

Aerodynamic Drag Reduction on a Simple Car-Like Shape with Rear Upper Body Taper

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ABSTRACT

Various techniques to reduce the aerodynamic drag of bluff bodies through the mechanism of base pressure recovery have been investigated. These include, for example, boat-tailing, base cavities and base bleed. In this study a simple body representing a car shape is modified to include tapering of the rear upper body on both roof and sides. The effects of taper angle and taper length on drag and lift characteristics are investigated. It is shown that a significant drag reduction can be obtained with moderate taper angles. An unexpected feature is a drag rise at a particular taper length. Pressure data obtained on the rear surfaces and some wake flow visualisation using PIV are presented.

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INTRODUCTION

Aerodynamic drag of a typical passenger car arises from a near equal split between the styled upper surfaces and the remaining less visual components comprising; cooling airflow, underbody, wheels and wheelarches. On the upper surfaces the major drag component occurs at the rear of the car, Howell, [1], and as this can exceed half the drag of the styled surfaces, dominates the front end drag, skin friction and protuberances such as mirrors. This can constitute over 25% of the overall aerodynamic drag and it results from the suction which occurs on the rearward facing surfaces, especially those in the separated flow regions at the base of the car. Similarly, from the 'unstyled' components, the wheels and wheelarches contribute up to one third of the overall aerodynamic drag, Pfadenhauer et al., [2], while the contribution from the underfloor is in the range of 10-15% approximately. While overall drag reduction is achieved by accumulating many small incremental benefits from all surfaces and components on the car, any major future impact on aerodynamic drag reduction will come from investigating these significant contributors.

Improving the rear end drag must primarily concentrate on increasing the pressure on the base and comes under the general heading of 'base pressure recovery'. The main routes for achieving this are rear body tapering (boat-tailing), base cavities, and base flow injection. A significant amount of

research has been conducted on the effect of the base region on drag reduction for axisymmetric bodies at high Mach numbers relevant to missile aerodynamics, as reviewed comprehensively by Viswanath, [3], but only a few studies have been at the low subsonic Mach numbers relevant for automobiles. Drag reduction from base cavities was recently investigated by Howell et al., [4], using a modified Ahmed body. This followed the early study by Morel, [5], with a small scale axisymmetric body and showed that ventilating the cavity allowed the cavity depth to be reduced. Very few experiments on base flow injection, applicable to road vehicle type bodies, have been reported. Exceptions are the work of Englar, [6], with high velocity Coanda type jets, and Sykes, [7] and Howell et al., [8] using low velocity bleed flow. Interestingly, the latter study showed that a significant part of the drag reduction achieved came from the cavity.

The significant potential for drag reduction from boat-tailing of simple elongated bodies in freestream has been investigated by Mair, [9], for axisymmetric bodies and Wong and Mair, [10], for a body of square cross section. Simple rectangular bodies in ground proximity with truncated tapered rear bodies representing truck and bus shapes have been studied by Gilhaus, [11], and Götz, [12], respectively. Significant drag reduction has been demonstrated on trucks with the use of angled base boards to provide a combination of cavity with boat-tailing effects, as exemplified by Cooper,

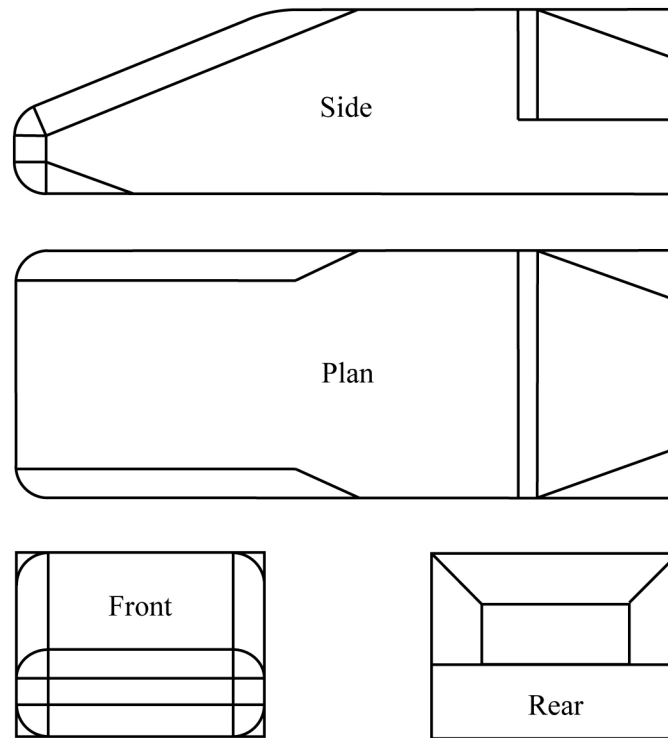


Figure 1. Windsor Body with Upper Rear Body Tapering.

[13], and Browand et al., [14]. Boat-tailing effects can be seen in saloon and fastback car shapes, although the top surface tapering for these vehicles tends to be excessive. It has also been exploited on 1- and 2-box shapes through the combined effects of roof and bodyside curvature, although design and packaging constraints have limited these benefits. In this paper the effects of tapering, (boat-tailing), the upper rear body of a simple car-like shape are investigated.

EXPERIMENTAL STUDY

Model

The simple bluff Windsor Body model used in these tests is shown in [Figure 1](#). The model details have been well documented previously; see for example Howell and Le Good, [15]. The model is 1.044m long, 0.39m wide and 0.29m high, and the overall dimensions represent an approximately quarter scale small hatchback car. The model has a removeable upper rear body section which allows shape variation in this region. For the study reported here the interchangeable body sections were tapered on the roof and upper body sides. The length, L , and angle, ϕ , of the taper were varied, but for any given section, the taper angles were the same on both top and sides. The ground clearance was set at 0.040 m. The model was mounted to an underfloor 6-component balance via four thin supports of 0.008m diameter, which protruded the wind tunnel floor. No adjustment was made for the strut tare drag. The distance between the legs was 0.668 m, symmetrically placed, which represents the 'wheelbase'. Force coefficients are based on

frontal area, while moment coefficients are based on frontal area and the 'wheelbase'. The moment centre is located at mid wheelbase on the ground surface.

The taper lengths investigated were 0.075, 0.125, 0.175 and 0.225m, and the taper angles varied from 5° to 25° in 5° steps. The maximum depth of the upper rear body tapered section was 161mm, representing 56% of the overall depth of the body. The longest taper length, $L=0.225$ m, allowed comparison with previous experiments where only the roof taper (backlight) angle was varied and the roof slope length was 0.220m. The initial tests were conducted with a sharp intersection between the tapered rear surfaces and the bodyside and roof, and these were followed by introducing a radiused intersection, except for the 5° tapered rear ends. Some additional rear sections were made, where only the roof was tapered, with a taper angle of 15° and the taper length was varied approximately as above. The data is compared with a baseline configuration; the squareback model with no roof or bodyside taper.

Wind Tunnel

The aerodynamic data for the Windsor model were obtained using the Loughborough University low speed wind tunnel. This wind tunnel is a closed jet facility with a working section 1.9m wide by 1.3m high; (Area 2.5 m²). The wind tunnel is described by Johl et al., [16]. It has a maximum airspeed of 45m/s and the turbulence intensity at the model location is 0.2%. The data was obtained at a nominal airspeed of 40m/s, which gives a Reynolds No. of 2.8×10^6 based on

model length. The boundary layer displacement thickness is approximately 0.007m at the centre of the balance, with no model present. Blockage corrections, using the standard MIRA continuity-based correction procedure, as detailed in [17], have been applied to the force, moment and pressure coefficients.

Pressure measurements were taken on the tapered rear surfaces and on the vertical base for the body with a 15° taper angle and taper lengths of 0.125 and 0.225m. For comparison, pressure data was obtained for the basic body with a 15° roof slant (backlight) and no bodyside taper, on the roof slant and vertical base, and base pressure data was also taken on the squareback model. The pressure data is corrected for blockage using the standard MIRA correction procedure. PIV measurements were obtained in a transverse frame immediately aft of the model base for a limited range of configurations.



Figure 2. Tapered Windsor Body in the Loughborough University Wind Tunnel

RESULTS

The initial tests were conducted with a limited range of taper angles from 15° to 25°. This was because the data from trucks, [13, 14], suggested the optimum angle was approximately 16° and simple body tests, [9, 10], gave an optimum taper angle of 20°–22°. The data subsequently showed that this range did not capture an optimum taper angle and additional rear body sections were made with a taper angle of 10°, followed considerably later by a further set with a 5° taper angle; both with a range of taper lengths as in the initial experiment. The effect of taper length on the reduction in drag coefficient is shown in Figure 3 for the range of taper angles.

The data is plotted in Figure 3 as a change from the reference squareback configuration. For the squareback configuration the basic aerodynamic coefficients for drag and lift are: $C_D = 0.290$, $C_{LF} = -0.087$ and $C_{LR} = 0.038$. The

open symbols with dotted lines represent the rear bodies with a sharp intersection at the leading edge of the tapered surfaces, while the solid symbols and lines represent bodies with this intersection rounded. For the 5° taper case only the sharp edged intersection was tested. Figure 3(a) shows the extremely high drag coefficient that can be obtained for the 25° taper case at certain taper lengths, while Figure 3(b) shows the drag benefits from the smaller taper angles. For these bodies the radiused and sharp intersections give very similar results. An unexpected result for the trend in drag reduction was the local peak which occurred at a model taper length of 125 mm for all taper angles. The limited published data for the effect of roof taper length on car shapes, Buchheim et al., [18], and the effect of base board length on trucks, [13], has not identified this feature although in the case of the truck data the range of taper lengths was considerably shorter than the range tested here.

The effect of taper length and angle on the lift coefficient is shown in Figure 4. Data is presented as incremental to the squareback configuration. In general, lift increases with taper angle. For taper angles 10° to 20°, lift increases to a steady value for taper lengths greater than 125mm. This approximately coincides with the taper length for the local drag peak. For the 25° taper case the maximum lift occurs at the same taper length as the drag peak, 125mm, and then falls. The intersection condition at the taper leading edge, radiused or sharp, has only a small effect on the lift coefficient in all cases except the largest taper angle.

Almost all the lift is generated at the rear axle. The front axle lift is always negative, while the rear axle lift is always positive for this model and the range of configurations tested. The total variation of front axle lift coefficients is in the range $C_{LF} = -0.05$ to -0.11 , while the rear axle lift coefficients vary from $C_{LR} = 0.03$ to 0.50 . Relative to the squareback configuration the front axle lift initially reduces with the shortest taper length of 0.075m and then increases with increasing taper length.

The general trend is for front lift to increase with taper angle. Rear axle lift follows the trend of total lift and in general increases with taper length and angle. The influence of taper on the drag and lift characteristics at yaw are not particularly marked. The drag rise with yaw reduces as taper length increases but the lift curve is similar for all taper lengths.

The lateral aerodynamic characteristics are influenced by taper. Side force and rolling moment at yaw reduce with taper length, and also reduces with taper angle, while yawing moment at yaw increases with increasing taper length and taper angle. The result is summarised in Figure 5 which shows the lateral aerodynamic data obtained at 15° yaw angle. The data is presented as the increase from that obtained on the squareback model and the yaw data is the mean of the measurements at $\pm 15^\circ$ yaw angles.