Aerodynamic Effects of Different Ventilation Methods on Buses

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ABSTRACT: This paper describes a study of the aerodynamic effects of open windows and mechanical ventilation units on large vehicles. Predominantly it considers a MAN city bus, and the aerodynamic effects resulting (including Helmholtz Resonance excitation) from window openings and presence of air conditioning units. Analysis was conducted using both wind tunnel testing and Computational Fluid Dynamics modelling. The results of both analyses, CFD and Wind tunnel, show an increase in drag of up to 2% for single openings, and up to 5% for multiple openings. The analysis also revealed for Strouhal numbers between 0.27 and 0.4 the Helmholtz resonance present was significantly large enough to represent an increased breathing mode. Analysis of air conditioned buses shows an increase in drag of up to 3% (for standard positions on the roof), similar to the increase in drag expected of multiple openings, but a decrease in drag of up to 12% when the unit is shifted forward.

KEYWORDS: Bus aerodynamics, Window openings, CFD, Drag

1 INTRODUCTION

As the price of petrol increases, the demands on public transport will increase. Good business sense shows that to improve the profitability of a transport business, one must maximize the capacity while maximizing the fuel economy. Buses and heavy transport are largely restricted by a need to maximize cargo capacity; the aerodynamics of such vehicles becomes a secondary feature [1]. Previous work at the University of Auckland [2, 3] has investigated methods of reducing drag by changing the external shape of the bus. The results of these investigations were quantified using wind tunnel testing, and CFD analysis was used primarily to visualize flow patterns. As air-conditioning units count for a small amount of the fuel usage in their running alone, this project looks to assess the aerodynamic effects of using natural ventilation compared to air-conditioned ventilation. The results of this study are quantified by CFD analysis and wind tunnel testing, with CFD also providing flow visualization.

2 METHODOLOGY

This study compares the drag of three variants of the MAN city bus (see Figure 1): (1) a bus with a roof-mounted air conditioning unit; (2) a bus with open windows; and (3) a control bus with no windows or air conditioning. Three variants of the air conditioned bus were tested, with the air conditioning unit in two standard places (over the front and rear wheels), and at the leading edge. Eight standard variants of the windowed bus as shown in Figure 2 were individually analysed for drag and lift, as well as internal pressure variation in the bus cavity due to the excitation of the Helmholtz resonance.

Figure 1. MAN Buses with narrow openeable windows

2.1 *Experimental Methodology*

Experiments were conducted in the University of Auckland de-bray wind tunnel. A 1/20th scale model of the MAN 10.160 series bus was specifically developed, taking care to ensure the internal cavity representation, opening (window) and bus dimensions were preserved. For wind tunnel testing of blunt bodies, accepted practices adopted included neglecting moving wheels and ground in the raw results, with actual results including correction factors. A false ground was erected in the tunnel (see Figure 3) to model the flow over the ground expected in a real life situation, and to minimize the wall/ground boundary layer effects present at the bottom surface of the wind tunnel. A three component force balance was used to measure the lift and drag forces, while a Setra differential pressure transducer was mounted inside the vehicle cavity for measuring internal pressure. The main errors factored into analysis were blockage error and drag on the struts [4]. Blockage of the scale model was 3.5%, and appropriate corrections were made to the data.

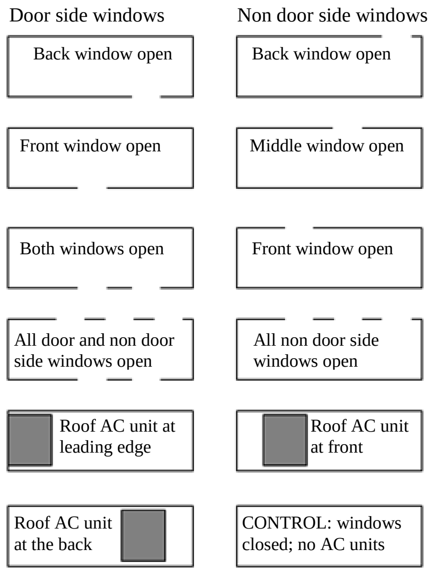

Figure 2. Window openings and AC unit locations

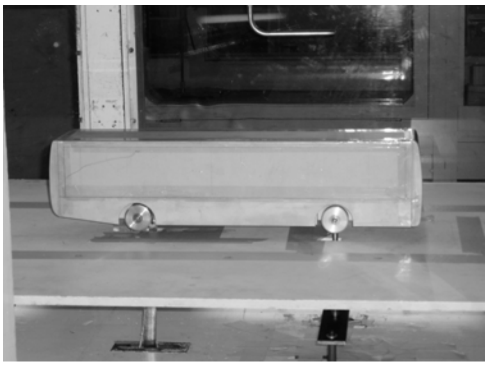

Figure 3. Bus model in the wind tunnel

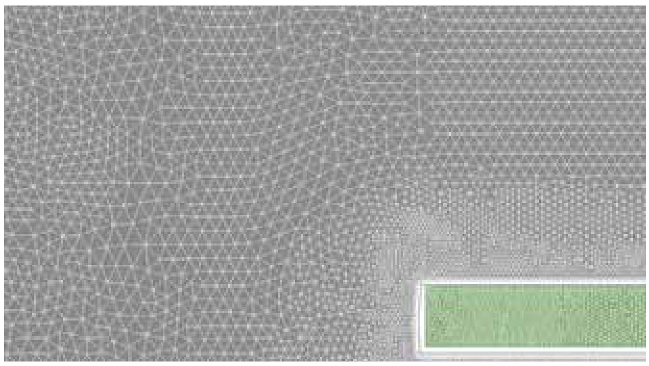

Figure 4. CFD Mesh around the bus

2.2 *CFD Methodology*

Analysis of the flow over the bus was conducted in Ansys Workbench / CFX 5.7.1. The dimensions of the computational domain were determined through standard practices for blunt bodies, including extending the domain length ten model heights to the rear [5, 6] and five model heights to the front, and at least ten model heights vertically. The domain was enlarged to five obstruction heights by five obstruction widths, to allow for flow disturbance [7, 8]. CFX employs an unstructured 3-D mesh, with user defined mesh settings. For bus simulations, standard near surface mesh resolution was attained, in particular around the body edges and openings (see Figure 4). A 50km/hr wind speed was used, and the K-Epsilon turbulence model was employed due to its ability to accurately predict near-wall flows. Each simulation was converged to the target RMS residual of 1.0×10^{-5}, considered appropriate for engineering applications. Simulations were used for flow visualization, for example as shown in Figure 5, however upon investigation quantifiable results were also obtained.

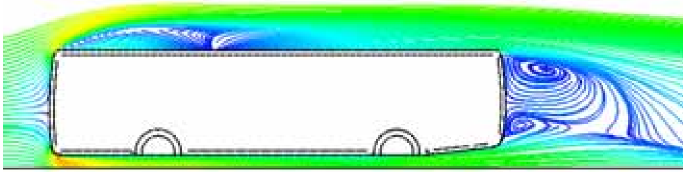

Figure 5. Streamlines from CFD for a standard bus

3 RESULTS AND DISCUSSION

Table 1. Drag coefficients from CFD and wind tunnel testing for buses with open windows

below shows drag coefficients from CFD and wind tunnel testing of windowed buses. As can be seen, the CFD data and the wind tunnel testing results demonstrate good agreement, showing trends of an increase in drag with opening of windows in the bus. This amount of drag can be low enough (measured to be 1-2%) with only one open window to be insignificant. However when multiple windows are open this increases the drag significantly by up to 4%. The differences between CFD and wind tunnel test results is consistent across the simulations, and is attributed to the K-epsilon model and scale errors.

Table 1. Drag coefficients from CFD and wind tunnel testing for buses with open windows

	CFD	**% Diff#**	**Wind Tunnel**	**% Diff#**
Control Bus	0.837		0.866	
Front non-door side window open	0.844	0.8	0.874	1.0
Back non-door side window open	0.839	0.2	0.856	-1.1
Middle non-door side window open	0.843	0.7	0.872	0.7
Front door side window open	0.842	0.6	0.875	1.1
Back door side window open	0.843	0.7	0.884	2.1
All non-door side windows open	0.861	2.8	0.878	1.5
All door side windows open	0.842	0.5	0.865	-0.1
All windows open	0.865	3.3	0.896	3.4

Note: # %Diff = 100 x (C_D - $C_{D(\text{control})}$)/ $C_{D(\text{control})}$

Table 2 shows drag coefficients from CFD and wind tunnel testing of air conditioned buses. Once again CFD analysis and wind tunnel testing are in good agreement, which shows when considering an air-conditioning unit the placement has to be taken into account. The same trends were revealed in both the CFD and wind tunnel testing that shifting the air-conditioning unit forward into the area usually occupied by the separation bubble reduces the drag experienced by the body. This is quantified to be 4-12% depending on the location, with the greatest benefit with a air conditioning unit located at the leading edge. As expected, the drag increases on the bus if the air-conditioning unit is placed at the rear, by 2.3%. This is in the same range as that of a multiple window bus, but is a significant increase compared to a single open window.

Table 2. Drag coefficients from CFD and wind tunnel testing for buses with air conditioning units

	CFD	**% Diff C_D**	**% Diff F_D**	**Wind Tunnel**	**% Diff C_D**	**% Diff F_D**
Control Bus	0.837			0.866		
Front AC-Unit	0.744	-11.2	-4.1	0.730	-14.5	-7.5
Leading Edge AC-Unit	0.682	-18.6	-12.1	0.699	-18.1	-11.3
Back AC-Unit	0.793	-5.3	2.3	0.808	-5.2	2.3

A sample of the type of internal pressure fluctuations obtained with an open widow is shown in Figure 6 that demonstrates the presence of intense fluctuations believed to be due to Helmholtz resonance. Since the resonance frequency is changing, it is clear that grazing flow excitation is involved. This may be beneficial from the point of view of natural ventilation, which should be investigated further.

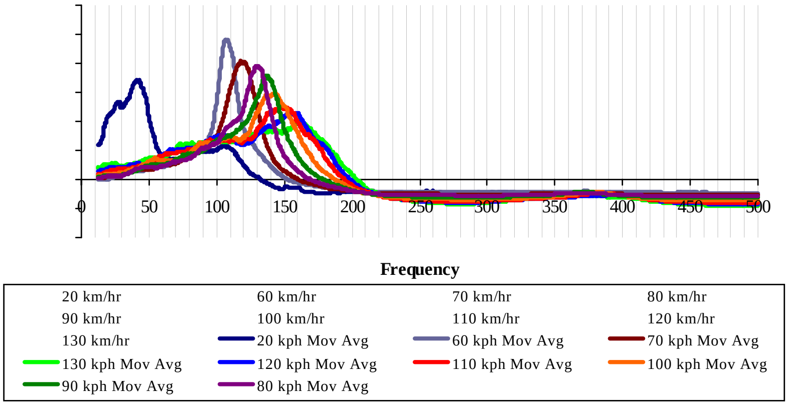

Figure 6. Internal pressure spectra for non door side back open window

4 CONCLUSIONS

From the testing performed on buses with open windows, the following conclusions are made:

- Wind tunnel and CFD analysis agree, showing a trend of increase in the drag coefficient, with the number of open windows. With a single window opening a 2% increase was obtained while multiple openings produced increases of up to 4%.
- Spectral analysis shows that large fluctuations in internal pressure result from grazing flow excitation of Helmholtz resonance.

From the testing performed on Air-conditioned buses, the following conclusions were made:

- In the standard position at the back, the air-conditioning unit increases drag force by 2%.
- Shifting the air-conditioning unit to the front of the bus reduces drag by over 11%.

5 REFERENCES

1. Cooper, K.R. (2004) Commercial Vehicle Aerodynamic Drag Reduction: Historical Perspective as a Guide, *The Aerodynamics of Heavy Vehicles: Trucks, Buses, and Trains.* National Research Council of Canada, Ottawa, Canada.
2. Lee, C.J., and Oram, W. (2003) Aerodynamic Drag Reduction of Buses. Department of Mechanical Engineering, Auckland, New Zealand.
3. Haines, J.G., and Chadwick, D. (2004) Aerodynamic Drag Reduction of Intercity Buses. Department of Mechanical Engineering, Auckland, New Zealand.
4. Filippone, A. (2003) *Advanced Topics in Aerodynamics,* [online] Available from: http://www.aerodyn.org last viewed on 14th July 2005.
5. Cooper, K., Gerhardt, H.J., Whitbread, R., Garry, K.P., and Carr, G.W. (1986) A Comparison of Aerodynamic Drag Measurements on Model Trucks in Closed-Jet and Open-Jet Wind Tunnels. *Journal of Wind Engineering and Industrial Aerodynamics*, **22**, 299-316.
6. Ortega, J.M., Dunn, T., McCallen, R., and Salari, K. (2004) Computational Simulation of a Heavy Vehicle Trailer Wake, *The Aerodynamics of Heavy Vehicles: Trucks, Buses, and Trains.* Lawrence Livermore National Library.
7. Hinterberger, C., García-Villalba, M., and Rodi, W (2004) Large Eddy Simulation of Flow Around the Ahmed Body, *The Aerodynamics of Heavy Vehicles: Trucks, Buses, and Trains.* Institute for Hydrodynamics, University of Karlsruhe, Germany.
8. Bayraktar, I., Bayraktar, T., and Baysal, O. (2004) Computational Parametric Study on External Aerodynamics of Heavy Trucks, *The Aerodynamics of Heavy Vehicles: Trucks, Buses, and Trains.* Old Dominion University, Norfolk, VA 23529.