Identification of a Low-Frequency Sound Source in an Aircraft Engine Test Stand

Wilhelm von Heesen, Andy Péus, Raimund Grüner

Müller-BBM GmbH, D-82152 Planegg, Germany, Email: hsn@mbbm.de

Introduction

The tenants of an office building complained about strong low-frequency noise < 50 Hz from a nearby aircraft engine test stand. Müller-BBM was commissioned to identify the location and the nature of the sound generating mechanism.

Test stand

The test stand (cf. Fig. 1) resembles an open-circuit wind tunnel with the aircraft engine located at the end of a horizontal inlet duct. The engine discharges into a horizontal pipe with a conical collector at the inlet. At the end of the pipe there is a 90° bend followed by a vertical exhaust duct. The inlet and the outlet of the test stand are equipped with absorptive baffle-type silencers giving high attenuation at frequencies > 80 Hz.

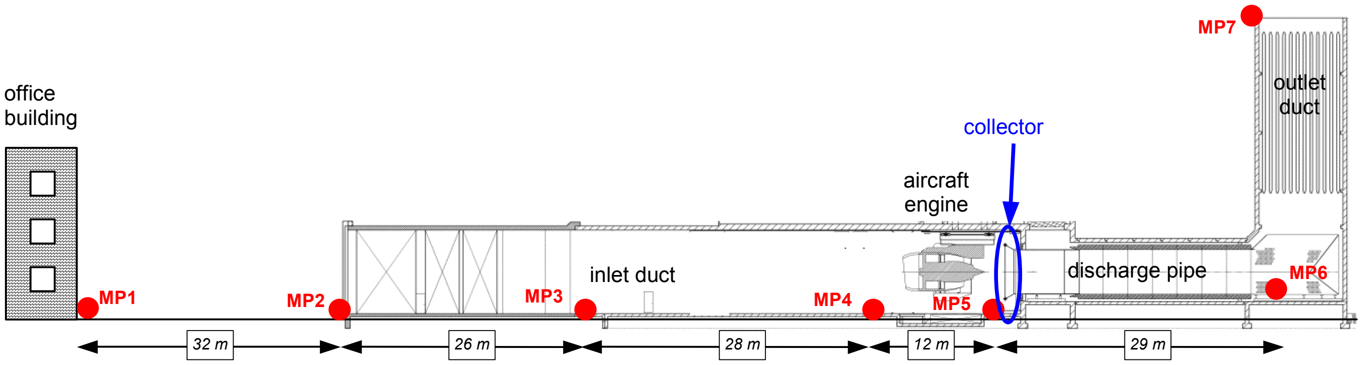

Figure 1: Test stand and microphone positions.

Procedure

Several microphones were installed in the test stand and at the office building (cf. Fig. 1). The source localization method utilizes the fact, that the time delay and the phase spectrum between two microphones contains information on the direction and the velocity of sound propagation.

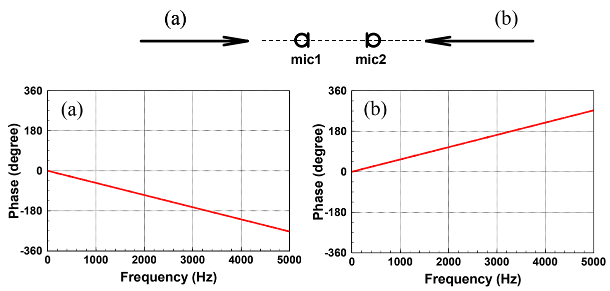

Figure 2: Detection of propagation direction using phase spectrum between two microphones.

Consider a plane wave impinging on two microphones as illustrated in Fig. 2. The time delay τ between the two microphones is a function of the propagation velocity c and the distance d between the microphones: $\tau = d/c$. A positive delay indicates propagation from microphone 1 to microphone 2 and a negative delay indicates propagation from microphone 2 to microphone 1. The time delay can be measured via the cross-correlation function. The phase spectrum between the microphones also contains information on the propagation velocity and direction. A negative phase gradient indicates propagation from microphone 1 to microphone 2 and vice versa.

Inside the test stand the propagation velocity c is the sum of the speed of sound $c_0 \approx 340$ m/s and the flow velocity v.

MP4 → MP3

Fig. 3 shows the phase spectrum and the cross-correlation from MP4 to MP3. The distance between the microphones is $d = 28$ m; the flow velocity in the inlet duct is approx. $v = 15$ m/s. The negative phase gradient indicates propagation from MP4 to MP3, i.e. against the flow. The optimum correspondence between the measured and the computed phase spectrum is obtained assuming a propagation velocity of $c = 315$ m/s. This is consistent with expectations. The cross-correlation shows a maximum at $\tau = +0.088$ s which corresponds to a propagation velocity of $c = 318$ m/s. The cross-correlation was obtained with a bandpass filter 5 - 40 Hz for both microphone signals.

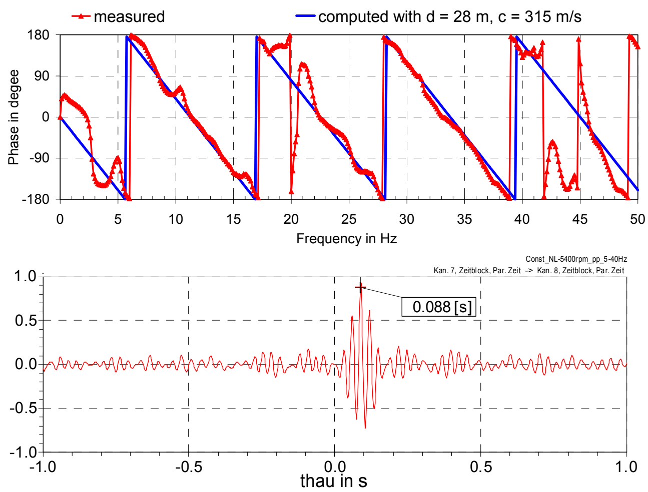

Figure 3: Measured and computed phase spectrum (top) and measured cross-correlation (bottom) from MP4 to MP3.

MP3 → MP2

Fig. 4 shows the phase spectrum from MP3 to MP2. The negative phase gradient indicates propagation against the flow. The propagation velocity is c = 285 m/s. This seems plausible, since the flow velocity in the silencer is somewhat higher than in the free duct between MP 3 and MP4.

The cross-correlation shows a maximum at τ = +0.092 s which corresponds to a propagation velocity of c = 283 m/s. A second maximum can be identified at τ = +0.273 s. The corresponding propagation velocity is 95 m/s, which does not really make sense. If we, however, consider a sound wave which is reflected from the building, then the corresponding distance covered by the sound wave on its way from MP3 via MP1 to MP2 is $d = 26 + 2{\cdot}32 = 90$ m and the resulting propagation velocity is c = 330 m/s. This is consistent with expectations since the wave travels mostly through air with no mean flow.

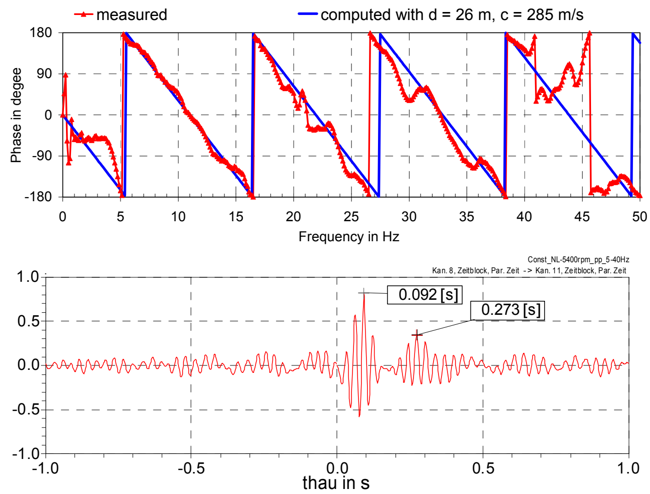

Figure 4: Measured and computed phase spectrum (top) and measured cross-correlation (bottom) from MP3 to MP2.

MP5 → MP4

The phase spectrum from MP5 to MP4 (cf. Fig. 5) has a negative gradient indicating propagation against the flow. The propagation velocity is c = 300 m/s. The sound source is located upstream of MP5.

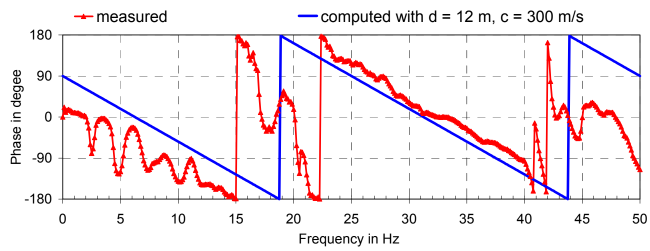

Figure 5: Measured and computed phase spectrum from MP5 to MP4.

MP6 → MP5

The gradient of the phase spectrum from MP 6 to MP5 is positive, indicating that the propagation now is with the flow. The correspondence between measurement and computation is not very good and the coherence between the microphone signals (not shown) is rather low, presumably because the microphone signal at MP6 is contaminated by flow turbulence.

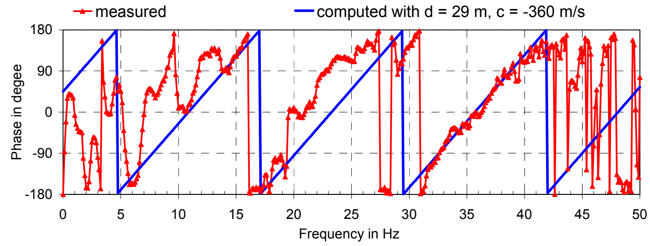

Figure 6: Measured and computed phase spectrum from MP6 to MP5.

Nevertheless the phase spectrum suggests a propagating velocity of approx. c = 360 m/s which is quite close to $c_0 + v$. From this can be concluded that the sound source is upstream of MP6 and close to MP5. If it were in the middle between MP5 and MP6 the time delay would be very short and the phase gradient would be very steep, both resulting in an implausibly high propagation speed.

MP7 → MP1

The phase spectrum from the test stand outlet (MP7) to the building (MP1) shows a negative phase gradient below 30 Hz and a positive gradient above 30 Hz (cf. Fig. 7). This means that below 30 Hz the sound propagates from the outlet to the building whereas above 30 Hz the energy flows contrariwise from the building to the outlet.

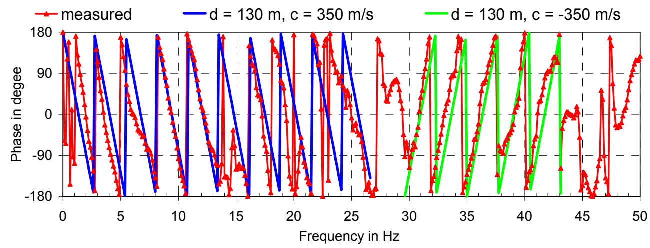

Figure 7: Measured and computed phase spectrum from MP7 to MP1.

Obviously the sound measured at the outlet at frequencies > 30 Hz is radiated not from the outlet but from the inlet and is reflected by the office building. This might indicate that there are actually two different noise generating mechanisms (one at < 30 Hz, the other at > 30 Hz).

Summary and conclusions

By analyzing the phase spectrum and the cross-correlation between several microphones in the test stand it could be shown that the low-frequency sound is generated at the conical collector at MP5. Usually the phase spectrum and the cross-correlation contain equivalent information. Under certain conditions - and with appropriate choice of bandpass filter limits - the cross correlation contains additional information, e.g. on reflections (cf. Fig. 4).

The most probable cause for the low-frequency sound are large-scale turbulences in the shear layer of the engine jet which impinge on the collector and generate dipole-type sound sources. By decreasing the outer diameter of the conical collector the low-frequency sound could be reduced by 8 dB.