

## Properties of aerodynamic reference sound sources

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### Introduction

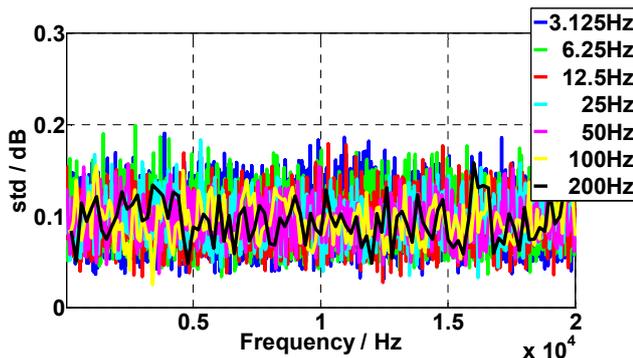
The work presented, lies within the scope of the European Metrology Research Programme (EMPR) and is related to the realisation and dissemination of the unit watt in airborne sound. The current sound power measurements are characterised by a lack of traceability, whose establishment is one of the main aims of the programme. The use of appropriate transfer standards to disseminate the unit is essential for the whole project. Investigations on aerodynamic reference sound sources (RSS) have been performed, since this kind of sources is intended to be used as transfer standards.

### Randomness of signal

The standard deviation of a random signal is related to signal bandwidth and measurement duration, according to the following equation:

$$\sigma = \frac{4.34}{\sqrt{BT}} \text{ dB} \quad (1)$$

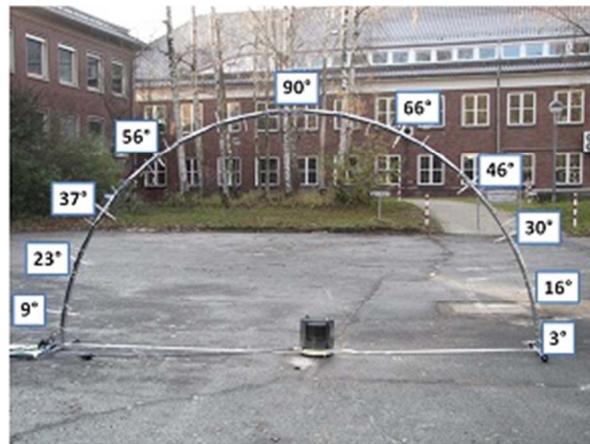
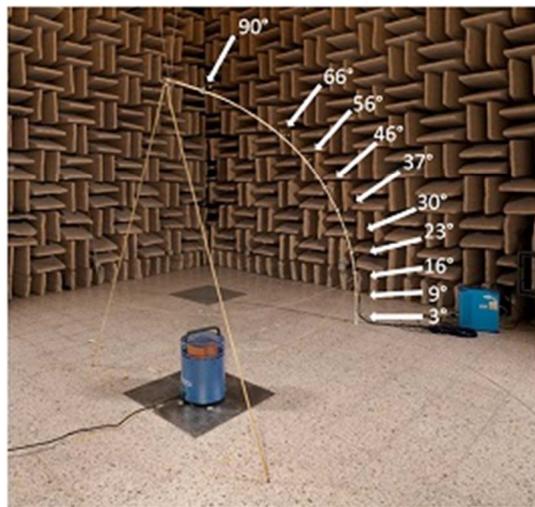
where  $B$  is the signal bandwidth in Hz and  $T$  the measurement duration in s [1]. The RSS signal randomness was checked by using eq.(1). The bandwidth of the measurements was set according to the available FFT resolutions of the acquisition software, namely 3.125, 6.25, 12.5, 25, 50, 100 & 200 Hz. A 1/2" condenser microphone was used for the signal recording and one RSS.



**Figure 1:** Standard deviation of RSS signal for measurements with different frequency resolution.

Initially, the measurement duration for each frequency resolution was chosen so as the standard deviation to have a theoretical value of 0.1 dB. The standard deviation results are shown in figure 1. For further validation of the RSS signal randomness, measurements were performed with 3.125 Hz frequency resolution. Based on this resolution, signals for the other resolutions were calculated and the corresponding standard deviation was estimated. It has been

found that the standard deviation decreases by increasing bandwidth and measurement duration. The signal randomness was further proven by showing that the distribution of standard deviation values follows a  $\chi^2$ -distribution.



**Figure 2:** Measurements setup for directivity measurements indoors (top) and outdoors (bottom). The arc radius is 2 m in both setups.

### Directivity and sound power

The uncertainty of a measured sound power is strongly related to the source directivity. Therefore, a measurement setup was developed for directivity measurements. After initial measurements including eleven 1/4" condenser microphones, it was decided to perform measurements using ten microphones placed at positions constituting a compromise between equal angles and equal surfaces positioning, which are recommended for directivity and sound power measurements in [2]. Measurements included six RSSs of four different types. Figure 2 (top) shows the setup.

Directivity measurements led to the calculation of the directivity index (DI) for each RSS, which is determined by the following equation:

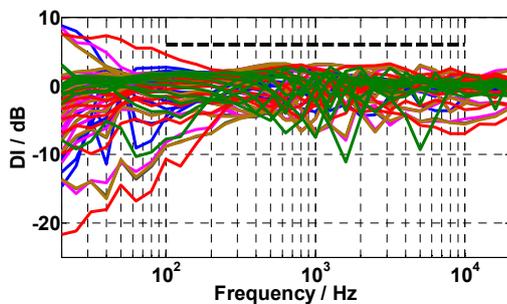
$$DI_i = L_{pi} - \bar{L}_p \quad (2)$$

where  $L_{pi}$  is the sound pressure level at the  $i$ -th position and  $\bar{L}_p$  is the sound pressure level averaged over the measurement surface [2]. The sound power level can be calculated, according to the following equation:

$$L_w = 10 \log \left( \sum_i S_i \times 10^{L_{pi}/10} \right) \text{dB} - 10 \log D \text{dB} \quad (3)$$

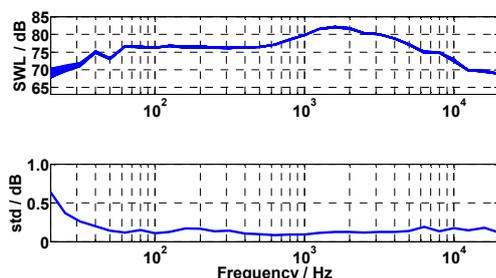
where  $S_i$  is the area of the  $i$ -th microphone,  $L_{pi}$  the sound pressure level of the  $i$ -th microphone and  $D = \rho c / (400 \text{ N} \cdot \text{s}/\text{m}^3)$ , with  $\rho$  and  $c$  being the density of air and the sound speed in air [3].

The directivity index values for all RSS measurements fulfill the requirements of ISO 6926 as shown in figure 3.



**Figure 3:** Directivity index for all RSS measurements (coloured) and maximum value according to ISO 6926 (dashed).

Results of sound power levels and the corresponding standard deviation are presented in figure 4. The measurements lasted two months, during which 11 measurement sets of each source were concluded, yielding 110 sound power levels in total.

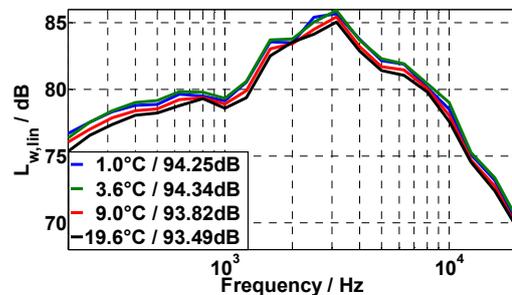


**Figure 4:** Sound power level (top) and corresponding standard deviation (bottom) for a RSS source.

### Temperature influence

The sound power of a RSS is also influenced by environmental conditions, such as barometric pressure and temperature. For the study of this kind of influences, outdoor measurements were performed. For this purpose, another setup was constructed, using ten 1/2" condenser

microphones, placed at the same positions as mentioned in the previous paragraph. Figure 2 (bottom) shows the setup. Three RSSs of different types have been used for this investigation. A first representation of results corresponding to both indoor and outdoor measurements for a temperature range from 1°C to 19.6°C are shown in figure 5. The reader must note that data is presented in the frequency range from 200 Hz to 20 kHz, due to influence of background noise in lower frequencies for the outdoor measurements.



**Figure 5:** Sound power levels of a RSS for different ambient temperatures.

### Conclusions

The randomness of the signal emitted by reference sound sources was checked and validated by comparison to a  $\chi^2$ -distribution. The directivity has also been studied. It turned out that the directivity criteria of ISO 6926 are met by all investigated reference sound sources. Based on directivity measurements, sound power levels were calculated assuming rotational symmetry. The standard deviation of repeatability of these sound power levels is very small (about 0.2 dB), even though the measurements were performed in a relatively large time span of 8 weeks. Initial results of the influence of temperature on sound power levels were also presented. A temperature shift of about 18 K accounts for a sound power level change of about 1 dB. These results show that aerodynamic reference sound sources can be expected to be appropriate transfer standards for the dissemination of the unit watt.

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### Literature

- [1] Vorländer, M.: Intercomparison on sound power instruments by use of reference sound sources, PTB, 1992
- [2] ISO 3745:2012, Determination of sound power levels and sound energy levels of noise sources using sound pressure – Precision methods for anechoic rooms and hemi-anechoic rooms
- [3] Ver I. L. & Beranek L.L., Noise and vibration control engineering, Wiley, 2006
- [4] ISO 6926:1999, Requirements for the performance and calibration of reference sound sources used for the determination of sound power levels