

Contribution of Add-On Components to the Aerodynamic Drag of a Cab-Over Truck-Trailer Combination Vehicle

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ABSTRACT

Results from a wind tunnel testing program of a cab-over truck-trailer combination vehicle are presented. The model is scaled at 1:3, and represents an accurate replica of currently available trucks and trailers in Australia. Cooling intakes have not been modelled. Reynolds number independence is established to the maximum obtainable in the wind tunnel test configuration adopted equating to a full-scale forward speed of 57 km/h. The wind tunnel is a $\frac{3}{4}$ open jet facility with a nozzle area of 10.9m². The vehicle is mounted on a turntable to a 6 component force balance. A range of vehicle add-on devices are investigated, including boat-tails, side skirts, cab extenders, air-dams and roof fairings. Drag measurements are presented over a yaw angle range of 10 degrees. The results are compared to previous experiments in the literature and demonstrate that significant aerodynamic drag and fuel efficiency improvements remain easily obtainable by the industry by applying basic aerodynamic principles. The mechanisms by which base pressure is influenced by the various add on devices is discussed.

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INTRODUCTION

Since the Oil crises of the 1970s Aerodynamic drag reduction has been seen as an important field of research in order to reduce fuel costs associated with the freight industry. More recently the push for more fuel efficient heavy vehicles has been driven by a need to reduce emissions in addition to the economic factor of increasing fuel prices.

Early development work such as front edge rounding, cab extenders, tractor-trailer gap seals, trailer side skirts and boat-tails have been reviewed by Cooper [1]. The paper also presented reasons why some of these technologies have still not gained wide acceptance throughout the industry. Boat-tails in particular have received a lot of research attention: In a computational study Han et.al. [2] applied an optimization algorithm to minimize drag by varying the angles of the top, bottom and side boat-tails independently. Burton et.al. [3] found that the drag reduction for boat-tails with attached flow is proportional only to their rear projected area and is independent of the boat-tail angle. In recent times the research focus has shifted towards active flow control, part of the reason for this is that active flow control actuators can be made more compact than traditional geometric modifications.

This would allow a drag reduction with no negative effects on aesthetics, usability or cargo capacity. Methods such as tangential blowing [4], suction and oscillatory blowing [5] and rotating cylinders [6] have been investigated, mostly aimed at controlling the separated wake flow in order to increase base pressure.

The majority of experimental work on both passive and active flow control has been done on small scale, simplified geometries, often at Reynolds numbers far below those encountered by trucks on road [7,8,9]. Notable exceptions to this include the work at the NRC [10] which tested out various commercially available add-ons on a full scale bonneted truck and [11] which tested boat-tails on a full scale truck in the NASA AMES 80 × 120 Foot Wind Tunnel. There are very few facilities where this sort of testing is possible. As an alternative the open jet, automotive test section of the Monash University 1.4MW wind tunnel has been upgraded to accommodate 1:3 scale heavy vehicle models [12]. In this configuration width based Reynolds numbers of up to 2.4×10^6 are achievable, corresponding to a full scale velocity of 57km/h at a blockage ratio of 10.6%. This allows the facility to be used for validation of passive and active devices

on both simplified reference geometries such as the Ground Transportation System GTS [13,14] and on detailed models of road going trucks and trailers. It is not valid to assume that a particular design feature, such as side skirts or boat-tails has a specific drag increment as is often reported in the literature. The benefit is dependent on the detail of the design. It is demonstrated that an aerodynamic design optimization approach, similar to that undertaken in passenger car aerodynamics design can create significant benefits.

In Australia, length restrictions are generally based on total truck and trailer length. As a result there is a tendency for long haul vehicles to be cab over in design so as to maximize the trailer length, and therefore trailer volume. This paper attempts to replicate a generic detailed model of a cab-over truck and trailer for the purpose of identifying the level of savings available to the transport industry within Australia through aerodynamic optimization. Nonetheless, the results will be more widely applicable.

For this investigation a 1:3 scale model of a typical Australian Cab over Engine truck has been produced. This has been mated to a detailed model of a solid box trailer. Presented below are the results of a systematic development of the tractor-trailer model through the use of a range of passive aerodynamic devices.



Figure 1. 1:3 scale model in the modified open jet test section.

MODEL

The model tested in this work is a 1:3 scale detailed Cab over Engine truck-trailer combination can be seen in [figure 1](#). The model width is 0.83m, which is used as the reference length for calculating the Reynolds number. The other dimensions are height = 1.4m, length = 6.0m, tractor-trailer gap = 0.68m, ground clearance at the front of the truck = 0.083m ([figure 2](#)). For reasons of cost and simplicity no attempt has been made to account for engine bay flow, so the front radiator grille has been blocked off and the underside of the cabin is solid and flat. Details such as mirrors, sun visors, handrails, engine intake and exhaust and bull-bars have been

neglected. The trailer was fabricated using a steel sub frame, clad with aluminium sheet. This connected to the underfloor force balance via 4 support posts, 2 running down through the centre of the front wheel bogey and 2 through the rear wheel bogey. The cab consists of a steel sub frame with body panels machined out of ureal. The roof panel is interchangeable so the model can be tested with a flat roof, raised sleeper cab configuration or with the sleeper cab and an additional roof fairing. The truck is mounted cantilevered off the front of the trailer. This requires care to be taken so that the front wheels are kept from contacting the wind tunnel floor.

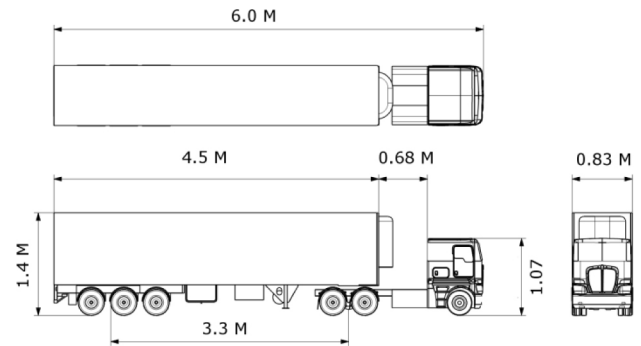


Figure 2. Model dimensions.

TESTING PROGRAM

Tests were undertaken in the Monash University 1.4MW wind tunnel, which is commonly used for full scale automotive and wind engineering projects. The tunnel is of closed return type, with a $\frac{3}{4}$ open jet test section which has been modified for testing of large models. The main modifications to the tunnel include raising the height of the jet exit, introducing a straight section between the final contraction and the jet exit and building a false floor to minimise boundary layer effects on the model.

The SAE Wind Tunnel Test Procedure for Trucks and Busses (SAE J1252) [15] sets out recommendations for wind tunnel set-up in terms of blockage ratio and boundary layer development amongst other things. The empty test section boundary layer displacement thickness at the front of the model was $\delta^* = 12\text{mm}$, which is 14% of the ground clearance of the model, as compared to the conservative value of 10% referred to in [15].

The blockage ratio for this series of tests is 10.6% at zero degrees yaw. The blockage correction method adopted is outlined in reference [16] and [17], which resulted in a total CD correction of less than 15%. SAE J1252 sets a maximum drag coefficient correction of 30% for open jet wind tunnels. The maximum yaw angle tested at was 10 degrees, at which the blockage was $\approx 24\%$. As the blockage ratio was high at yaw, a complete yaw sweep was not undertaken and wind averaged drag results are not presented although drag measurements at yaw can be found in the [Appendix](#). The

details of the test section modifications and the results of the validation experiments can be found in [12].

The model was mounted to four 3 component Kistler force balances via supports coming down through the trailer wheels with the cabin cantilevered off the front of the trailer. From this, the 3 force components: drag, lift, side force and 3 moment components: pitch, yaw and roll could be calculated.

Force and moment coefficients were measured over a width based Reynolds number range from $Re = 2.7 \times 10^5$ to 2.4×10^6 and at yaw angles of 0, 2.5, 5, 7.5, 10, -5 and -10 degrees. The majority of tests were conducted at a Reynolds number of $Re = 2.1 \times 10^6$ which corresponds to a full scale speed of 50km/h.

The different configurations tested were:

- Sharp vs. Rounded leading edges on the front face of the trailer
- Trailer mounted refrigeration unit
- Sleeper cab
- Fairing cab
- Cabin gap extenders of varying length
- Front air dams of various heights
- Trailer side skirts of various heights
- Boat-tails
- Rear wheel covers
- Removing rear under run plate

RESULTS

The baseline model included a flat roof, refrigeration unit and rounded trailer. In this configuration the blockage correction was $\Delta C_D = +0.044$ as per the methodology developed from [16,17] with around half of this correction being due to a positive static pressure gradient over the length of the model. The repeatability of the drag measurements was assessed as a coefficient of variation $C_v = 0.36\%$ which is equal to the standard deviation divided by the mean of six repeated measurements.

Reynolds Number Sensitivity

A Reynolds number sweep was performed with the model in baseline configuration with the refrigeration unit and rounded trailer leading edges. The results in figure 3 show drag variation with Reynolds number, normalized by the drag value at the lowest test speed: $Re = 2.7 \times 10^5$. The curve for the detailed model shows a steep reduction in drag below $Re = 1.2 \times 10^6$ and a slower increase for higher Reynolds numbers. Although Reynolds number independence is not achieved at the maximum speed achieved, the drag gradient is relatively small and stable, rendering it unlikely that Reynolds number effects will significantly alter the

performance of aerodynamic add-on devices. Also displayed is the Reynolds number sensitivity of a 1:3 scale GTS model tested previously, which shows a steep change in drag coefficient over the lower part of the Reynolds number range, but achieves independence at around $Re = 1.0 \times 10^6$. It is noted however that the GTS has a significantly lower drag coefficient than the detailed model, leading to a greater change in C_D/C_{D0} .

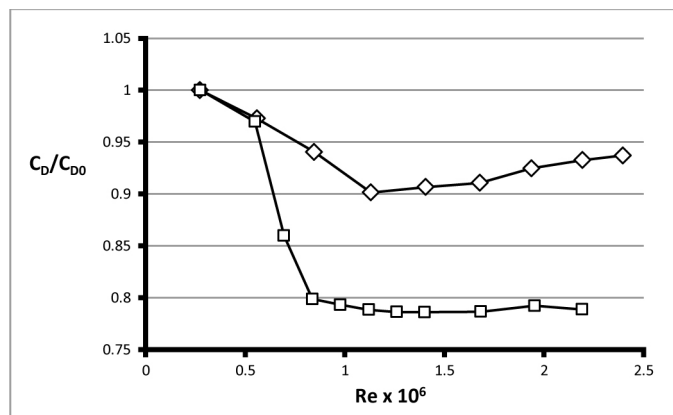


Figure 3. Drag coefficient vs. Reynolds number at 0 degrees yaw: $\diamond$ Detailed model, $\square$ GTS.

Add-On Component Testing

The changes in drag coefficient resulting from the various add-on components tested are presented in table 1. While in many cases the drag reduction of individual component changes will depend on the order in which they are applied, components were added in the order that the authors believe they are likely to be taken up by industry. In general this involved adding components from the front of the truck then progressing towards the rear of the trailer. After conducting a parameter sweep on a single component either the best performing or most practically applicable component was left on the model for the remainder of testing as detailed below.

A large reduction in drag coefficient $\Delta C_D = -0.165$ came from rounding the leading edges of the trailer. The rounded trailer leading edge consisted of an add-on 45 degree plate with small radius folds as depicted in Figure 4b. While most trailers in commercial usage utilize some form of rounding in this region, there are still applications such as flatbed trucks carrying shipping containers where large drag reductions can be easily achieved. All subsequent testing was conducted with the rounded trailer leading edges installed.