

The Effect of Center Belt Roughness on Vehicle Aerodynamics

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ABSTRACT

Recently built or refurbished wind tunnel facilities show a trend towards a detailed simulation of road conditions. Therefore, these wind tunnel facilities are equipped with boundary layer conditioning systems and a rolling road consisting of one or several belts in order to simulate the rotation of the wheels and the relative motion between the vehicle underfloor and the road. Belts are either realized in rubber or steel. Steel belts offer the possibility to be coated with rubber to protect the belt itself. This coating additionally offers the possibility to attain a certain roughness to represent the road surface.

This paper presents measurements of the roughness of the steel belt systems installed in the IVK Model Scale and Aero-Acoustic Full Scale Wind Tunnel in comparison to road surfaces. Additionally, the influence of roughness on the aerodynamic coefficients drag and lift is presented and discussed for the SAE reference body with different rear end configurations.

INTRODUCTION

One focus of research and development in aerodynamic measurement techniques in the last two decades was on the improvement of ground simulation during wind tunnel tests [1, 2]. A major concern was the reproduction of the relative motion between vehicle underfloor and the ground. This resulted in several new wind tunnel designs with advanced ground simulation techniques including boundary layer control systems and rotating wheels [3, 4, 5]. The boundary layer control systems in those tunnels usually consist of a combination of boundary layer suction, tangential blowing and some kind of moving belt under the vehicle. Boundary layer suction and tangential blowing are used to condition the

boundary layer to a block profile before it reaches the moving belt. Depending on the design of the wind tunnel, the moving belt is either realized as a wide belt which is wider than the vehicle track or as a so-called center belt, which runs between the vehicle wheels. The first version is very popular in race car wind tunnels and is thought to deliver the simulation of on road driving. The second version requires additional wheel rotating units but is more flexible in its usage and therefore more common in passenger car wind tunnels. The belt itself is realized either as a polymer or as a steel belt. Steel belts offer the possibility to be coated with rubber, which on the one hand can be used as a mechanical protection and on the other hand offers the possibility to take some influence on the roughness of the surface.

While it is very clear, that a fixed surface with a higher roughness increases the boundary layer compared to a smooth surface, so far, only little is known about the influence of moving belt surface roughness on the aerodynamic quantities of a vehicle. Gaylard et. al. observed in their investigation on high speed trains that the surface roughness which they introduced to simulate the sleepers, depending on the investigated configuration, had a remarkable effect on drag [6]. Since their investigations were focusing on trains, the information about the effect on lift is missing.

IVK / FKFS WIND TUNNEL FACILITIES

In 2001 the IVK Full Scale Aero-Acoustic Wind Tunnel (FWK) and the IVK Model Scale Wind Tunnel (MWK) were upgraded with a state-of-the-art boundary layer conditioning and 5-belt road simulation system to simulate the situation on road. The systems consist of a boundary layer pre-suction system (BLPS) that reduces the boundary layer leaving the wind tunnel nozzle. In order to obtain the desired velocity "block" profile right at

the beginning of the center belt (CB), which runs between the vehicle's wheels, a tangential blowing system (TBCB) fills up the incomplete near wall velocity profile. This center belt runs at wind speed and simulates the relative motion between the vehicle underbody and the road. A distributed suction system on the turn table (TDS) prevents the boundary layer again from growing. Four balance mounted wheel rotation units are used to rotate the wheels. The complete wind tunnel floor is displayed in figure 1. The comprehensive

use of all subsystems is referred to as FKFS-Straßenfahrtsimulation (SFS), i.e. road simulation [5]. It effectively reproduces the situation of a vehicle travelling on a road. A measurement without the use of the system comparable to a standard wind tunnel without any boundary layer conditioning or belt rotation is called Conventional Ground Simulation (CGS).

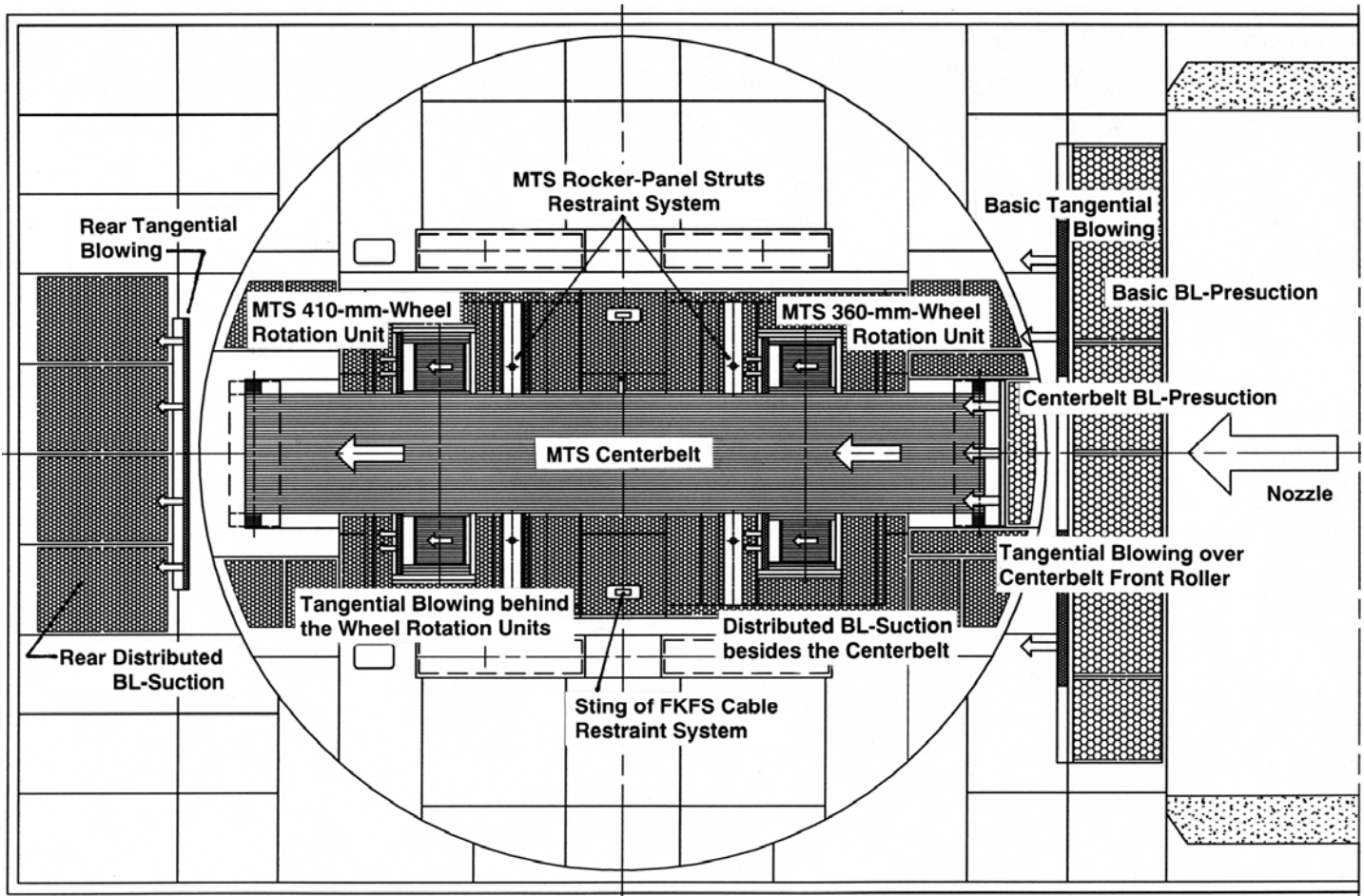


Figure 1: Test-section floor in the IVK Aero-Acoustic Full Scale Wind Tunnel with the turntable, center belt, wheel rotation units, car restraint systems and boundary layer control by suction and tangential blowing [5]

The effect of the road simulation system's different subsystems on the aerodynamic properties of full scale vehicles and scale models has been heart of many investigations, e.g. [7, 8, 9]. In this section only the basic effects on the SAE notchback model that will also be used in the following is shown for completeness.

Figure 2 shows the effect of the boundary layer pre-suction system and the combined effect of the boundary layer pre-suction, tangential blowing and moving center belt in comparison to conventional ground simulation. Of course, due to the absence of wheels on the standard SAE model use of the wheel rotation units cannot be realized [10, 11].

It can be seen that c_D rises as the different subsystems are successively turned on. At the same time lift decreases. Changes of both coefficients are attributed to the reduction of the boundary layer that leads to more kinetic energy, i.e. higher velocities and lower pressures underneath the vehicle.

Figure 3 shows the effect of these road simulation subsystems on the total pressure distribution in the wake of the SAE notchback model close to the ground (refer to figure 7 for measuring positions). While boundary layer reduction by suction only has a minor effect on the underfloor flow of the model, the center belt with an appropriate boundary layer condition fills in the flow

profile nearly over the full under floor range of this model with a ride height of 30 mm.

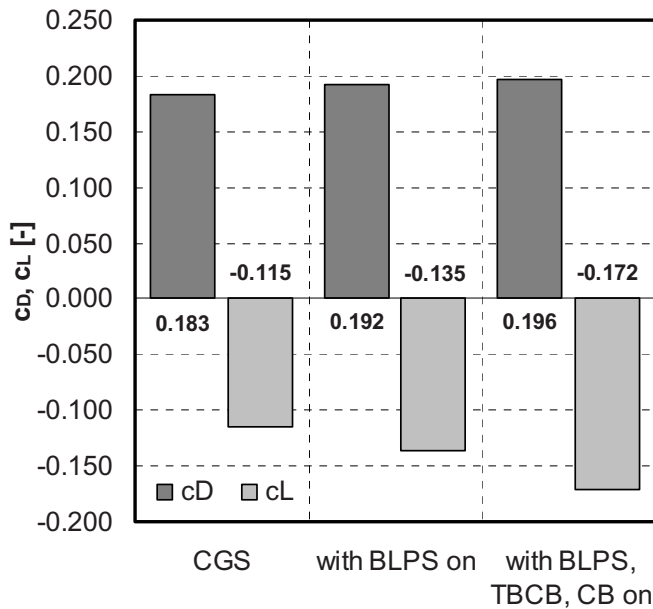


Figure 2: Effect of road simulation subsystems on drag and lift coefficients of SAE notchback model at a ride height of 30 mm

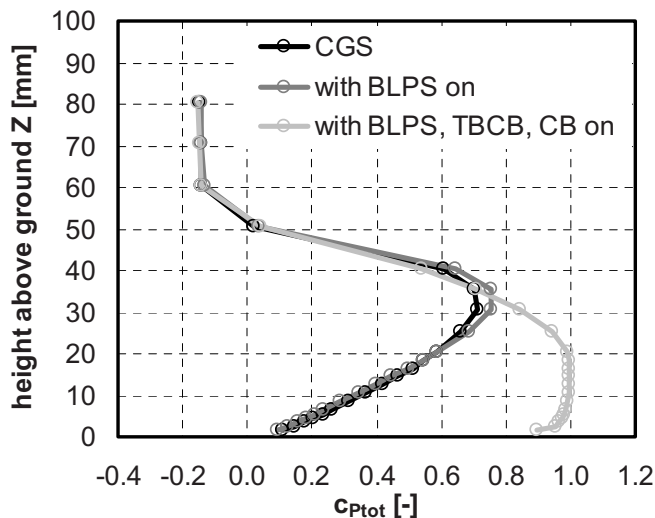


Figure 3: Effect of road simulation subsystems on total pressure distribution in the wake of SAE notchback model, $y = 0$ mm (center plane)

SURFACE ROUGHNESS

The official term for roughness of road surfaces is texture. Texture describes the shape or more specifically the deviation of a road surface from a perfect smooth plane for a wavelength range from a few micrometers to several decimeters. The texture affects the adhesive force between the tire and the road and therefore influences driving dynamics, rolling resistance and road noise.

For the case that texture is acquired in only two dimensions, like described below, the result is a profile.

This profile is described by two coordinates. The distance extends along the surface while the amplitude describes the vertical position with reference to the surface. With a Fourier analysis, this profile curve can be described mathematically by shares of different wavelengths and wave numbers.

Textures of road surfaces are classified in four ranges: macrotexture, microtexture, megatexture and unevenness. The texture range important for these investigations is the macrotexture with a wavelength range between 0.63 and 50 mm. These wavelengths are in the same order as the tire profile elements in the tire contact area. The peak-to-plateau values vary in the range of 0.1 to 20 mm [12].

Different measures are defined to standardize the assessment of road surface textures.

The distance between the profile and a plane through the peaks within a certain range in longitudinal and lateral direction is called Profile Depth (PD). The investigated area has the dimensions of about the tire contact area. The most important measure in this context is the Mean Profile Depth (MPD), which is calculated as the difference between the arithmetic mean value of the two peak values of each half of the ground line and the mean value of the ground line [13, 14, 15]. The above described measures are illustrated in figure 4.

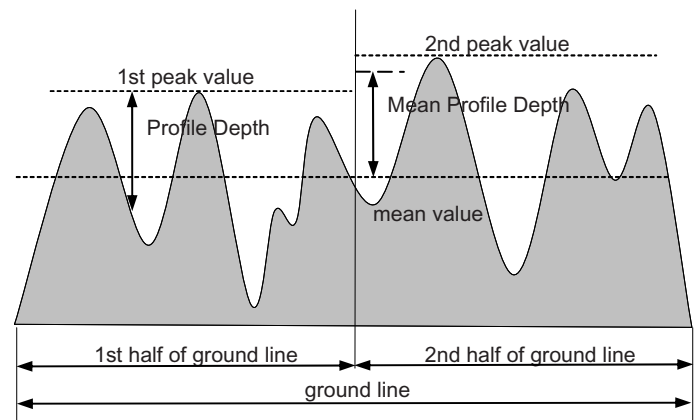


Figure 4: Illustration of the measures ground line, profile depth and mean profile depth

MEASUREMENT SETUP

Methods to determine texture can be subdivided into volumetric and profilometer methods. Since the different methods result in measures which are not necessarily comparable, the norm ISO 13473 [13, 14, 15] defines profilometer methods, which are more robust and economical compared to the volumetric methods, a standard procedure to assess and analyse the texture of road surfaces.