

The Aerodynamics of a Small Car Overtaking a Truck

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ABSTRACT

The influence of a large truck on the aerodynamics of a small passenger car in an overtaking manoeuvre on the motorway was considered, many years ago, during the 1970's, to be a potential problem for the vehicle aerodynamicist. The concern never became significant as vehicle architecture evolved and car weights increased. The current drive for improved fuel economy is advocating that a considerable reduction in vehicle mass is desirable and therefore it may be time to readdress the significance of the truck passing manoeuvre. A quasi-steady experiment has been undertaken at small model scale to examine the aerodynamic characteristics of a small car in proximity to a large truck. Measurements at yaw were included to crudely simulate the effects of a crosswind. The wind tunnel data is presented and the limitations of the experimental procedure are discussed. An estimate of the increased aerodynamic input on a car in a real world overtaking manoeuvre with relative velocity between the two vehicles is introduced. The data is compared with the steady state yaw characteristics of the car alone to relate truck passing with the general concern of crosswind sensitivity. Under the same crosswind conditions the truck passing manoeuvre is shown to be a more extreme, but rarer event.

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INTRODUCTION

The primary role of the passenger car aerodynamicist is to ensure competitive aerodynamic drag, while maintaining adequate high speed stability. Significant improvement in fuel economy is required to meet increasingly strict CO₂ emissions targets. While the major input will come from powertrain both aerodynamic drag and weight reduction must contribute to that process and the trends in both parameters are expected to accelerate. If significant weight reduction can be achieved this has implications for aerodynamic development as the task of ensuring adequate aerodynamic stability becomes more complex.

A major aspect of aerodynamic stability is the response to crosswinds, but an associated driving experience concerns the response of a passenger car while passing, or being passed by, a larger vehicle such as a truck, or bus, on the motorway. An investigation of this event forms the basis of this paper. The issue has received little attention in recent years, because trends in vehicle design such as front wheel drive and increasing vehicle mass have mitigated the aerodynamic inputs. Reversal of the vehicle mass trend will increase the susceptibility of passenger cars to concerns of aerodynamic stability. Adoption of different and novel vehicle layouts such as rear engine configurations will exacerbate these concerns.

In the past, when cars were considerably lighter than they are today, a truck passing event was considered to be a potential aerodynamic problem. Larrabee, [1], conducted a brief study following rumours that truck drivers were concerned by the effect they had on certain small cars. Goetz carried out wind tunnel tests to assess the aerodynamic characteristics of one vehicle in the presence of another of similar size, [2], and also a much larger one, which was unpublished. He also conducted similar tests on a car-caravan combination overtaking a bus, [3]. Howell, [4], investigated the aerodynamics of a car in proximity to a truck using small scale models. The effects of car shape and the lateral spacing between truck and car were investigated at zero yaw. The highest side force coefficients were obtained on the estate car configuration, but yawing moment coefficients were comparable for the different car configurations. The truck length was also varied and showed that the significant inputs to the car at truck nose and tail could be represented with a short truck body. Heffley, [5], and others conducted similar steady state experiments at this time.

A more ambitious dynamic experiment was undertaken by Brown and Seeman, [6], using models catapulted along parallel tracks and passing a crosswind generator. Spacing between vehicles and relative velocities, including vehicles passing in opposite directions could be represented. The shape of the

disturbing vehicle and the lateral spacing were found to be important parameters. Side force coefficients appeared to correlate well when based on the velocity of the disturbing vehicle, regardless of the speed of the smaller disturbed vehicle. Peak side force coefficients were nearly identical even when the vehicles were passing in opposite directions.

Telionis et al, [7], also conducted a dynamic small scale experiment of a car passing a truck using a towing tank. Side force and yawing moment coefficients were not significantly affected by a relative velocity between car and truck. Hucho, [8], reports on a study by H. Engelhard, who carried out steady state wind tunnel experiments on different car shapes and found that the rear end shape of the car had little significance.

Yamamoto et al, [9], conducted various experiments on the effect of a bus passing a car, with steady state and dynamic wind tunnel tests and a full scale on-road study. A 1-box shape showed higher side forces than 2- or 3-box shapes, which were comparable, but yawing moments were similar for all car shapes. It was concluded from the different experiments that for small relative overtaking speeds the static tests were adequate. From the dynamic model scale tests for a bus overtaking a car, it was found that at higher relative speeds the peak side force and yawing moment coefficients increased as the bus overtaking speed increased, when the coefficients were based on the speed of the overtaken car. The situation representing a car overtaking a bus was not investigated.

Széchényi, [10], has conducted a thorough review of the overtaking process. A rail system was installed in the St. Cyr S4 and S10 full scale wind tunnels to assess dynamic overtaking manoeuvres using 1/5th scale models of Ahmed bodies. The rail system was able to yaw. Using this system, Gillieron and Noger, [11] investigated the effects of two Ahmed bodies, with 30° backlight angles, passing. The overtaken vehicle experienced a large increase in the side force coefficient as the passing speed increased, with the coefficient based on the speed of the overtaken vehicle. Noger and Széchényi, [12] used a similar set up with two squareback Ahmed bodies to investigate the effects of overtaking speed, yaw angles and lateral spacing. For the overtaken vehicle, lateral aerodynamic coefficients were found to be effectively independent of relative passing speed when the coefficients were based on the speed of the overtaking model and the interference phenomenon can be considered quasi steady. In the case of the overtaking vehicle, with coefficients based on the speed of the overtaken model, a significant attenuation in the loads was found as overtaking speed increased.

Schrefl et al, [13], undertook an on-road experiment to investigate aerodynamic loads on a saloon car passing a truck. The loads on the car were derived from pressure measurements, which were obtained for a range of truck and car speeds. It was found that if the coefficients were based on the truck speed that the side force and yawing moment coefficients

increased slightly as the overtaking speed increased. Lift measurements derived from suspension displacement showed a negligible variation during the passing event.

Van Grevenynghe and Noger, [14], demonstrated that a dynamic truck passing manoeuvre could be simulated for a passenger car in a full scale wind tunnel using a relatively small box to represent the truck, although the experiment was restricted to zero yaw.

EXPERIMENTAL STUDY

It was intended that the experiment would generate engineering level information on the aerodynamic loads to be experienced by a small car in proximity to a large vehicle. A steady state simulation of the overtaking manoeuvre was considered appropriate, based on the review of the literature summarized above. The effects of a speed differential between the two vehicles would be introduced as a scaling factor, using data derived from the on-road study by Schrefl, [13]. Presented data in the literature is almost entirely limited to drag, side force and yawing moment, and although these are the primary aerodynamic inputs, the data for lift and roll could be of interest.

Wind Tunnel

The wind tunnel used for this experiment was the Cranfield University Atmospheric Boundary Layer Wind Tunnel. The working section is 2.44m wide by 1.22m high and 14m long. The tunnel has a closed jet and an open return. It is situated in a large hangar and the outlet flow is turned through 90° to exhaust upwards into the hangar roof space. The tunnel is normally used for industrial aerodynamic applications and the maximum airspeed is only 20m/s, but the long working section was considered essential for this experiment.

The models were mounted to the wind tunnel floor at the upstream end of the working section to minimize the effects of the floor boundary layer, although the minimum distance of the truck leading edge aft of the working section entrance was one truck length. A separate ground board was not considered as it would have had a negligible effect on boundary layer thickness.

The truck model could be traversed along the working section via a pulley mounted cable system. It was constrained laterally by a pair of shallow rails. The rails could be fitted at an angle to the wind tunnel axis to facilitate yaw measurements and a range of lateral offsets between car and truck. The car model could be mounted at various lateral positions depending on the lateral spacing and the yaw condition.

Models

The overall dimensions for the two models, representing the truck and the car, are given in Table 1. The truck represents a 1/8th scale full size articulated vehicle. The truck model height of 0.6m simulates the 4.8m tall vehicles allowed on UK roads. The model was fitted with a clean front bumper and side skirts

as it was considered, based on limited anecdotal evidence, that these would tend to exacerbate the disturbing effects between the truck and the car.

Table 1. Model Dimensions

	Car	Truck
Length (m)	0.388	2.040
Width (m)	0.187	0.335
Height (m)	0.200	0.600
Frontal Area (m ²)	0.032	0.190

The car model represents a small one-box car as this is expected to be the most sensitive shape, with a relatively large side area; an expectation supported by the data from Yamamoto et al, [9]. Detail was kept to a minimum. The model had no cooling flow simulation as this has a small effect on the lateral aerodynamic characteristics. No door mirrors were fitted and the underfloor was simulated by roughness strips. A simple front spoiler was attached to the front bumper. A flat was added to the wheel surface adjacent to the ground. The car model was mounted to an underfloor 6-component balance, modified from a robotic arm sensor, by a single cylindrical strut at mid-wheelbase and on the model centreline. The clearance between 'tyre' and ground plane was 0.0015m.

Lane widths on roads can vary. The lateral offset between truck and car model was varied in steps to represent half a typical lane width, where the lane width was chosen to be 0.45m, (3.6m full scale). An additional lateral spacing was included to represent the car in very close proximity to the truck, with a gap between the vehicles of 0.040m, (0.32m full scale).

Experimental Procedure

The two models are shown installed in the wind tunnel in [Figure 1](#). The datum point is given by the front edge centreline of the truck and the relative positions of car and truck are defined by the front edge centreline of both models. A body axis system is used. For yaw measurements both truck and car model are yawed. A diagram defining the relative positions of the car and truck and the axis system employed for the aerodynamic data on the car is shown in [Figure 2](#).

The truck model was initially located 2.00m downstream of the car model. With the tunnel turned on and the airflow stabilized, the truck model was pulled along the rails using a stepper motor drive. The total travel distance for the truck model was 5.50m. The maximum air gap between the leading edge of the aft model and the trailing edge of the front model was 1.61m when the truck was behind the car, and 1.50m with the car behind the truck.

The car model alone in the wind tunnel has a solid blockage ratio of only 1.1%, while the truck model blockage ratio is 6.4%. The aerodynamic data measured on the car is subject to blockage effects. These are negligible when the car is upstream of the truck, but when the car is aft of the truck

leading edge it will experience an excess velocity because of the truck and the wake blockage. When the car model is in these positions a reduction in the aerodynamic loads of 10% has been applied to the data, although a continuity based blockage correction is 12%. The effect is reduced to zero over one car model length forward of the truck leading edge.



Figure 1. Truck and car model in the wind tunnel.

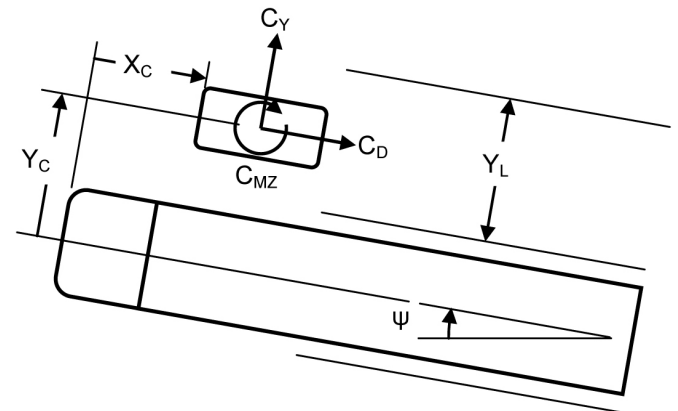


Figure 2. Relative positions for the truck and car models.

The truck and the car model can be yawed to simulate the effects of a crosswind. For the particular arrangement used in this experiment, when the yaw angle is +10° the truck is traversed along the windward side of the car, while at a yaw angle of -10° the car is on the windward side of the truck.

RESULTS

The variation in the principal aerodynamic characteristics of the car, as the truck is traversed along its track, are given in [Figures 3 and 4](#) for a range of lateral offsets, with both models at zero yaw. The length of the truck is indicated on each graph. X_C is the distance between the leading edge of the car and the leading edge of the truck and for $X_C > 16.3$ m the car is behind the truck. For the car overtaking the truck, the car can be considered as starting its manoeuvre at the right side of the graph and moving from right to left.

The dimensions for lateral offset and the distance aft of the truck nose are given as full scale values. The two lowest lateral spacings represent a car within the same lane occupied by the truck. The other offsets are for a car in adjacent lanes; at either lane centre or with the car centred on the lane divider, except for the car at $Y_c = 2.4\text{m}$, which represents a car passing extremely close to the truck, with a gap of only 0.32m. The data is presented in absolute terms.

The full range of aerodynamic data for yaw angles of 0° and $\pm 10^\circ$ is given in the [Appendix](#) to this paper. For all coefficients it can be seen that with the car in the most forward position it appears to be out of the influence of the truck as the variation in the coefficients with lateral offset in this forward position is small. The variation of the aerodynamic drag and lift coefficients of the car, with longitudinal position, is given in [Figures 3\(a\) and 3\(b\)](#), respectively. Significant drag changes are experienced with the car immediately behind, or in front of, the truck and when the car is near the nose of the truck. The highest drag, at a given lateral offset, occurs when the car is slightly more than half a car length forward of the truck. With the car positioned directly behind the truck it can experience very low drag and when very close the drag becomes a thrust.

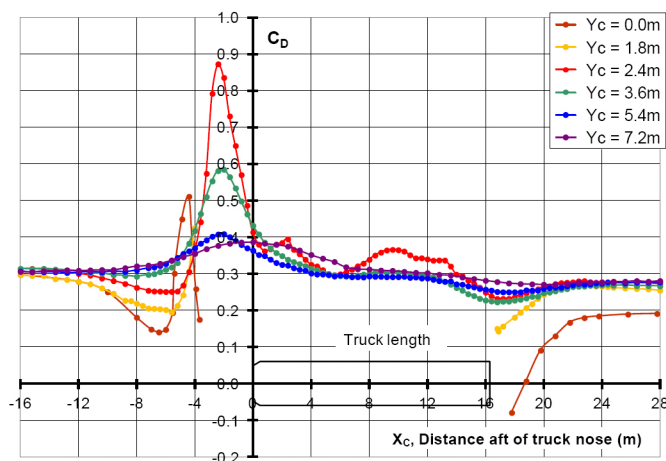


Figure 3(a). Variation of drag coefficient at zero yaw.

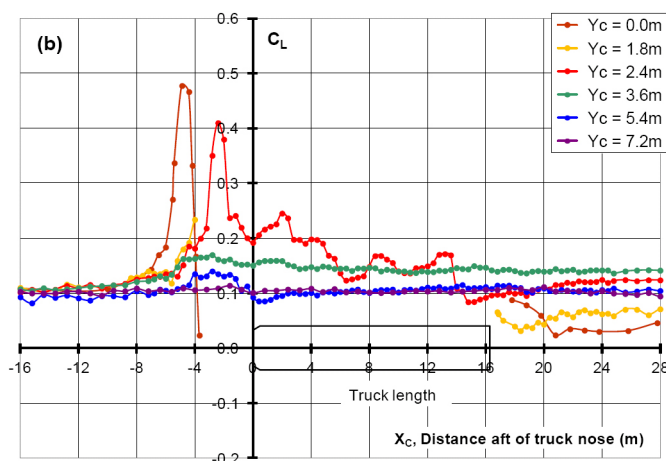


Figure 3(b). Variation of total lift coefficient at zero yaw.

The significant changes in lift only occur around the nose the truck and in general, lift variation is small. The rear axle lift loads, which are positive, peak near to the nose of the truck. At the front axle the loads are much lower, but of opposite sign. These combine to give a strong negative pitching moment at the nose of the truck.

The variation in the lateral aerodynamic characteristics of the car; side force, rolling and yawing moment, as the truck is traversed along its track, are given in [Figures 4\(a\), 4\(b\), 4\(c\)](#) for a range of lateral offsets, with both models at zero yaw. When the car is beside the truck the lateral loads show a distinct maximum when the car is just forward of the nose of the truck, and a less pronounced peak of opposite sign when the car is just aft of the rear of the truck. In both cases the magnitude increases as lateral spacing decreases. At the truck nose the forces and moments act away from the truck, while at the rear of the truck they act towards the truck. The maximum side force and rolling moment occur when the car is slightly more than half a car length forward of the truck, while the maximum yawing moment occurs when the car is slightly less than half a car length forward of the truck. Alongside the truck the variation in the lateral loads on the car is relatively small.

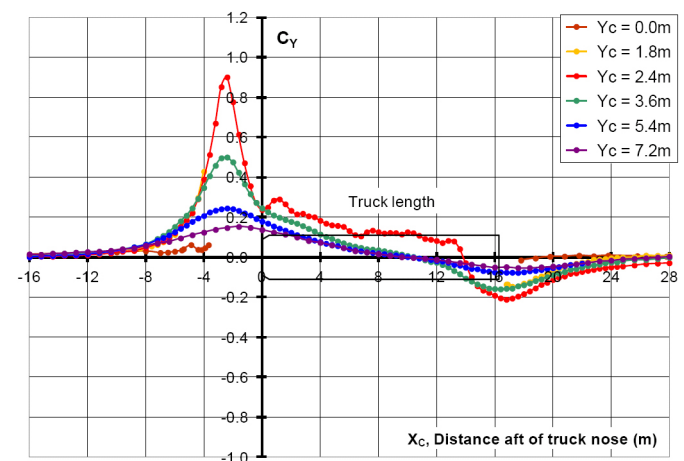


Figure 4(a). Variation of side force coefficient at zero yaw.

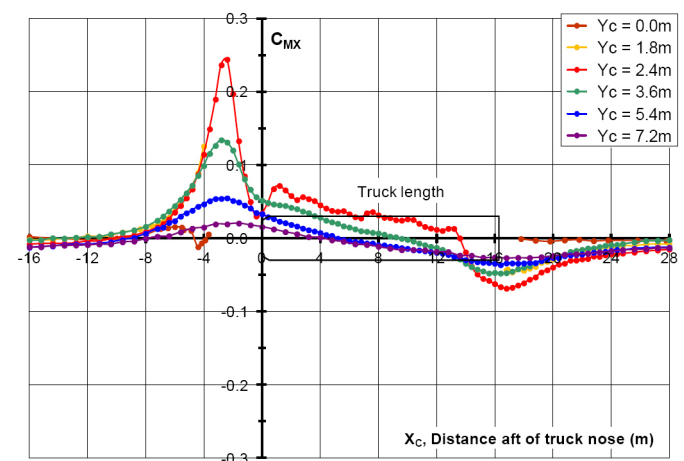


Figure 4(b). Variation of rolling moment coefficient at zero yaw.