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The effect of vehicle spacing on the aerodynamics of a representative car shape

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Abstract

Inter-vehicle spacing on highways is considered and an analysis of spacing is presented, deduced from data from an instrumented highway. Vehicle drag reductions arising from close spacing are discussed and drag and lift data from wind-tunnel tests on two co-linear Ahmed bodies (representative vehicle shapes able to replicate typical car airflow, configured with 30° slant back angles) are given. Inter-body, non-dimensional spacing was varied from 0.1 to 4.0, based on vehicle length. Surprisingly, significant drag increases were found for the rear Ahmed body for spacing of 0.1–1.0, when compared to the drag of the body in isolation. For greater spacing, the drag of the rear body fell below the value of the isolated case, up to the maximum spacing considered. The lift coefficient of the rear body was also found to be very sensitive to spacing. It was concluded that the effect of the strong vortex system arising from the slant back was the cause of the drag and lift changes of the rear vehicle. Since traffic spacing is likely to reduce with the increasing use of intelligent transport systems (ITS), it is argued that more attention should be paid to understanding these effects.

Keywords: Vehicle; Aerodynamic; Interaction; Lift; Drag; Spacing; Ahmed body; Convoy; Platoon

1. Background

Cars are bluff bodies with typical drag coefficients of 0.3–0.4. The majority of aerodynamic drag arises from form drag (also known as pressure drag; Hucho et al., 1998).

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Development work is performed physically (usually via wind-tunnel testing) or, increasingly, via numerical simulation (i.e. CFD). Almost without exception the vehicle testing domain is bounded with real or virtual side boundaries, including a fixed or moving ground representation. The air (real or numerically simulated) into which the test vehicle is positioned is usually smooth with no or low turbulence levels and a uniform velocity through the test domain. Thus the test domain is free from the influences of other vehicles and either simulates the case of no atmospheric wind or includes the simulation of a time-averaged atmospheric wind (via rotating an isolated vehicle at an angle to the flow). Corrections for the mean effects of atmospheric winds (including yaw angle) on moving road vehicles include the "wind-averaged-drag" method, Buckley et al. (1978) or the more comprehensive model suggested by Sovran (1984).

In contrast, road driving is in the influence of turbulent atmospheric winds and traffic wakes. The effects of these influences are to modify the relative wind environment experienced by the moving vehicle to one which has significant temporal and spatial variations. In the last two decades road vehicle aerodynamic research has increasingly been focussed on understanding and simulating parts of this "real" flow environment. Work has drawn on data and methods used in wind engineering where simulation of a correctly scaled model atmospheric boundary layer and the wakes of other close buildings are considered essential.

The effects of upstream bodies on the drag of following bodies can be significant and have been used for drag reductions in a number of ways. These include matching the wake size of a relatively small upstream bluff body (deflector) to shield the front of a downstream bluff body (Roshko and Koenig, 1978), thus minimising the forebody drag of the latter. This wake matching is utilised in some drag-reducing devices fitted to commercial road vehicles. The low drag coefficient experienced by a carriage in a length of train is the result of the upstream carriage shielding the downstream one (as well as the downstream carriage raising the base pressure, except for the last carriage in the train). Early work identifying these effects can be found in Hoerner (1965), with more recent work on goods wagon drag and drag reduction given in Watkins et al. (1992).

Fluctuations at a single point in the on-road relative flow have been measured by prior researchers via vehicle-mounted hot wires (Watkins and Saunders, 1998; Howell, 2000) or at four points in space using multi-hole pressure sensors (Watkins and Melbourne, 2003). In all cases, the intention has been to document the flow field in the absence of traffic. Effects of upstream vehicles include the provision of a complex flow environment for the test vehicle, resulting in modulation of wind noise by the larger scale fluctuations in the atmospheric wind, as well as generating transient forces and moments on vehicles. Limited research to simulate the effects of upstream vehicles has included the positioning of small vehicles upstream of the test vehicle in aero-acoustic wind tunnels and measurements with multi-hole pressure sensors in the immediate wake of driven road vehicles (see Watkins et al., 2001; Saunders and Mansour, 2000). Recently, active turbulence generation systems have been used to more closely simulate the transience in "real" road environments in full-scale automotive wind tunnels (Cogotti, 2004).

2. Aim and scope

Little work is evident on how the reality of road driving in traffic influences the mean drag coefficient of a vehicle. Whilst inter-vehicle spacing is known to have a significant