Methodology for Unsteady Wind Noise Measurements in an Aeroacoustic Full-Scale Wind Tunnel

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Introduction

The aeroacoustic development of vehicles, for interior noise as well as for exterior noise, is mainly done in aeroacoustic wind tunnels. These wind tunnels usually are designed to generate homogeneous and reproducible flow conditions with low turbulence levels. For example, the airflow in the empty test section of the full-scale aeroacoustic wind tunnel of University of Stuttgart shows a turbulence level lower than 0.3%.

The real situation on road, however, shows that the incoming flow is disturbed significantly by for example side wind gusts, obstacles at the roadside in combination with even steady side wind, or vehicles driving in front. Thus, the on-road flow under real conditions is locally and temporally not constant. At the car, the flow vector results from the summation of the vehicle speed vector and the atmospheric wind velocity vector. Due to different climatic, topographic (e.g. hilly or plane scenery with or without trees, guard rails), and traffic situations the flow conditions and turbulence intensities may vary strongly (e.g. [1]).

A real on-road situation can be seen in **Figure 1**. The time history of the real incoming flow has been measured on the road by a four-hole dynamic pressure probe, a so-called Cobra probe, ahead of the car [2]. A Cobra probe is capable to resolve the three components of the velocity vector as well as the local static pressure. Its frequency range reaches up to 2 kHz, the static calibration ranges from 3 m/s to 75 m/s and from - 45° to +45° for pitch angle and yaw angle.

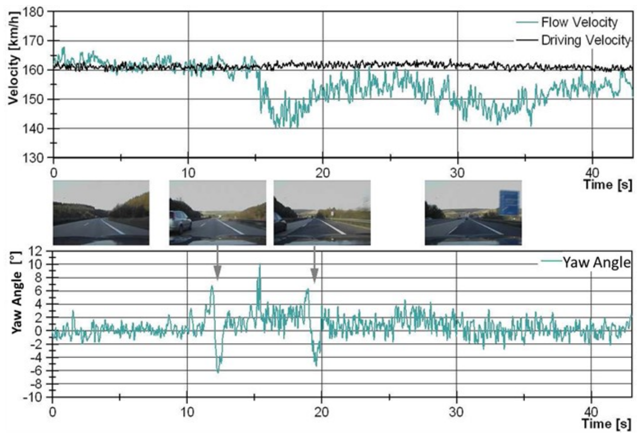

Figure 1: Measurement of the incoming flow in terms of velocity (top) and angle (bottom) on a motorway at a driving velocity of approx. 160 km/h [2].

The resulting flow fluctuations cause an audible effect on the flow noise in the interior of the vehicle. Time-varying changes of the flow speed result in an amplitude-modulated noise signal. Changes of the yaw angle affect the amplitude as well as the frequency spectrum. Thus, in a real on-road situation the interior noise is modulated in amplitude and frequency (see e.g. [1] [3])

In respect of these realistic on-road flow conditions, an increasing interest to investigate wind noise under these conditions could be observed during the last years. Particularly the increasing demand for even more comfort and thus the need for enhanced psychoacoustic evaluations underline this trend.

Methodology

To be able to simulate typical unsteady flow scenarios with regard to aeroacoustics and aerodynamics a new active side-wind gust and turbulence generator has been developed for the full-scale aeroacoustic wind tunnel of University of Stuttgart. The requirements for the system with respect to an efficient reproduction of typical on-road situations in the wind tunnel for aeroacoustics and aerodynamics have been determined by on-road measurements, by considering psychoacoustic aspects as well as considering the typical vehicle responses.

The investigation of the results of these on-road measurements showed that the variation of the yaw angle is responsible for the more significant changes of the noise in the vehicle's cabin. They are discussed in [4]. Hence, the flow deflection and its deflection rate in terms of frequency are necessary parameters to reproduce the relevant unsteadiness of typical on-road situations for aeroacoustics and aerodynamics. With respect to aeroacoustics, the maximum frequency amounts to 10 Hz with a maximum deflection angle at the vehicle of ca. 3°. For lower frequencies larger deflection angles shall be possible.

Figure 2: FKFS ***swing***® in the nozzle exit plane of the full-scale wind tunnel of University of Stuttgart [5]

At the end, the new active side-wind gust and turbulence generator consists of 8 wing profiles vertically positioned at the nozzle exit. It is shown in **Figure 2** and it trades under the name FKFS ***swing***® (side wind generator). Each profile is operated by its own drive, among others by signals measured on the road.

Results

For vehicle tests, usually time history data from on-road measurements or artificially generated signals are used. To reproduce the flow angle at the vehicle in the wind tunnel accurately as on the road, the transfer function of the whole system from data input to flow at the vehicle has to be known. Once determined and using the inverse of this transfer function, the on-road flow situation in terms of yaw angle can be reproduced accurately by the system. A comparison between on-road time history (blue solid line) and its reproduction in the wind tunnel (red dashed line) is given in **Figure 3**.

First, basic aeroacoustic investigations have been carried out using two different vehicles. Whereas vehicle 1 has been highly rated on road regarding wind noise under transient flow conditions, vehicle 2 has been rated more poorly under these conditions. Since modulations of around 2 Hz to 6 Hz are most important for the psychoacoustic value “fluctuation strength”, one investigation focused on the determination of the part of the interior noise frequency spectrum which is most affected by this modulation. The difference of the modulation degree of the two vehicles in the noise levels of the octave bands from 500 Hz to 8 kHz has shown that the negatively rated vehicle 2 produces higher values especially in the 4-kHz octave [4]. Therefore, this octave band has been chosen for further analysis of the unsteady aeroacoustic measurements.

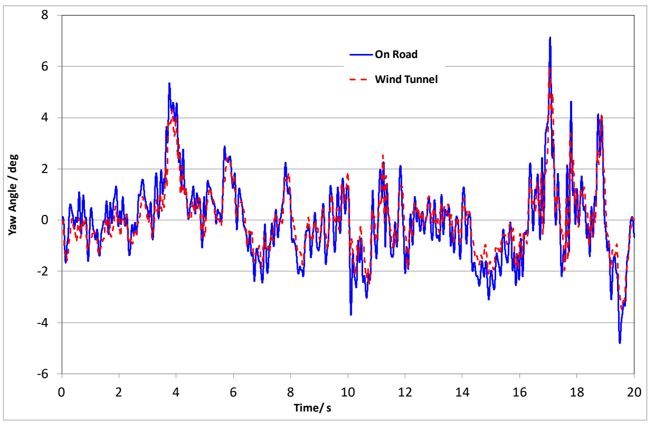

Figure 3: Flow angle above the vehicle roof measured while driving on road (blue solid line) and measured using FKFS ***swing***® in the wind tunnel (red dashed line) [4].

In a next step, the modulation of the interior noise has been investigated. **Figure 4** shows the modulation spectra of the 4-kHz octave band of the interior noise of vehicle 1 (blue line with diamonds) and vehicle 2 (red line with squares). The vehicles were exposed to the same on-road flow simulated in the wind tunnel. As can be seen in figure 4, the modulation degree for vehicle 2 is considerably higher than that for vehicle 1 over the whole frequency range. Hence, it can be concluded that these modulation spectra can be used for rating vehicles with respect to their acoustic behaviour in turbulent flow. Additionally it proves that the system is able to reproduce on-road flow fluctuations such that the perception of the interior noise is similar to that on the road. It leads to similar ratings of different vehicles.

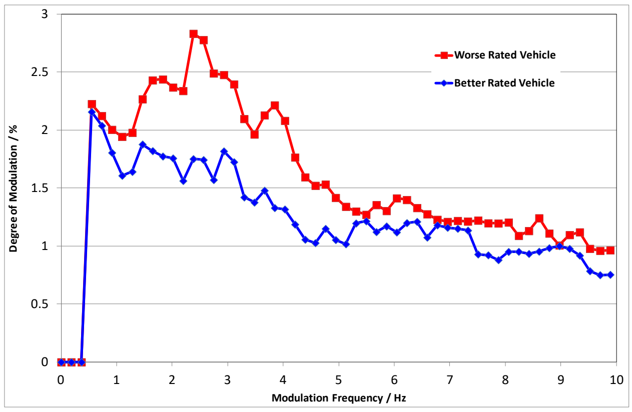

Figure 4: Modulation spectra in the 4-kHz octave band of the interior noise from two differently rated passenger vehicles exposed to the same unsteady on-road flow reproduced in the wind tunnel. [4]

Conclusions

First investigations confirm that the system meets the requirements which have been determined by on-road measurements as well as considering psychoacoustic aspects. It is able to reproduce the time histories of the incoming flow yaw angle. The turbulence of the flow leads to a modulation of the in-cabin noise similar to that on the road which in turn leads to a comparable rating of the vehicles as on the road. The modulation spectra of the interior noise underline this finding. Further investigations are necessary to affirm these results and to enhance the range of application

Literatur

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