Microphone array measurements for aeroacoustic investigations using a frequency band averaging method

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Introduction

The joint research project *SWING+* (Simulation of Wing Flow Noise Generation) aimed on the numerical simulation of aerodynamic airframe and wing noise. Part of this project were extensive aeroacoustic measurements for the validation of numerical examinations. For sound source localization applications a microphone array had to be set up. To obtain knowledge about basic array parameters and distributions, a student's work [1] was carried out on the example of a line array. The line array in use consisted of eight equally spaced microphones and had a total length of 1.5 m. It was applied for the localization of acoustic model sources and aeroacoustic sources. All experimental investigations were carried out using a Bruel & Kjaer eight channel spectrum analyzer and condenser microphones. For the array signal processing the frequency domain farfield beamforming algorithm was applied [2, 3].

Band averaging technique

For the localization of model sound sources with small dimensions, it is necessary to use an array possessing a directional pattern with small mainlobe. This is the case for an equidistant microphone distribution. Important disadvantages of equidistant arrays are the dominant sidelobe structures in the directional diagram, which are due to spatial undersampling. They occur, if at high frequencies less then two microphones per wavelength are available. Hence these sidelobe structures are a function of frequency and it is possible to decrease them by summing the magnitude values of the spectral lines of the array's output signal in a certain frequency band. This technique is especially suitable for broadband noise sources (octaves and broader frequency ranges) but can also be applied to narrowband noise sources (e.g. 1/3-octaves or 1/12-octaves), then yielding lower sidelobe suppression levels.

Test measurements in the anechoic chamber

The first experimental investigations with the line array were carried out in the anechoic chamber. Different distributions of acoustic model sources (monopoles and dipole) were localized and separated. The examinations showed, that for the measurements at a single monopole a source localization was possible also without frequency band averaging. But for the case of two monopoles (compare Figure 1) and dipole only with frequency band averaging useful results could be obtained. It is therefore proposed, to always decide depending on the configuration and the targeted frequency range, whether to use frequency band averaging or not.

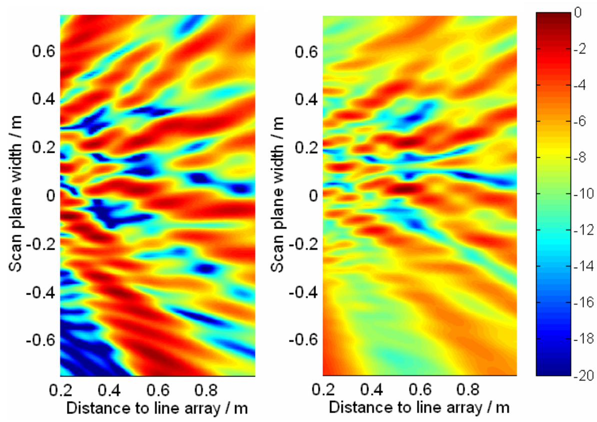

Figure 1: Separation of two monopole sources at $P_1(0.55,0)$ and $P_2(0.55,0.2)$, normalized SPL [dB], left hand side: without frequency band averaging, right hand side: with frequency band averaging

Measurements on a generic wing profile in flow

All aerodynamic examinations were carried out in the anechoic wind tunnel of the institute. The first aeroacoustic test case was a generic aerodynamic profile of the type NACA0012 with a chord length of 120mm and a span length of 140mm (with end caps). The mean flow velocity was v_0=38m/s (related to a Mach number of M=0.11 as used during the corresponding numerical examinations) and the angle of attack was zero for all examinations.

The trailing edge of the profile could be determined as the major sound source in horizontal and vertical direction. An example is demonstrated in Figure 2, where the localization in spanwise direction in parallel to the center of the array and for a distance between array and profile chord of 0.55m is demonstrated. The position of the profile is indicated by a dashed rectangle and a wing sketch. The normalized SPL are compared for a single spectral line f = 4kHz and after band averaging in the octave band with f_{moct} = 4kHz. Since the trailing edge noise is of broadband noise character, the frequency band averaging was especially suitable for this case. Similar to the case of the two monopole sources as discussed before, only with this frequency band averaging useful results could be obtained.

But useful conclusions could only be drawn for the 1-D case. The spatial resolution in vertical direction was strongly limited, since the directional pattern of a line array normal to the line axis is a sphere. So for further measurements of this sound source a 2-D-array is proposed.

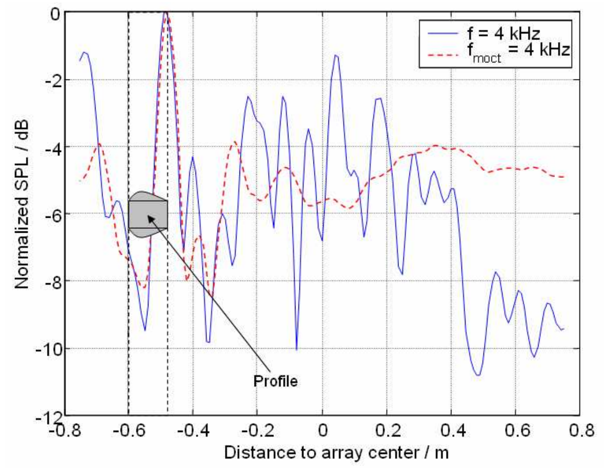

Figure 2: Detection of the trailing edge of the NACA 0012 wing profile as major sound source in spanwise direction, comparison of results for single spectral line f = 4kHz and octave band averaging f_{moct} = 4 kHz

Measurements on a cylinder in flow

For comparison, experiments were also carried out on a cylinder in a flow. The basic applicability of a line array to rather tonal acoustic sources like in the case of a cylinder in flow should be demonstrated. The tested cylinder had a diameter of d = 4.5mm and was examined at two different mean flow velocities, v_{01} = 20m/s and v_{02} = 40m/s, corresponding to tones of f_{01} = 900Hz and f_{02} = 1800Hz. The cylinder could be localized as the major sound source at both frequencies. The result for v_{01} = 20m/s is shown in Figure 3 for a single spectral line of f = 896Hz. The position of the cylinder is indicated by a dashed line.

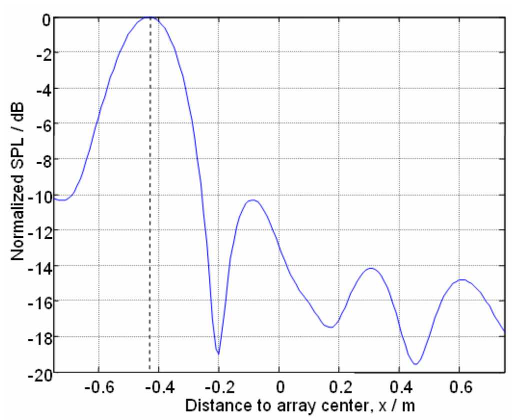

Figure 3: Localization of the sound source caused by a cylinder in flow, v_{01} = 20m/s, f = 896Hz

The tests showed that for low frequencies the frequency band averaging delivers no improvement of the localization results since the sidelobe structures do not show significant changes. But a different display of array data can be used: a 3D-plot of location in source line, frequency and SPL level. In such a graph, only the location of the main source remains constant, mirror sources vary in location with frequency. An example is demonstrated in Figure 4, showing the result for v_{02} = 40m/s displayed in the octave band with f_{moct} =2 kHz. Also in this figure, the position of the cylinder is indicated by a dashed line.

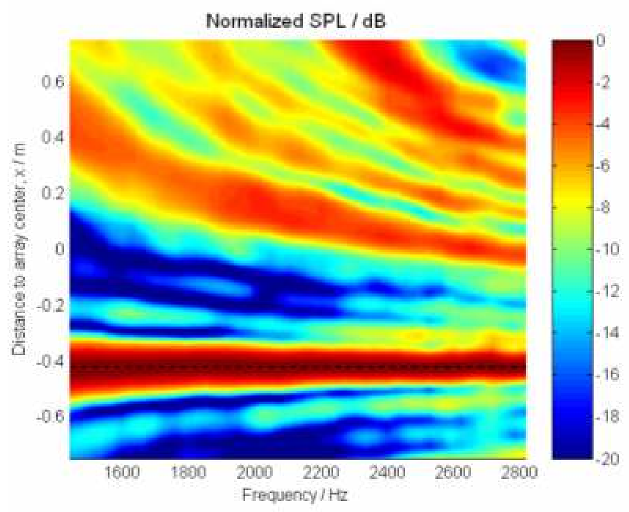

Figure 4: Localization of the sound source caused by a cylinder in flow for v_{02} = 40m/s

Summary

Frequency band averaging was found to be a useful tool for the enhancement of microphone array results. This technique can be applied especially for high frequencies and broadband noise sources (averaging in octave or broader bands), but can also be useful for narrowband noise sources (averaging in 1/12-, 1/3-octave bands). Only at low frequencies the averaging method is limited. Precautions should be taken to determine the frequency and spatial distribution of sound sources before applying the band averaging. For such an investigation a graphical scheme like in Figure 4 demonstrated can be used. These assumptions were proven by line array measurements, carried out on model sources as well as on aeroacoustic sources. Since the 2-D-spatial resolution of a line array is limited, a 2-D-microphone array was already set up for further investigations.

Acknowledgements

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