvature and observed that add-on gives reduction of drag upto 14%. Wang et al. [8] carried out aerodynamic drag measurement by using filament method and laser flow visualization technique. This study provided foundation for styling optimization of a minibus. Thorat and Rao [9] showed that slight modification in exterior bus design and frontal area with improved aesthetic, drag can be reduced significantly. An investigation of changing aerodynamics of a bus with small alteration such as boat end extension, panel and spoiler at rear side was done by Patil et al. [10]. It was concluded that a drag reduction of about 20 to 30% is possible. Using solar energy for vehicle transport has been investigated by many researchers. Past, present and future use solar energy, related issues, influencing parameters and modelling of solar car was reviewed by Singh et al. [11].

Allgood [12] carried out wind tunnel test and a numerical study of a design of hybrid solar–bio-diesel car. He developed an optimum 2D shape which had minimum drag coefficient characteristics. Using Cosmos FloWorks as numerical tool, Muhammad [13] investigated design of upper body structure for solar car and incorporated many changes- frontal area, shape and material in the design and concluded that these are important parameter of design for better performance. Augenberges [14] carried out an aerodynamics optimization study of a solar powered race car using wind tunnel. He included the effect of parameters like - angle of attack, ride height, wheel fairing length, surface finish, sealing and rear view mirror in his study and optimized them for lower drag and better stability.

It can be summarized through reviewed literatures that Ahmed body had been used by researcher as reference for design and development of an automotive vehicle. It has been used both for experimental as well as numerical investigations. The drag force affect the fuel economy of vehicle whereas lift force affect vehicle stability. Aerodynamic study of vehicle with many external modification has been done by many investigator for the assessment and improvement of vehicle performance. Investigations on solar panel mounted vehicle are limited. A large number of city vehicle can be easily altered to a partial solar powered vehicle without large investment which may significantly help this world to be more green. Unfortunately there is no documented guidelines for the designers to suggest alteration without compromising significant vehicle performance. A systematic assessment of aerodynamic performance is a need of time which would help designer to recommend fitment of rooftop solar panels.

Objective of the present work is to investigate the effect of rooftop mounted solar panels on the vehicle performance in terms of fuel economy with respect to coefficient drag and stability of vehicle with respect to coefficient of lift under few geometrical and dynamic parameters. The methodology adopted for investigation is as discussed below:

- Feasibility study of most common automotive vehicles used for public transportation,
- Identifying the most appropriate and feasible vehicle model with possible solar panel configurations - flat, triangular and arc through numerical investigation,
- Parametric investigation of selected vehicle with respect to orientation of solar panel, mounting height of solar panel above rooftop, vehicle speed and yaw angle.
- Wind tunnel testing and numerical simulation of selected vehicle scaled model for validation of results.

SELECTION OF VEHICLE FOR SOLAR PANEL MOUNTING

Based on survey, four most common public transport vehicle types such as 3 wheelers auto rickshaw, passenger car, mini bus and bus are selected for feasible study. A typical solar panel produce power of about 203 W/m^2. Assuming a panel can produce approximately 4 hours energy in a typical day. Based on parameters such as vehicle type, vehicle speed, vehicle frontal projected area and available roof top area for solar panel mounting, the approximate contribution of solar energy is given in table 1.

Table 1. Contribution of approximate solar energy in vehicle

No.	Parameters	Unit	Three Wheeler	Passenger Car	Mini Bus	Bus
1	Category average vehicle weight (W)	kg	630	1460	6000	16000
2	Average vehicle frontal projected area (A_P)	m^2	2.55	2.24	5.00	8.75
3	At maximum design speed, the average power required at wheels, (P)	kW	25.10	117.75	372.08	1252.48
4	Average area available for installing solar panels (A_I)	m^2	3.75	7.20	14.00	22.50
5	Average electrical energy available on vehicle area (A_E)	kW	3.09	5.94	11.55	18.56
6	Approximate contribution of solar energy (E_S)	%	12.32	5.04	3.10	1.48

(The above table is for illustration purpose only, the actual calculations may vary from vehicle to vehicle.)

Based on above assumptions and calculations, it is observed that with most efficient solar panel, the 3 wheeler model gives maximum utilization of solar energy. But this will increase vehicle and maintenance cost. In case of passenger car model, most of the customer may not accept the external fitment on personal cars which will affect the aesthetic look and shape of vehicle. The good option is mini bus model which gives optimum utilization of solar energy as compared to bus model with respect to local passenger carrying capacity, power to weight ratio etc. Also mini bus model would be appropriate choice because it is one of the largest moving vehicle under local transportation. So the e-mobility concept would be possible in this case. Whereas the bus category vehicle gives minimum utilization of solar energy. Also these are heavy vehicles and generally used for long distance travel. So finally the mini bus model is selected.

NUMERICAL INVESTIGATION

Numerical investigation of the case is described in the following sections.

PROBLEM DEFINITION

A mini bus of size 6.5 m length, 2.6 m width and 3.8 m height with rooftop dimension of 5.6 m length and 2.3 m width considered for investigation. It is assumed to be mounted with

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 22 (2018) pp. 15456-15464

three convenient and easy configurations of solar panels such as external flat, triangular and arc-shaped with open and closed fitment over roof. Flow dynamics around the bus may get altered by rooftop solar panel arrangement and it is expected to be the function of significant parameters such as mounting height of the panel, vehicle speed and yaw angle. To assess the impact of mounting height (*h)* of solar panel, it is varied in practical range of 100 mm to 300 mm. To investigate the impact of vehicle speed, it is varied from 60 to 120 kmph and yaw angles *(α)* are changed to 6^0, 12^0 and 18^0. An assessment of impact of these parameters would help designer to take key decisions related to solar panel mounting on mini bus for optimum fuel economy.

MATHEMATICAL MODEL

The flow around solar panel mounted vehicle may be assumed to three dimensional Newtonian, incompressible, isothermal and steady without any external energy interaction. The forces responsible for flow are pressure gradient, viscous and inertial forces. The body force can be completely neglected. Mass, momentum and turbulence flow equation is expected to be the basic governing equation to decide the flow structure evolving around the vehicle.

Governing Equations

Mass transport equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (1)$$

Momentum transport equation

$$-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)=\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)$$

$$-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)=\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)$$

$$-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)=\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right) \quad (2)$$

Where,
x, y, z represents coordinate direction,
u,v, w represents velocity components in *x, y, z* direction respectively,
p, ρ and *μ*, represents pressure, density and dynamic viscosity.

All parameters carries usual meaning. Transient terms are retained here to represent updation of velocity field under pseudo timing.

Turbulence Model

To model the turbulence arising in the present problem, with reference to Andersson et al. [15], realizable turbulent kinetic energy - dissipation model is used for the investigation. The choice is based on numerical experimentation by Muhammad [13] and Augenberges [14] who carried out similar investigations.

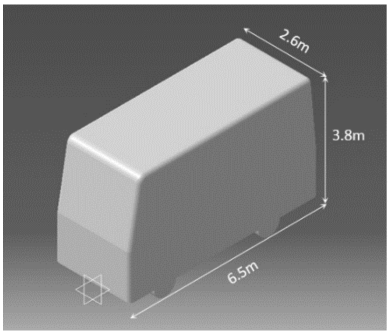
Boundary Conditions

The boundary conditions applicable to the problem under investigation are velocity inlet as per the speed of the vehicle, pressure outlet at far end of the vehicle, no-slip condition at the ground and body surface of the vehicle, and outflow at remaining sides.

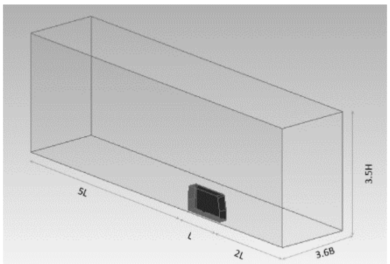
NUMERICAL IMPLEMENTATION

The flow structures evolving around a vehicle moving at a specific speed with rooftop solar panels, is expected to create a 3D flow field which will affect the performance of a vehicle. The formation of long vortex street behind the object is common feature at moderate to high speed of the vehicle. The flow structure is expected to be symmetrical about a vertical longitudinal plane in the direction of flow. The work under investigation has been executed using commercial software 'ANSYS Fluent' and solid model has been created using CATIA software.

The investigation is carried out on a mini bus model of size 6.5 m length (L), 2.6 m width (B) and 3.8 m height (H) as shown in figure 1 (a). Expecting flow structure symmetry about length wise mid vertical plane, the computational domain of size (8L×3.6B×3.5H) is selected with 4% blockage ratio, 0.7 as aspect ratio and characteristic length of 6.5 m for investigation which is depicted in figure 1 (b).



(a)



(b)

Figure 1. Mini bus model and computational domain

The vehicle is assumed to have a ground clearance of 210 mm and front space of 2L for flow to develop in the computational domain before reaching to vehicle. Rear ends are kept sufficiently long to take care of vortex shedding. The domain and vehicle body are meshed using advance size function as proximity & curvature and patch confirming tetrahedrons method with an optimum cell size to capture all relevant details. The convergence criteria for residual of continuity, x, y and z are selected as 0.001. The boundary conditions, solver setting and under relaxation factors are applied during investigation are listed in the table 2 (a), (b) and (c) respectively.

Table 2. (a) Boundary conditions, (b) Solver setting and (c) Under relaxation factors

(a) Boundary conditions		
1	Velocity inlet	80 kmph
2	Bottom of domain and vehicle wall	No-slip
3	Pressure outlet	Atmospheric pressure
4	Side and top outlet	Outflow
5	Fluid	Air
6	Turbulent intensity	5%
7	Viscosity ratio	10
8	Reynolds number	9.18×10^6

(b) Solver setting		
1	Turbulence model	Realizable k-epsilon
2	Coupling	Pressure-velocity
3	Scheme	SIMPLE
4	Gradient	Least squared cell based
5	Pressure	Standard
6	Momentum	First & second order upwind
7	Turbulent kinetic energy	First & second order upwind
8	Turbulent dissipation rate	First & second order upwind

(c) Under relaxation factors		
1	Pressure	0.2
2	Momentum	0.2
3	Turbulent kinetic energy	0.25
4	Turbulent intensity	0.25
5	Turbulent dissipation rate	0.25

To ensure the independence of result from mesh size, mesh independence test is performed on vehicle model. The cell thickness near the surface and their growth rate are considered for mesh sensitivity test. Keeping growth rate as 1.2, cell thickness is varied from coarse to fine and variation of C_D is observed which is depicted in figure 2. It shows the variation is negligible and mesh independent.

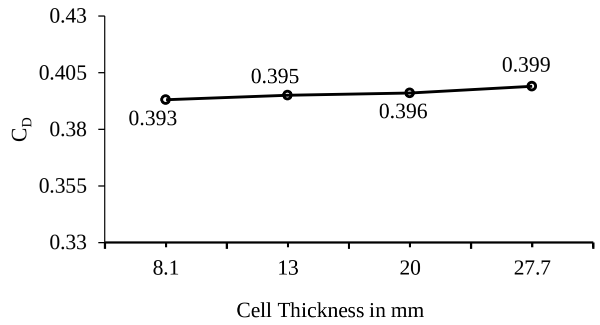


Figure 2. Mesh independence test

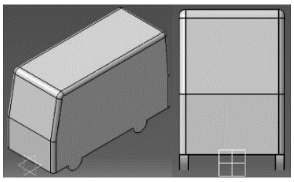
RESULTS AND DISCUSSION

A moving mini bus mounted with solar panels of different configuration, arrangement and dynamic state are expected to affect vehicle flow characteristics significantly. Any change in geometry of vehicle will change frontal area which affect aerodynamic characteristics. So geometric orientation of solar panel will be important parameter. The mounting height of solar panel would play significant role to define flow separation between roof and solar panel. Also change in speed and yaw angle affects performance in terms of fuel consumption and stability of vehicle. So based on all these parameters, the following cases are considered for investigation to get insight of flow pattern arising around the vehicle.

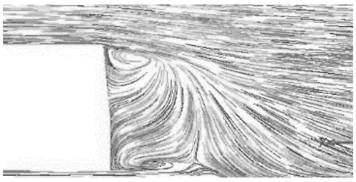
1. Effect of solar panel configurations,
2. Effect of solar panel mounting height from vehicle roof,
3. Effect of vehicle speed, and
4. Effect of yaw angle.

1. Effect of Solar Panel Configurations

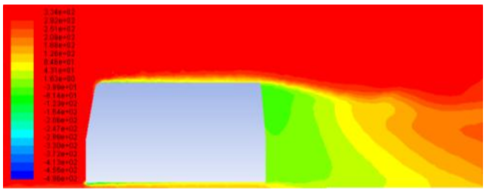
An investigation of flow characteristics developing around a model of mini bus without solar panel moving with 80 kmph is depicted in figure 3. The stagnation of flow at front and separation of flow at rear end of the vehicle can be observed from pressure distribution. The presented contours are symmetrically cross section with respect to longitudinal axis of vehicle model. The pressure contour represent the variation of pressure at front and rear of vehicle model. This shows that the pressure is high at front and low at rear. Due to pressure difference, flow gets separated and produce more turbulence at the rear which leads to formation of large vortices and gives more form drag. This resisting force affect performance of vehicle in terms of fuel consumption. The coefficient of drag and lift under this condition are found to be 0.393 and 0.031 respectively.



(a)



(b)



(c)

Figure 3. (a) Mini bus model without solar panel (b) flow separation at rear (c) pressure contour

The drag and lift coefficient is expected to significantly affected by mounting solar panel on the rooftop. Three different arrangement of solar panel mounting- flat, triangular and arc shaped, on vehicle rooftop considered for investigation. All panels are of approximately same surface area with mounting height 150 mm. The vehicle is assumed to be moving at a speed of 80 kmph. The vehicle modelling, simulation result and variation of parameters with different configuration of solar panels are depicted in table 3 (a), (b) and (c).

Table 3 (a). Mini bus model with different configuration of solar panel at 150 mm mounting height

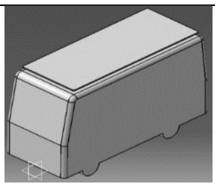
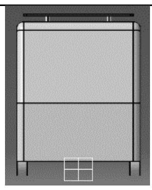
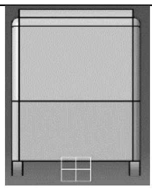
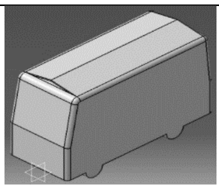
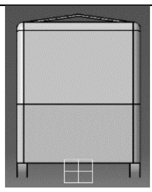
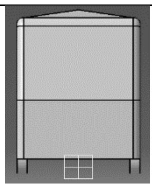
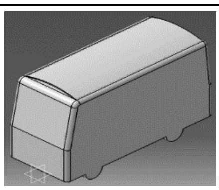
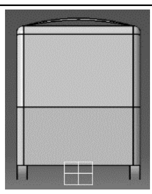
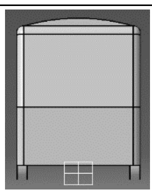
No.	Solar Panel Configuration	Open Front	Closed Front
1.			
	Flat Solar Panel		
2.			
	Triangular Solar Panel		
3.			
	Arc Shaped Solar Panel		

Table 3 (b). Pressure contour and variation of C_D and C_L with different configuration of solar panel at 150 mm mounting height

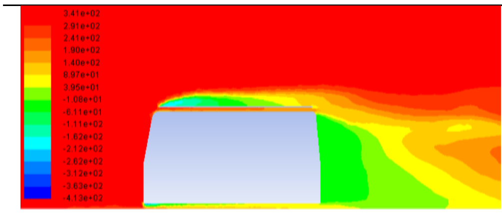
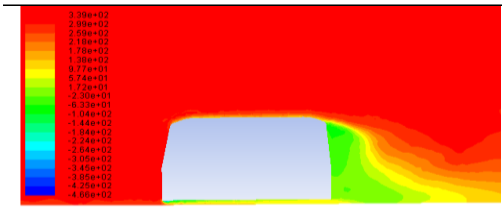
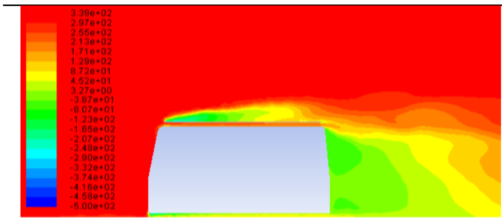
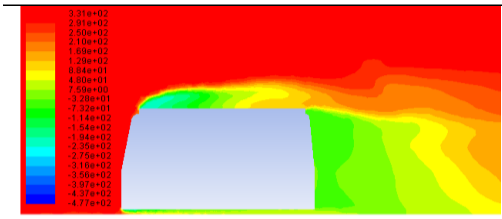
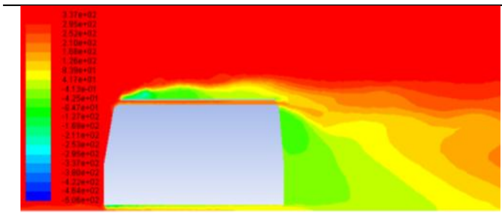
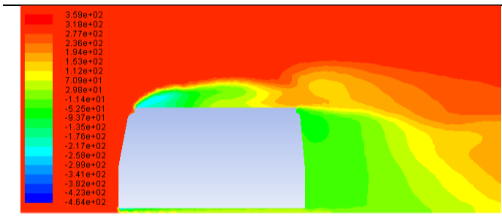
	C_D= 0.439 C_L= 0.008
Open Front	
	C_D= 0.399 C_L= 0.185
Closed Front	
Flat Solar Panel	
	C_D= 0.463 C_L= -0.035
Open Front	
	C_D= 0.479 C_L= -0.046
Closed Front	
Triangular Solar Panel	
	C_D= 0.453 C_L= 0.013
Open Front	
	C_D= 0.503 C_L= -0.069
Closed Front	
Arc Shaped Solar Panel	

Table 3 (c). Percentage variation of C_D with different configuration of solar panel at 150 mm mounting height

Configuration	Open Front		Closed Front	
	C_D	% variation in C_D	C_D	% variation in C_D
Vehicle model without solar panel	0.393	-	0.393	-
Vehicle model with flat solar panel	0.439	10.47%	0.399	1.51%
Vehicle model with triangular solar panel	0.463	15.11%	0.479	17.95%
Vehicle model with arc shaped solar panel	0.453	13.24%	0.503	21.86%

The closed front arrangement imposed more resistance compared to open front arrangement of solar panel except for the case of flat plate. This is due to early flow separation caused by increased frontal area. This induces additional pressure drag. In open solar panel mounting, the flat shape gives low drag coefficient and reasonable lift coefficient which result to low fuel consumption but unstable vehicle condition. Whereas triangular shape gives low lift but high drag coefficient due to venturi effect which gives good stability but increases fuel consumption. The arc shape solar panel give intermediate result of drag and lift coefficient between flat and triangular solar panel. Whereas in close solar panel mounting, the flat shape gives low drag coefficient due to less flow separation at the rear but gives high lift coefficient which result to low fuel consumption but unstable vehicle condition. The arc and triangular shape gives high drag coefficient and low lift which increases fuel consumption but gives good vehicle stability. The analysis also shows that flat close solar panel mounting gives low drag coefficient as compared to open solar panel because of absence of flow separation area between panel and roof of vehicle but gives high lift coefficient which affect vehicle stability. Whereas it is reverse effect in triangular and arc-shape solar panel mounting due to increase in frontal area results to more drag and less lift coefficient.

2. Effect of Solar Panel Mounting Height from Vehicle Roof

The solar panel mounting height (*h*) from vehicle roof as shown in figure 4 is expected to influence the drag and lift characteristics of vehicle. In order to investigate this effect, the solar panel is assumed to be mounted at a height of 100 mm, 150 mm, 200 mm and 300 mm above mini bus model.

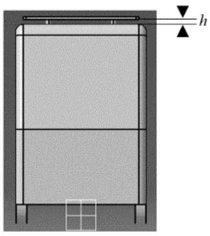


Figure 4. Flat open solar panel mounted on mini bus with mounting height *(h)*

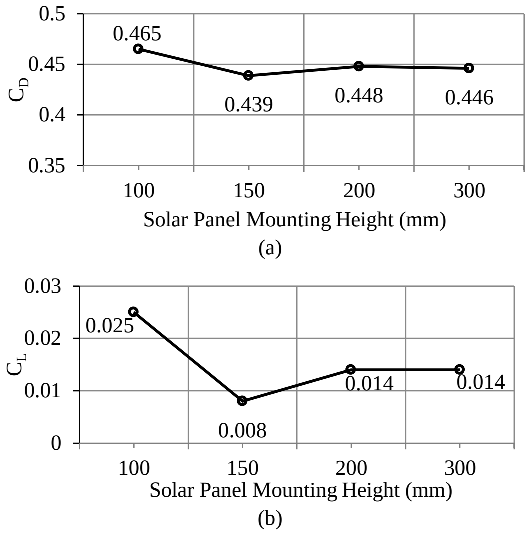


Figure 5. Variation of C_D and C_L with flat solar panel mounting height

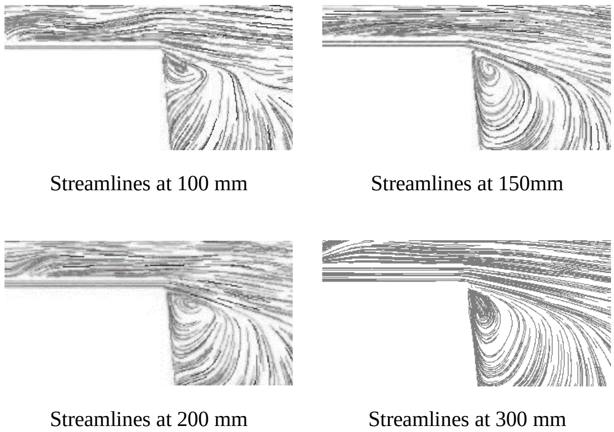
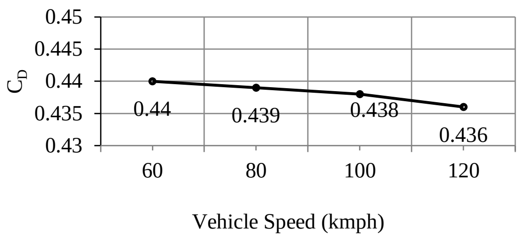


Figure 6. Effect of solar panel mounting height

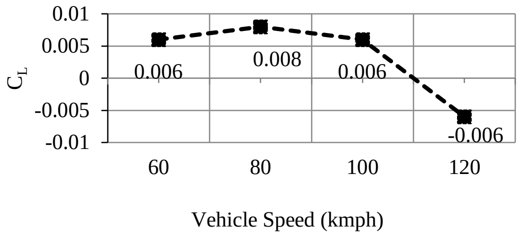
Figure 5 (a) & (b) shows that the solar panel mounting height affect drag and lift coefficient. A channel flow is created in between the gap of solar panel and vehicle roof. The solar panel mounting height of 150 mm gives lower drag and lift coefficient as compared to other mounting heights. As the mounting height increases the drag and lift coefficient increased. Also at mounting height of 100 mm, stronger drag and lift coefficient is observed. This is due to congestion effect which leads to flow separation and turbulence as shown in figure 6. Hence 150 mm mounting height gives low drag and optimum lift which will balances fuel consumption and vehicle stability.

3. Effect of Vehicle Speed

An effect of changing the vehicle speed from 60 to 120 kmph on vehicle performance in terms of drag and lift coefficient is represented in figure 7 (a) & (b). Mini bus is assumed to be mounted with flat solar panel at mounting height of 150 mm.

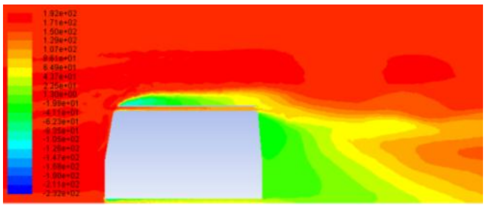


(a)

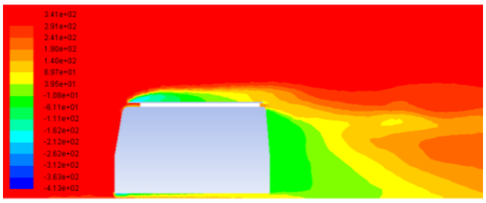


(b)

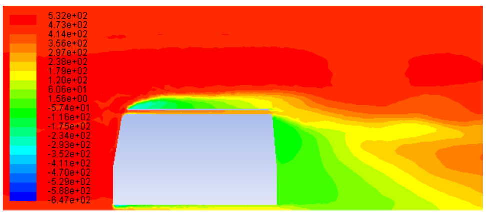
Figure 7. Variation of C_D and C_L with vehicle speed



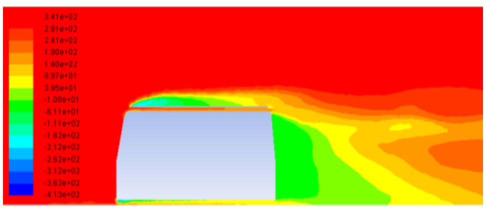
(a)



(b)



(c)



(d)

Figure 8. Pressure contours at (a) 60 kmph, (b) 80 kmph (c) 100 kmph and (d) 120 kmph

The drag coefficient remain almost constant as shown in figure 8 whereas a marginal decrease in lift coefficient for speed beyond 80 kmph which is good from vehicle stability point of view.

4. *Effect of Yaw Angle*

The flow around vehicle body is result of its shape, vehicle speed & direction and wind speed. The yaw angle is the angle between the vehicle longitudinal axis and the relative wind direction as shown in figure 9.

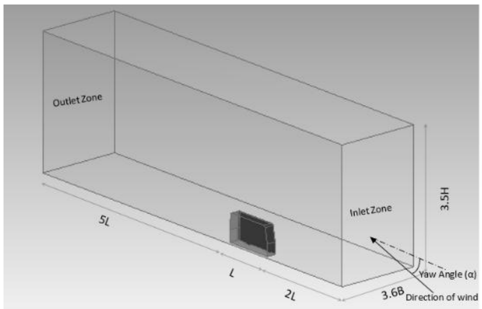
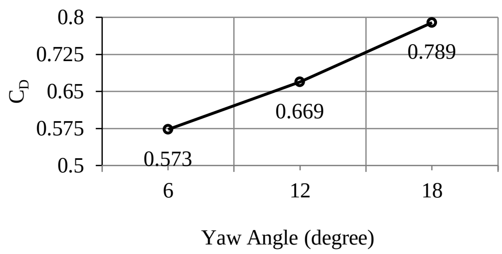
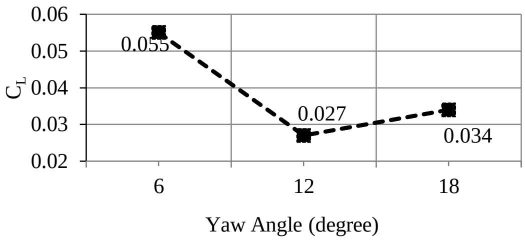


Figure 9. Domain with yaw angle

To investigate the effect of yaw angles on the performance of the proposed vehicle with flat solar panel of mounting height 150 mm, the yaw angle is varied to 6^0, 12^0 and 18^0. In this case, using relative velocity concept, it is assumed that vehicle is in static condition and air is flowing around it at speed of 80 kmph in the direction of 6, 12 & 18 degree with respect to vehicle longitudinal axis. Figure 10 (a) & (b) shows the effect of yaw angle on C_D and C_L.



(a)



(b)

Figure 10. Variation of C_D and C_L with yaw angle

The result shows that drag coefficient increases with increase of yaw angle as expected. This is because of impact of lateral and longitudinal air resistance components on vehicle due to yaw angle whereas Lift coefficient is marginally influenced by change of yaw angle. This will affect fuel consumption drastically and also stability of vehicle.

INVESTIGATION ON SMALL SCALED MODEL

To investigate the result of numerical and experimental investigation, a 1:50 scaled model of mini bus is considered. The experimental and numerical analysis has been performed on scaled model and results are compared.

EXPERIMENTAL INVESTIGATION

An experimental investigation of final model of mini bus carried out is presented in this section. A 1:50 scaled 3D printed prototype mini bus models without and with flat solar panel are fabricated by fused deposition modelling (FDM) method using polylactic acid (PLA) material as shown in figure 11.

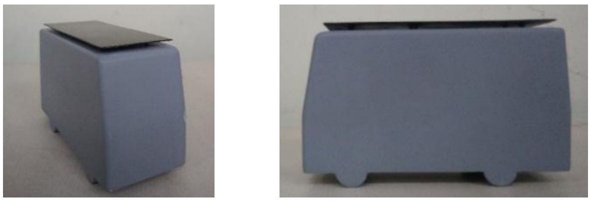


Figure 11. Scaled 3D printed prototype mini bus model with flat solar panel

The schematic diagram of wind tunnel considered for investigation is presented in figure 12. An open type wind tunnel is used in present investigation. It has flow cross sectional area of 0.3 x 0.3 m^2 and 1m length of test section with maximum air velocity up to 30 m/s by using 3 hp power of motor. The wind velocity can be controlled by a regulator. The velocity of air measured by using anemometer. The mounting is connected to digitized transducer measuring system where output parameter is directly displayed on panel. Before performing the experimentation, the traducers are calibrated against the applied load.

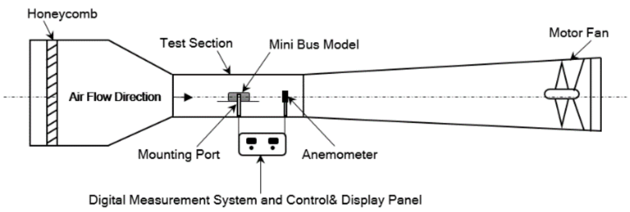


Figure 12. Wind tunnel setup (schematic diagram)

The wind tunnel test is performed on scaled model at speed of 80 kmph (22.22 m/s). The mini bus model is fixed to the mountings available in the test section. These mountings are connected to digitized transducer setup. The wind over the model is induced in channel through ID fan. The drag measurement is done by a digitized transducer setup where the drag force is displayed on a digital display panel. Based on drag force, the calculated drag coefficients are 0.414 for mini bus model without solar panel and 0.454 for mini bus model with flat solar panel.

NUMERICAL INVESTIGATION

On same scaled model, the numerical investigation is performed at speed of 80 kmph with realizable k-epsilon turbulence model and boundary conditions using ANSYS fluent tool. The simulated values of drag coefficients are 0.426 for mini bus model without solar panel and 0.469 for mini bus model with flat solar panel.

COMPARISON BETWEEN EXPERIMENTAL AND NUMERICAL INVESTIGATION

The experimental value of drag coefficients are compared with CFD simulated values of similar scaled model, which shows the close correlation between them as given in table 4.

Table 4. Experimental and numerical results of scaled model

	C_D (Experiment)	C_D (Numerical)
Mini Bus Model without Solar Panel	0.414	0.426
Mini Bus Model with Flat Solar Panel	0.454	0.469

CONCLUSIONS

Present work is successful to illustrate the development of flow arising around a minibus mounted with rooftop solar panel. The work deals with numerical investigation based selection of a solar panel among three simple and convenient geometry- flat, triangular and arch shaped. Based on computational result, a scaled prototype mini bus model with flat solar panel is fabricated by using 3D printing technology and validated by wind tunnel testing. Work also addresses the impact of solar panel mounting height, vehicle speed and the effect of yaw angle on flat solar panel mounted mini bus model. Following points can be concluded:

1. The flat solar panel is a better option compared to other geometry (investigated) from fuel economy point of view which gives low drag coefficient and optimum lift coefficient gives better stability.
2. The mounting height of about 150 mm would be a reasonable choice for low drag and reasonable lift coefficient.
3. The change of speed of vehicle from 60 to 120 kmph, doesn't show significant change in lift and drag coefficient of the vehicle.
4. Effect of yaw angle on C_D and C_L of vehicle is significant. So there may be appreciable impact on fuel economy and stability of the vehicle.
5. The drag coefficient values shows close correlation between numerically simulated and wind tunnel experimental results for scaled model.

This parametric investigations would help vehicle designer in their decision making for selection of solar panel configuration, mounting height, effect of speed and yaw angle to design efficient and stable vehicle.

REFERENCES

[1] Ahmed, S., Ramm, G., and Faltin, G., 1984, "Some Salient Features of the Time-Averaged Ground Vehicle Wake," SAE Technical Paper No. 840300.

[2] Vino, G., Watkin, S., Mousley, P., Watmuff J., and Prasad, S., 2005, "Flow Structures in the near Wake of Ahmed Model," Journal of Fluids and Structures, 20, 673-695.

[3] Hobeika, T., and Zaya, J., 2011, "Road Vehicle Aerodynamic Advanced," Chalmers University.

[4] Agrewale, M. R. B., and Maurya, R. S., 2016, "Numerical Investigation of Evolving Flow Structure around Ahmed Body Mounted with Solar Panel of Different Configuration," Proceeding of Sixth International Congress on Computational Mechanics and Simulation, 964, pp. 363-366.

[5] Agrewale, M. R. B., and Maurya, R. S., 2017, "Numerical Study of Flow Structure Developed around Ahmed Body with Roof Top Solar Panel of Different Geometric Configurations," International Journal of Automobile Engineering Research and Development, Jan, pp.127-136.

[6] Rodrigues, A., Cervieri, A., Gertz, L. C., and Telh, M. A., 2014, "Aerodynamic Analysis of a Vehicle Minibus, SAE Paper No. 2014-36-0327.

[7] Mohamed, E. A., Radhwi, M. N., and Gawad, A. F. A., 2015, "Computational Investigation of Aerodynamic Characteristics and Drag Reduction of a Bus Model," American Journal of Aerospace Engineering, 2, 1-1, pp. 64-73.

[8] Wang, J., Hu, X., Zhang, Y., and Yang, B., 2011, "Research of Aerodynamic Characteristics about Minibus," Applied Mechanics and Material, 97-98, pp. 752-755.

[9] Thorat, S., and Rao, G. A. P., 2011, "Computational Analysis of Intercity Bus with Improved Aesthetic and Aerodynamic Performance on Indian Roads," International Journal of Advance Engineering Technology, July-Sept, II, Issue III, pp. 103-109.

[10] Patil, C. N., Shashishekar, K. S., Balasubramanian, A. K., and Subbaramaiah, S. V., 2012, "Aerodynamic Study and Drag Coefficient Optimization of Passenger Vehicle," International Journal of Engineering Research & Technology, I, Issue 7.

[11] Singh, R., Gaur, M. K., and Malvi, C. S., 2012, "Study of Solar Energy Operated Hybrid Mild Cars: A Review," International Journal of Scientific Engineering and Technology, 1(4), pp. 139-148.

[12] Allgood, N. A., 2008, "Aerodynamic Optimization of a Solar – Bio-Diesel Hybrid Vehicle," American Institute of Aeronautics and Astronautics.

[13] Muhammad, S. B. A., 2010, "Upper Body Structure Design for Solar Car," Thesis, University Malaysia Pahang.

[14] Augenberges, P. K., 2005, "Aerodynamics Optimization of Solar Power Race Car," Thesis, Massachusetts Institute of Technology.

[15] Andersson, B., Andersson, R., Hakansson, L., Mortensen, M., Sudiyo R., and Wachem, B., 2011, Computational Fluid Dynamics for Engineers, Cambridge University Press.