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The aerodynamic interaction of platooning and overtaking vehicles

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SUMMARY:
Given the recent advances in connected and autonomous road vehicles (CAVs), there is an increasing prospect that it will soon be commonplace for a number of communicating CAVs, to travel in close proximity, safely and at high speed, in what is known as a 'platoon' formation. Current public perception to CAV suggest that early adopters of this technology are likely to be haulage industry, specifically for heavy goods vehicles (HGVs). The experiments presented here are designed to determine aerodynamic forces on a series of HGV in both a uniform and non-uniform formation. The experiments were conducted at The University of Birmingham TRansient Aerodynamic INvestigation (TRAIN) rig facility. The platoon consists of five, equally spaced, 1/20th scale lorries. The Reynolds number, based on vehicle height, is of the order of $2.8\text{x}10^5$. Measurements included slipstream velocities and pressure coefficients of the flow around the vehicle, as well as each vehicle's surface pressures. The characteristic slipstream behaviour was shown to be influenced by the spacing between vehicles.

Keywords: Aerodynamics, CAV, road vehicles, experiments, drag, stability, close-proximity platoons

1. INTRODUCTION

It is commonplace to see lorries in groups of two or more on motorways and in motorsport, slipstreaming is a well-known technique for overtaking. When bluff vehicles travel in close proximity, the reduction in air pressure in the wake of an upwind vehicle reduces the pressure on the front of the downwind vehicle, tending to reduce drag. As such, driving in the wake of a vehicle may lead to improved fuel efficiency or electric vehicle range, with benefits in terms of cost reductions and CO_2 emissions. This phenomena is of further interest given recent advances in connected and autonomous vehicles (CAVs). A number of CAVs communicating with each other, can travel in close proximity, safely and at high speed, in what is known as a 'platoon' formation. It has been estimated that well-programmed CAVs could reduce road accidents by 90% and that the optimisation of driving could cut emissions by 60% [1]. Furthermore, research suggests that CAVs have the potential to increase road capacity, because of platooning and because automated systems can select the best route taking account of traffic, as well as allowing the "driver" more free time to focus on economically productive or leisure activities [2]. It has been predicted that CAVs will be travelling alongside traditional vehicles in the next ten years, with mainstream consumer adoption by 2030 and CAVs as the primary means of transport by 2050 [1]. However, current public perception suggests that early adopters of this technology are likely to be haulage industry, specifically for heavy goods vehicles (HGVs).

This study is part of the EPSRC funded project entitled ‘The aerodynamic interaction of platooning and overtaking vehicles - EP/V010689/1’. The study aims to provide a better understanding of the nature of the aerodynamic flow surrounding a platoon of HGVs. This includes providing methods of quantifying the benefits (e.g. drag reduction) and problems (e.g. stability) associated with driving through upwind vehicle’s wakes. This study also extends beyond previous close proximity investigations by not only considering vehicles in perfect alignment, but also vehicles consistently out of alignment and dynamically moving out of alignment. The extent to which stability issues can be exacerbated by crosswinds which cause asymmetric wakes will also be investigated. The aims of the project are achieved through a series of complex experimental approaches. The experimental work for vehicles in alignment, measuring boundary layer velocities and on-board surface pressures for scale models of five equally spaced HGV, is the focus of this presentation. Section 2 outlines the method used to obtain laboratory results. This begins with a description of the laboratory equipment and an explanation of how it was used. Section 2 then concludes with consideration of how the data was analysed. Section 3 presents preliminary results from the experimental campaign.

2. METHODOLOGY

Experiments were conducted at the University of Birmingham TRansient Aerodynamic INvestigation (TRAIN) rig facility, which is designed to investigate the transient aerodynamics of moving vehicles [3]. The rig consists of a series of 150 m long tracks with a mechanism that is capable of firing vehicles at speeds up to 75 m/s, depending on weight. The rig was modified to maintain a constant separation between the vehicles, which were mounted on a long spine running through a slot in the middle of a suspended ground plane. The platoon consists of five 1/20th scale HGV lorries, as shown in figure 1. Five lorries were chosen for the platoon based on knowledge of boundary layer development for multiple vehicle configurations and to fit within capability ranges for the facility [3]. The models were manufactured from PLA using 3D printing technologies. Fine details such as wing mirrors or underbody skirts were either simplified or removed. This is consistent with other scale model tests where such inducers of small scale turbulence have been removed previously [3]. The lorries were fired at a nominal speed of 22.5 m/s (50 mph). The overall height of the lorry is 170 mm, giving a Reynolds number of the order of 2.8×10^5. The lorries were separated by a nominal space of 6 m at full-scale.

Figure 1. Platoon of five HGV lorries moving above a suspended ground plane with fixed intervehicle spacing of 6 m at full-scale.

Multi-hole pressure probes, manufactured by Turbulent Flow Instrumentation, were used in an array of 50 positions to monitor the boundary layer development of slipstream velocities at the vehicle side and above the roof. These probes measure three components of velocity and the static pressure. The sampling frequency is 5 kHz and the uncertainties in the measurements are ±0.5 m/s, ±5 Pa, ±1° respectively for velocity, static pressure and flow direction. In addition to the slipstream results, the pressure development on the surface of lorries, from which force coefficients were computed, was also measured. Four pressure monitoring systems were included in each lorry. Each pressure monitoring systems consists of a data logger connected to fourteen FirstSensor miniaturised differential pressure transducers. The sampling frequency is 3 kHz. A series of SICK photoelectric position finders were set up along the ground plane with reflectors on the opposite side of the track. The vehicle speed was then calculated, to an accuracy of 0.1 m/s, from the time taken for the nose of the lorry to pass through consecutive beams. The position finders were also used to align data from each run, allowing an ensemble average time series of slipstream velocities and pressure coefficients to be calculated where τ is a normalised time scale such that $\tau = 0$ and $\tau =1$ occur as the front of the first lorry and the rear of the last lorry respectively pass a control point, i.e. $\tau = Ut/L$, where U is lorry speed, t is the time and L is the platoon length.

All data was non-dimensionalised, such that the normalised velocity U_{res} and pressure coefficient Cp are calculated as:

$$U_{res} = \sqrt{u^2(\tau) + v^2(\tau)} \tag{1}$$

$$Cp(\tau) = \frac{p(\tau) - p_0}{\frac{1}{2}\rho U^2} \tag{2}$$

where u and v are the longitudinal and horizontal velocities respectively, p_0 is the ambient pressure, ρ is air density and U the vehicle speed. Twenty runs of boundary layer measurements were taken for each position. The data was resampled and normalised with respect to the nominal vehicle speed before ensemble values were calculated. The results are presented relative to a coordinate system (x,y,z) where the x-axis is aligned in the direction of vehicle travel, the y-axis is in the horizontal plane perpendicular to the direction of travel and the z-axis is in the vertical direction, measured relative to the ground plane.

3. RESULTS

Figure 2 illustrates the ensemble coefficient of pressure and normalised resultant velocity measurements for probe positions to the side of the platoon for increasing height. It is clear to see how the pressure oscillates with a pair of peaks (one positive and one negative) for each vehicle in the platoon. Each pressure transient clearly relates to the nose of each HGV model, with a smaller transient negative peak at the vehicle end. For measuring positions above the mid-height of the vehicle, the pressure transients relate to a clear peak in velocity, as the lead of each vehicle. This feature is suppressed for lower measuring heights, due to the rapidly development of the highly turbulent flow field around the vehicle underbody and wheels.

Figure 3 illustrates a snapshot of the ensemble resultant velocity flow field at the position midpoint along the platoon ($\tau = 0.5$). The figure is created through an interpolation of results from the multi-hole pressure probes across the enclosed area. It is clear to see the influence of the underbody

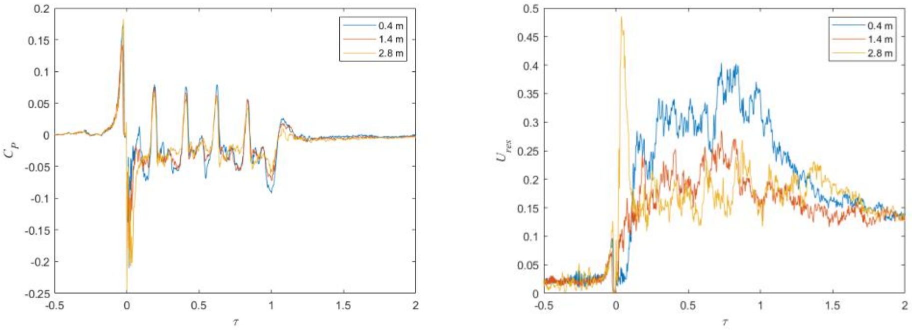

Figure 2. Ensemble coefficient of pressure and normalised resultant velocity measurements for probe positions 0.5 m to the vehicle side for increasing heights 0.4 m, 1.4 m and 2.8 m above the ground plane.

on velocity magnitudes. Similarly at the corner of the roofline it possible to observe the vortices separating from the leading corner edge of the lorry trailer and moving away from the vehicle, breaking up and feeding the global boundary layer flow. On the relatively smooth, flat trailer surface the boundary layer remains close to the vehicle side with a smaller velocity magnitude.

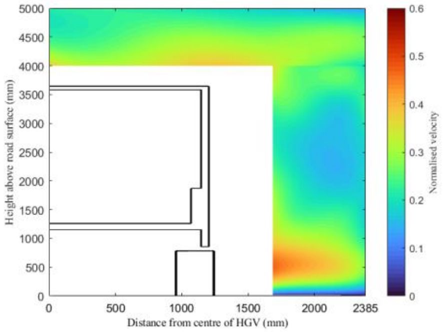

Figure 3. Ensemble resultant velocity flow field around the platoon taken at the position $\tau = 0.5$.

4. CONCLUSIONS

This paper presents preliminary results from a larger study to assess the transient aerodynamics of a platoon of HGVs travelling in close proximity, both in alignment but also dynamically moving out of alignment. The initial results suggest that the flow field is highly dependent on the platoon configuration, with key flow features, such as the outflow around the underbody and vortices at the roof line, exhibited from analysis of the flow field.

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REFERENCES

Ohio University's Online Master of Science in Civil Engineering program. *The future of driving*. Retrieved February 2018, from https://onlinemasters.ohio.edu/the-future-of-driving, 2017.

S. Le Vine, A. Zolfaghari and J. Polak. *Autonomous cars: The tension between occupant experience and intersection capacity*, Transport. Res. Part C: Emerging Tech., 52:1-14, 2015.

C.J. Baker, S. J. Dalley, T Johnson, A. Quinn, and N. G. Wright. *The slipstream and wake of a high-speed train.* Proc. IMechE, Part F: J. Rail and Rapid Transit, 215(2):83–99, 2001.