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Full scale experiments on vehicle induced transient pressure loads on roadside walls

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ABSTRACT

Every day numerous vehicles of different types pass roadside walls. Typical roadside walls represent noise barriers, windbreak walls, screen walls, billboards, walls of lowered streets, underpasses or tunnel walls containing also traffic guidance and surveillance equipment. The aerodynamic interaction between the passing vehicle and the wall generates a vehicle-specific flow and pressure field, which leads to transient pressure forces acting on the wall. In order to quantify the pressure load on the wall, full scale experiments were performed for different vehicle types. To measure the pressure, a pressure scanner with multi-tapping technique and high temporal and spatial resolution was integrated into a test wall. The experiments provided a big database for the proper quantification of vehicle induced pressure loads on roadside walls as a function of vehicle types, vehicle velocities and the passing distance. Characteristic pressure patterns (or called more impressively as "pressure imprints") on the wall could be found for different types of vehicles.

1. Introduction

Characteristic pressure distribution develops around moving vehicles. There is a zone of overpressure at the front of the vehicle followed by a zone of suction due to the air flow acceleration behind the leading edge of the vehicle. These zones, which can also be characterized as a pressure jump, are located close to each other. Analogously, a pressure jump is formed at the rear edge of longer vehicles or at junctions of vehicle trains, although the forces at the rear edge are not as strong and stable as the forces induced by the vehicle front. Therefore a moving vehicle is covered by a 3D pressure distribution travelling with the same velocity as the vehicle. The movement of the vehicle also induces a slipstream in the nearfield, which represents a highly turbulent unsteady boundary layer and wake flow. If the moving vehicle approaches a roadside wall, an interaction of the dragged pressure distribution, the slipstream and the wall occurs, leading to a pressure pattern moving on the wall. The strength of the pressure pattern and, hence, the strength of the pressure force on the wall, depends on the vehicle type and shape, its aerodynamics, the vehicle velocity and the passing distance between vehicle and the wall.

In the last decades, several studies have been published on vehicle aerodynamics, see e.g. Choi et al. (2014), Sovran et al. (1978), Hucho (1994), Watkins and Pagliarella (2007), Ahmed et al. (1985). However, the interaction of the vehicle induced flow and pressure field with roadside elements or walls has been investigated rarely. Cali and Covert (2000) conducted scaled experiments measuring transient loads on overhead highway signs induced by passing of simplified model vehicles. Full-scale experiments on vehicle induced forces acting on flat plates were carried out by Quinn et al. (2001a, 2001b), who tested plates of different shapes and inclinations on a road side irrespective of the vehicle type, distance and travelling speed. Sanz-Andrés et al. (2003a; 2003b; 2004). introduced mathematical models of vehicle-induced transient loads which roughly approximated experimental results in the vehicle front section regarding traffic signs, pedestrians and pedestrian barriers. A field experiment and numerical study on vehicle-induced aerodynamic loads on highway sound barriers were done by Wang et al. (2013a, 2013b). where three vehicle types were considered passing along a barrier. Recent experimental work was done within a research project (see the acknowledgement) consisting of several parts, i.e. a wind tunnel study, field experiments on plates, field experiments on walls and generation of a database, as described in Ruck and Lichtneger (2014). Experimental results concerning pressure and suction forces on roadside square plates were presented by Lichtneger and Ruck (2015). The induced forces were systematically investigated as a function of the plate size, vehicle type, vehicle velocity, distance and alignment of the plate with respect to the track of vehicle. The results are freely accessible in the Data base VIPAS. The novel experimental results concerning induced pressure and suction forces on roadside walls are the subject of

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Table 1
Fleet of testing vehicles – classification and main parameters.

No.	Vehicle type	Total width B [m]	Total height H [m]	Total length L [m]	Specification	Illustration (DIN 70010)
1	Passenger car (saloon)	1.8	1.35	4.7	VW Passat CC	
2	Passenger car (station wagon)	1.8	1.45	4.8	Audi A6	
3	Passenger car (multi-purpose vehicle)	1.75	1.73	4.7	VW Sharan	
4	Van (commercial vehicle)	2.0	2.6	6.8	Iveco Daily	
5	Truck (goods vehicle)	2.53	3.43	7.85	rigid body 7.5 t Renault D	
6	Truck (goods vehicle)	2.53	4.0	9.7	canvas cover 18 t MB Actros	
7	Tour-bus (long distance coach)	2.55	3.1	12.1	2-axle, roof structures MB Tourismo	
8	Trailer-truck (articulated vehicle)	2.55	4.05	16.45	canvas cover (MB Actros)	
9	Truck with trailer (road train)	2.55	4.0	18.7	canvas cover MB Actros	

this paper.

In comparison to car- or truck-induced pressure loads, more studies exist on train-induced loads concerning e.g. noise barriers and trackside structures at high speed train lines, where frequent passings can also lead to dynamic reactions and material fatigue, see e.g. CEN (2005), MacNeill et al. (2002), Friedl et al. (2013), Lee (2009) or Carassale and Brunenghi (2013). The aerodynamics of trains in confined spaces was investigated by Gilbert et al. (2012). Comprehensive reviews including field and numerical studies of high speed trains especially regarding the aerodynamics in tunnels, trains passing each other and the crosswind exposure can also be found in Schetz (2001) and Raghunathan et al. (2002).

Regarding vehicle-wall interactions, only a few studies exist. Wallis and Quinlan (1988) showed by wind tunnel tests with a 3/8-scale model racing car that significantly large changes of lift and drag forces can be generated when a car passes in close proximity to a stationary wall. Strachan et al. (2012). performed numerical and experimental investigations with a car-like bluff body (Ahmed reference model, see Ahmed et al. (1984).) in wall proximity and found that the pressure jump at the front of the vehicle increases sharply with decreasing wall distance. Comparing numerical and experimental results, they concluded that available numerical models (Reynolds Stress viscous model and k-ε RNG model) cannot be used for accurate pressure force predictions.

Until now, no systematic investigation exists about the vehicle-wall interaction comprising all relevant factors of influence i.e. vehicle type, vehicle velocity and vehicle distance from the wall. Therefore, an experimental full scale measurement campaign has been performed with nine different vehicle types and with an artificial wall consisting of stacked 40 ft sea containers. The aim of this full scale campaign was to measure vehicle type specific pressure patterns on the wall as function of the vehicle velocity and the wall distance. In a further step, by the reduction of variables, characteristic pressure patterns which are specific to the vehicle type were deduced. They can be used to describe the wall pressure irrespective of vehicle velocity and passing distance. The results complement the existing Data base VIPAS with the interaction of vehicles and walls.

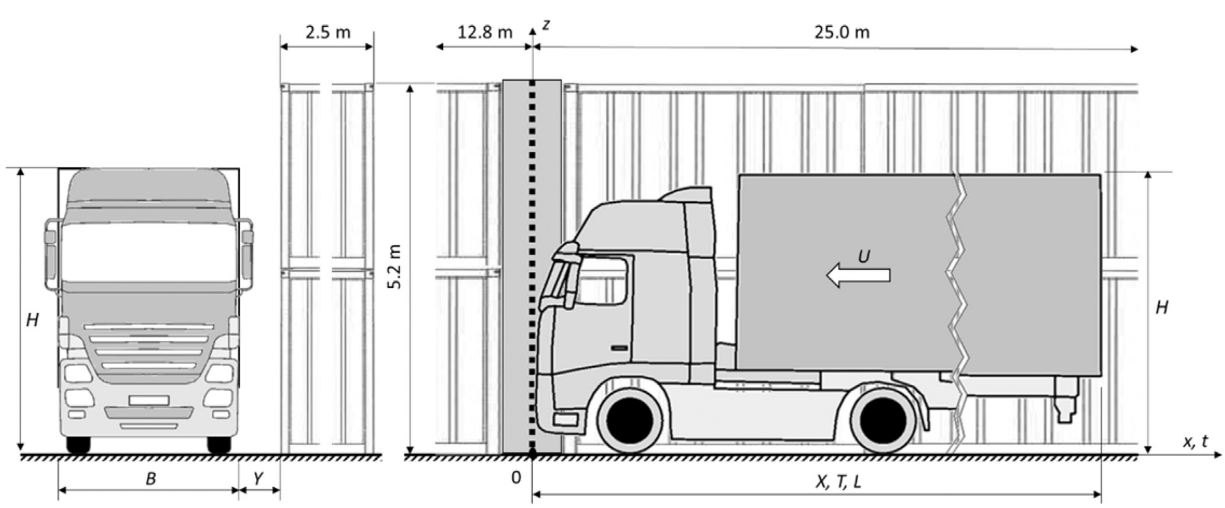

Fig. 1. Layout of the experiment showing the main parameters: vehicle distance from the wall *Y*, driving direction and velocity *U*, vehicle length *L*, vehicle width *B*, and vehicle height *H*, as well as the dimensions of the sea-container wall height, width and lengths before and after the pressure scanning section (denoted with the vertical dotted line).