Labor Windkanal/Strömungsmesstechnik

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Spectral Turbulence Analysis of the Regensburg Wind Tunnel (RWT) With Respect to Different Sealing Procedures

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1. Turbulence

The main objective of this work is a spectral turbulence analysis of the RWT. The turbulence intensity is an important parameter for wind-tunnels with regard to their flow quality. First of all it is important to know what turbulence is and how it is defined.

The superposition of the mean flow velocity $\bar{u}$ at a local point by temporal disordered changes of flow velocity $u'(t)$ is called turbulence [WU68]. The upper part of Fig. 1 shows the unsteady flow velocity in relation to the time. $\bar{u}$ makes the mean velocity. The turbulence intensity refers to all three spatial directions, however in wind-tunnel it is sufficient to measure the changes in flow direction. The turbulence intensity is specified in percentage and is defined as:

$$T_u = \frac{u_{rms}}{\bar{u}}$$

u_{rms}: root mean square
$\bar{u}$: mean velocity

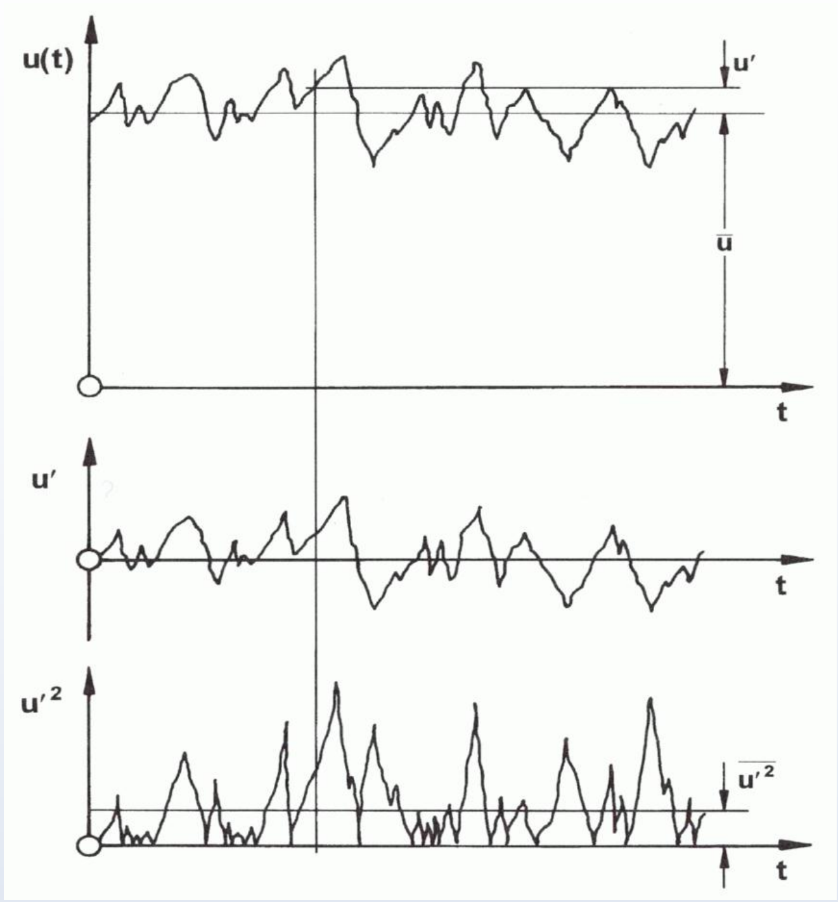

Fig. 1: chronological sequence of the velocity in a boundary layer

There are two possible ways to calculate the u_{rms}-value: the normal case, which is frequency-independent (equation on the left) and a frequency-dependent way (equation on the right), which is much more relevant for this work.

$$u_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(u_i - \bar{u})^2}$$

N: number of samples

$$u_{rms} = \sqrt{2 \cdot \sum_{i=N_c}^{N/2} |X_i|^2} \, .$$

X_i: Fourier coefficient of the velocity-time-signal
N_c: number of samples, related to the cut-off frequency

2. Experiment Setup

The registration of the turbulence intensity requires a temporal high resoluted velocity-time-signal. The measurement (DANTEC StreamLine) took place in the closed measurement section of the RWT. This measurement section is directly mounted on the wind-tunnel nozzle, seperated only by a sealing. The first measurement data had somewhat discouraging due to a not well established sealing between nozzle and testsection. Therfore, the test hab been expanded by the use of subsequent sealing concepts (Fig. 3 to Fig. 7). The data were acquired over 5 s by flow velocities between 5 and 45 m/s in steps of 5 m/s and a sampling frequency of 40 kHz. Therefore, oscillations up to 20 kHz can be evaluated.

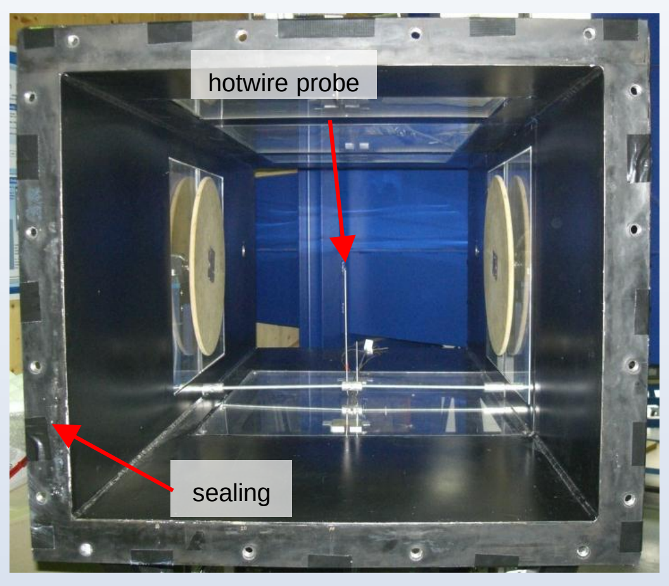

Fig. 2 : measure system in the test section, view in flow direction

Fig. 3: flat rubber seal

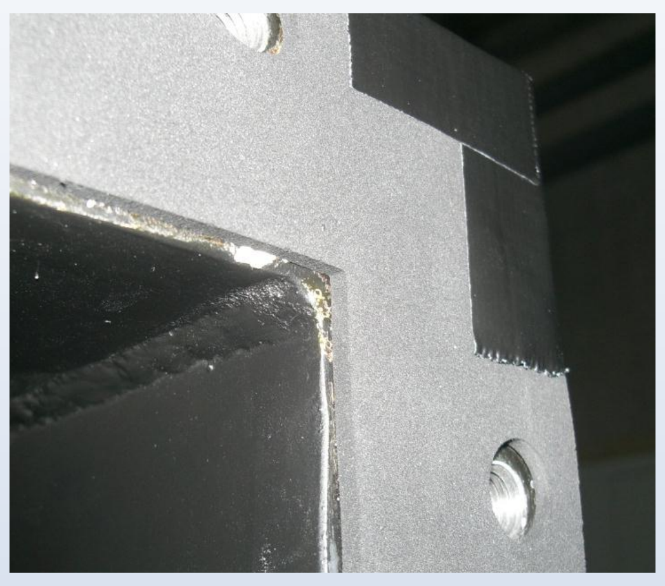

Fig. 4: foam seal

Fig. 5: P-profile seal

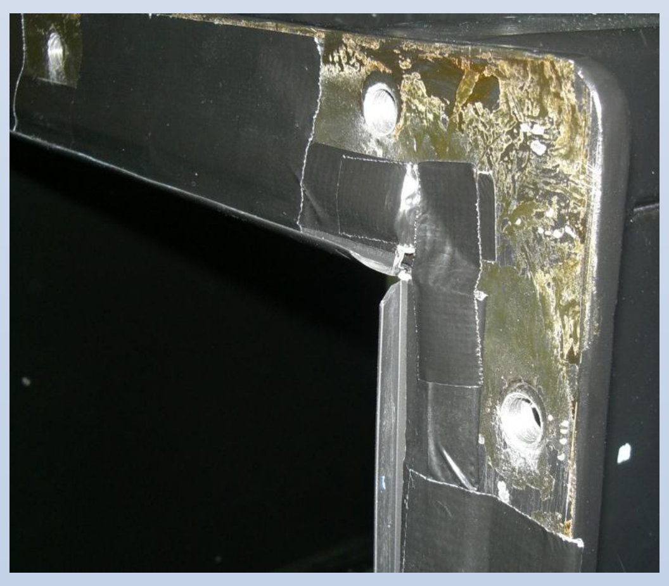

Fig. 6: mushroom seal

Fig. 7: Kombi seal

3. Spectral Turbulence Analysis

By means of Fourier transformation of the time signal, it is possible to extract the frequencies in which the flow velocity is oscillating. Fig. 8 shows the power density function of a perfect mounted flat rubber seal. This sealing provides the best results of the turbulence intensity in an area from 5 to 35 m/s. This corresponds to a turbulence rate of 0,30 %. Above 35 m/s it is more advantageous to use the P-profile seal (Fig. 9) or the mushroom seal (T_u = 0,35 %).

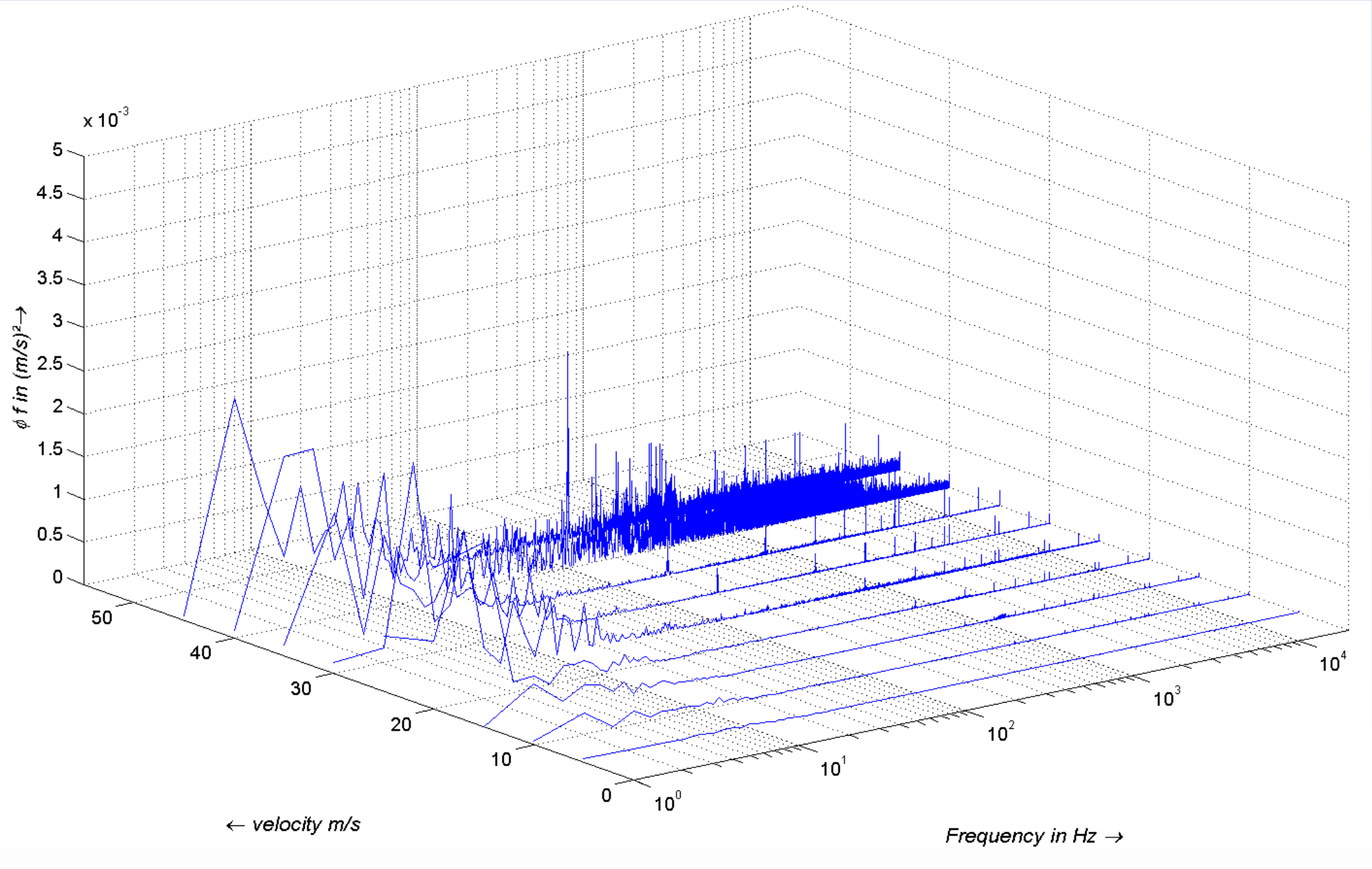

Fig. 8: power density function of the flat rubber seal

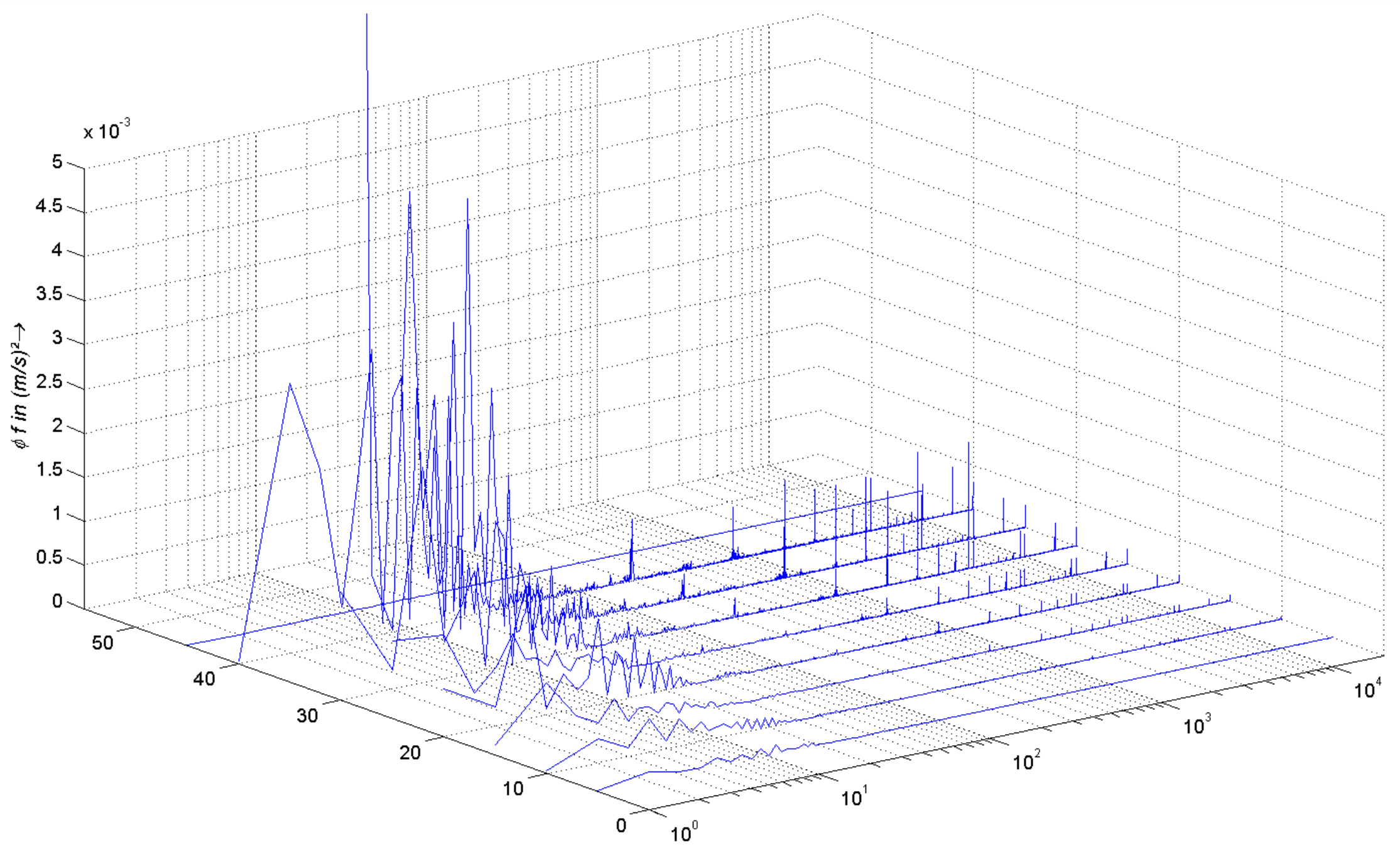

Fig. 9: power density function of the P-profile seal

4. Effective Turbulence Intensity

Long- and middle-wave oscillations can often be seen as quasi-stationary. Therefore these oscillations can be eliminated from the calculation of the turbulence intensity.
If for example an airfoil is investigated, oscillations with a minimum wavelength, which corresponds to the time, a particle needs to pass the airfoil, can be seen as quasi-stationary. In case of the airfoils at the laboratory "wind-tunnel / flow measure technique", oscillations below 20 Hz can be disregarded when calculating the turbulence intensity. Fig. 10 and Fig. 11 show the turbulence intensity for different velocities in relation to the frequencies above 20 Hz.

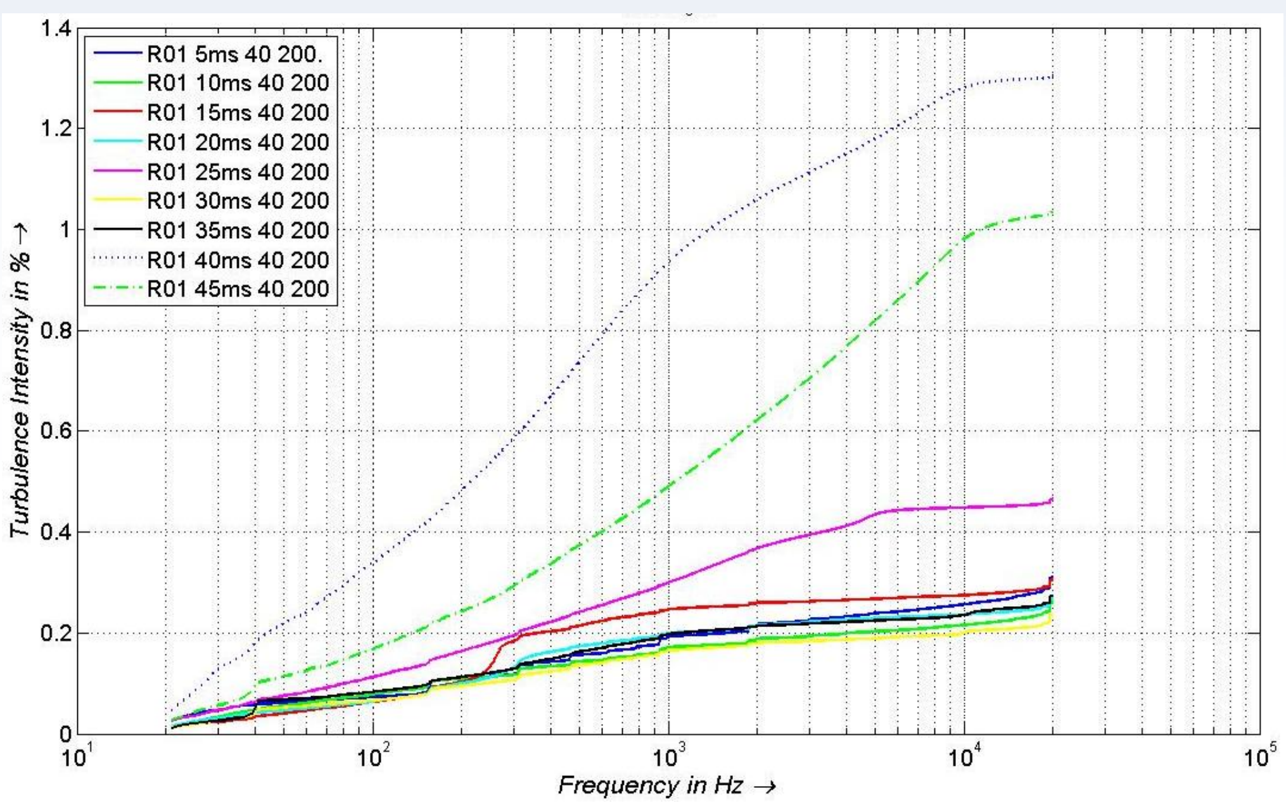

Fig. 10: increase in turbulence intensity in relation to frequency, flat rubber seal

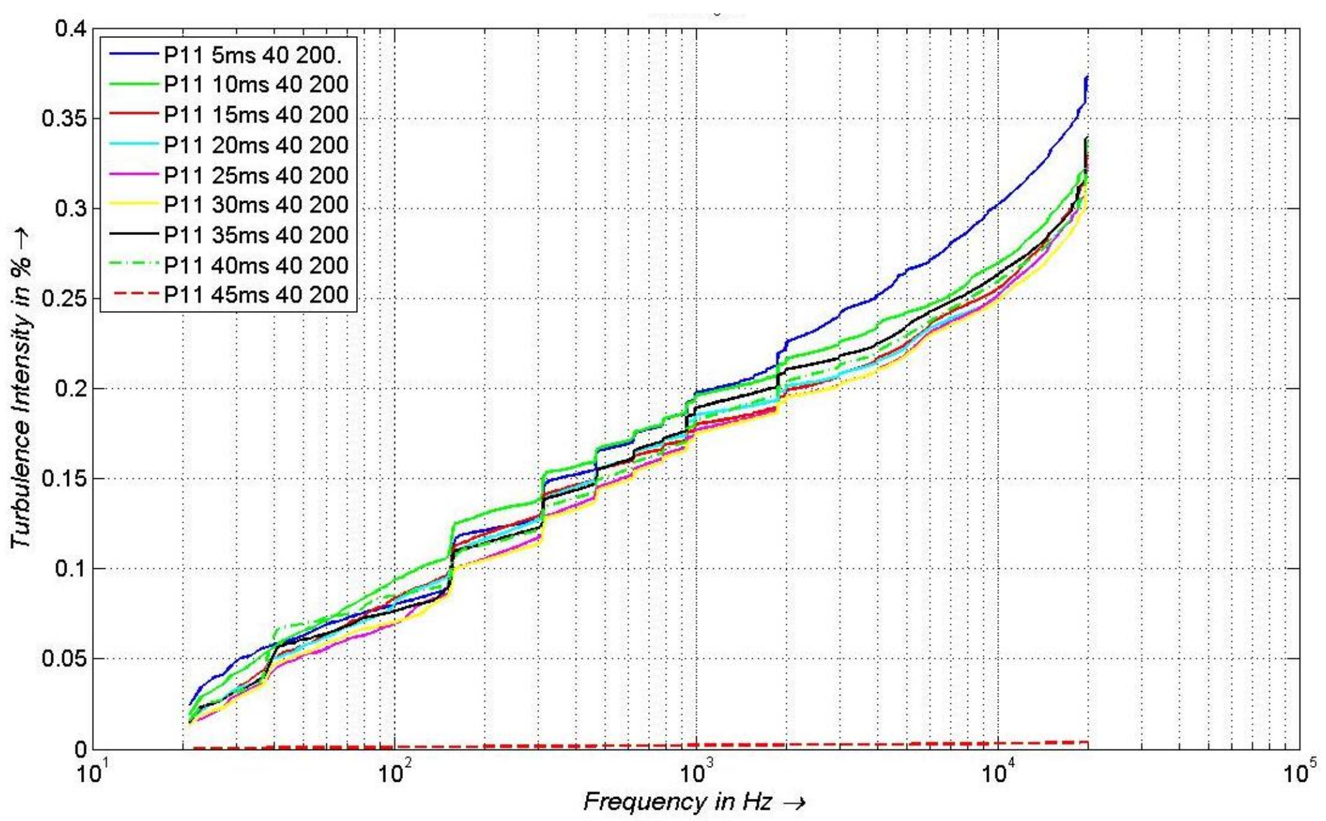

Fig. 11: increase in turbulence intensity in relation to frequency, P-profile seal

References: [WU68] Wüst, W: Strömungsmesstechnik. Braunschweig, Vieweg, 1968.