Mitteilung

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Aerodynamic Characterisation of a Compact Car Driving Behind a Heavy Vehicle

H. Wilhelmi[1*], C. Jessing[2], J.R. Bell[1], D. Heine[1], J. Wiedemann[3], A. Wagner[3] & C. Wagner[1,4]
[1]DLR Göttingen, Institute of Aerodynamics and Flow Technology
Bunsenstr. 10, 37073 Göttingen, Germany
[2]University of Stuttgart, Institute of Automotive Engineering
Pfaffenwaldring 12, 70569 Stuttgart, Germany
[3]Research Institute of Automotive Engineering and Vehicle Engines Stuttgart
Pfaffenwaldring 12, 70569 Stuttgart, Germany
[4]Technical University of Ilmenau, Institute of Thermodynamics and Fluid Mechanics
Helmholzring 1, 98693 Ilmenau, Germany
*henning.wilhlemi@dlr.de

Aerodynamic research and development of automotive vehicles is commonly conducted in wind-tunnel experiments and numerical simulations under idealized conditions, which are not necessarily representative of diverse, complex real-world flow conditions. The work presented provides new insight and understanding into the flow conditions and their effects on a vehicle's unsteady aerodynamics for a typical – particularly on the German Autobahn – real-world operating case: Driving behind a heavy vehicle.

The experiments were performed under ideal conditions, on a 2.9km runway at the Fassberg airfield next to *DLR* Trauen, Germany. The test track was clear of nearby infrastructure and isolated; no vehicle traffic was present other than the two test vehicles. Weather conditions were monitored during testing and all presented results were obtained during wind conditions of less than 5 m/s.

Figure 1: The compact car (with probe array mounted in front) driving behind the heavy vehicle on the runway of the Fassberg Airfield.

The compact vehicle (CV) was a full-scale, operational *Volkswagen Golf 7* provided by *Volkswagen*. The vehicle was modified to house measurement and data acquisition equipment. The heavy vehicle (HV) was a *Mercedes-Benz 2017 Sprinter 'Box Body'*. The vehicle's track-position and distance behind the heavy vehicle were controlled during testing by markings on the driver's windscreen. These positions were confirmed with a camera fixed at the top of the windscreen, operating at 1 *Hz.* The experiments were carried out with both vehicles driving at constant velocities of $V_{CV} = V_{HV} = 20 - 33.3$ *m/s* (80-120 *km/h*) with distances between the vehicles of $\Delta x = 10 - 100$ *m* (see Fig.1).

A 2D array of 11, five-hole dynamic-pressure probes was mounted 1 m in front of the compact car to measure the incoming flow properties. The array consisted of a 3 x 3 grid, with $\Delta y = 0.98$ *m* and $\Delta z = 0.6$ *m* spacing, starting $z = 0.5$ *m* above the ground. Two additional five-hole probes were included at the bottom row, resulting in a finer spatial resolution of $\Delta y = 0.48$ *m*. The probes had tip diameters of 3 *mm*, and protruded 100 *mm* out of 12 *mm* thick airfoil shaped vertical and horizontal beams that supported the probes and housed the pressure tubing. The probes have a calibrated cone of acceptance of ± 50°.

Pressure was measured at 188 points on the CV's surface. Silicone tubes of 1.5 *m* length and 1.4 *mm* diameter were connected to PSI differential pressure modules. The five-hole probes used the same pressure measurement system with equal tube dimensions in separate experiments. Pressure was normalised as: $C_P = (p_i - p_\infty)/(0.5\rho V_C^2)$, where p_∞ was atmospheric pressure measured inside a reservoir located inside the vehicle, density (ρ) was determined from the atmospheric temperature, and V_C was the compact cars velocity over ground. Data was sampled at 250 *Hz* and each individual measurement had – depending on the car's velocity – duration between 80 and 120 s.

In a first step, the change in flow during behind a leading vehicle and at different distances was determined. The time-varying velocity components *u, v, w were* measured by the 5 horizontal probes at *z* = 0.5 *m* as the CV travelled in undistributed air (no HV), 50 *m* and 10 *m* behind the HV are presented in Fig. 2. The CV experiences increasing fluctuations in all velocity components – most significantly in the u and v components – as the vehicle drives closer to the HV. Frequency analysis of these fluctuating velocity components have identified a dominant frequency of ~2.5 *Hz*, attributable to *von Kármán*-type vortex shedding originating from the sides of the HV. Further analysis has also identified increasing levels of in-phase correlation in velocity fluctuation across the width of the vehicle. The existence of a leading vehicle and the distance to it influence the on-flow condition on the test vehicle by introducing fluctuations. Furthermore, the existence of periodic structures in the wake of the HV was shown.

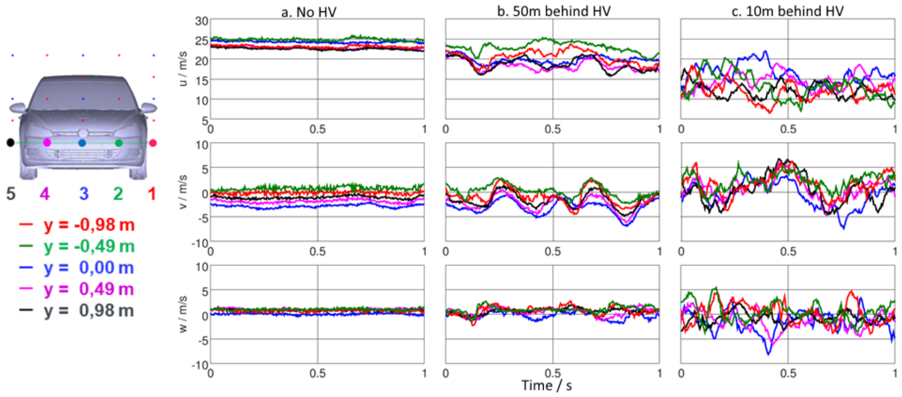

Figure 2: The time-varying velocity components: u, v, w measured by the 5 horizontal probes at z = 0.5 m as the CV travelled in a. undistributed air (no HV), b. 50m and c. 10m behind the HV.

To gain a first insight into the influence of the change flow conditions on the car, transient surface pressure at selected locations on the vehicle as the CV travelled in undistributed air (no HV), 50 *m* and 10 *m* behind the HV are presented in Fig. 3. Fluctuations across the front bumper are similar to the transient flow field measured by the probes. These fluctuations also display signs of correlation, but, in contrast to the flow, the correlation is out-of-phase across the front bumper. The roof centreline shows signs that the upstream flow has an effect that decreases away from the vehicles front. The pressure at the rear of the vehicle is largely, unaffected by the HV, as it exhibits moderate fluctuating pressure in all cases. Thus, the changed inflow conditions have an effect on the vehicle pressure distribution. However, the strength of the change in pressure depends not only on the vehicle distances, but also on the measurement position on the vehicle.

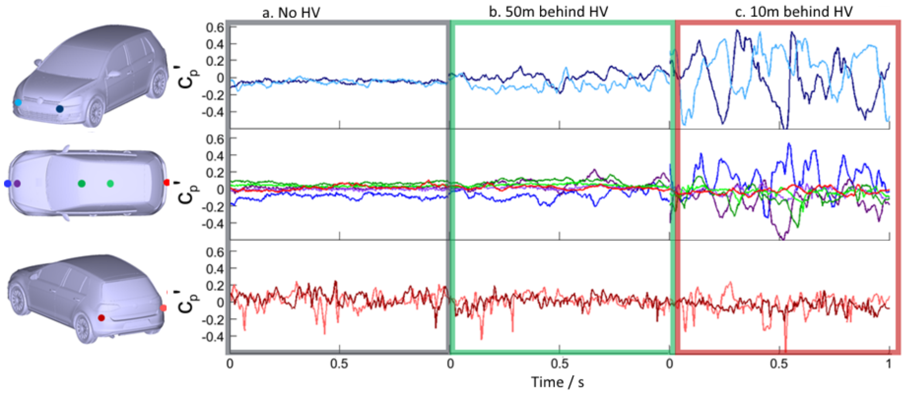

Figure 3: Time series of the fluctuating component of pressure at selected locations on the vehicle, as the CV travelled in a. undistributed air (no HV), b. 50 m and c. 10 m behind the HV.

In conclusion, this work has identified that the flow a compact vehicle experiences driving behind a heavy vehicle has coherent flow characteristics that are significantly different to undisturbed conditions. Further, these conditions have a noticeable effect on the compact vehicle – identified here through changes to the vehicle's transient surface pressure. These new insights can be utilized to improve aerodynamic research techniques to include modelling of real-world operating conditions and inform the development of next-generation automotive vehicles.