# Investigation of the noise emission of the V2500 engine of an A320 aircraft during ground tests with a line array and SODIX

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**ABSTRACT**

Within the framework of the DLR research project SAMURAI, the jet noise of a an Airbus A320 during ground tests was investigated with a linear microphone array. One of the objectives of SAMURAI was to perform parallel measurements with a microphone array and laser anemometry methods, which required the experiments to be performed in the noise-protection hangar for static engine tests of Lufthansa Technik at Hamburg airport. In order to assess the impact of the room acoustics on the sound field, reference measurements under free-field conditions were performed on the airfield in Cochstedt. The microphone array data was analysed using classical spectral methods. With the SODIX (Source Directivity in the Cross Spectral Matrix) method, equivalent source distributions for different freqency bands and emission directions were calculated from the Cochstedt and Hamburg data. They show sources at the engine inlet, nozzle and along the jet. The main result of a comparative analysis of the data is that the conditions in the hangar are suitable for jet-noise measurements of an aircraft during ground tests.

## 1 INTRODUCTION

Within the framework of the DLR project SAMURAI (Synergy of Advanced Measurement Techniques for Unsteady and High Reynolds Number Aerodynamic Investigations), several DLR institutes performed joint measurement campaigns to investigate the acoustic and and the jet characteristics of the V2500 engines on the A320 DLR research aircraft ATRA.

One focus of SAMURAI lay on the application of laser diagnostic methods that yield image data of the flow field of the jet. The general objective was to apply and further develop these measurement techniques for integrated and parallel applications in wind tunnels, test rigs and in flight tests with parallel measurements of different characteristics of the the flow field in high

Reynolds number flows. The data acquired will be used to validate complex and instationary numerical simulations of high Reynolds number jet flows.

*Figure 1: Set-up of the linear microphone array at the Cochstedt airfield (left) and in the engine test hangar of Lufthansa Technik at Hamburg airport (right).*

The main experiments with the laser optical flow measurements had to be performed in the engine test hangar of Lufthansa Technik in order to comply with laser safety regulations and to avoid problems with weather conditions. Because of the unknown impact of the room acoustic poperties of the hangar, a set of reference measurements with the microphone array was performed under free-field conditions at the airfield in Cochstedt. Figure 1 shows the different set-ups.

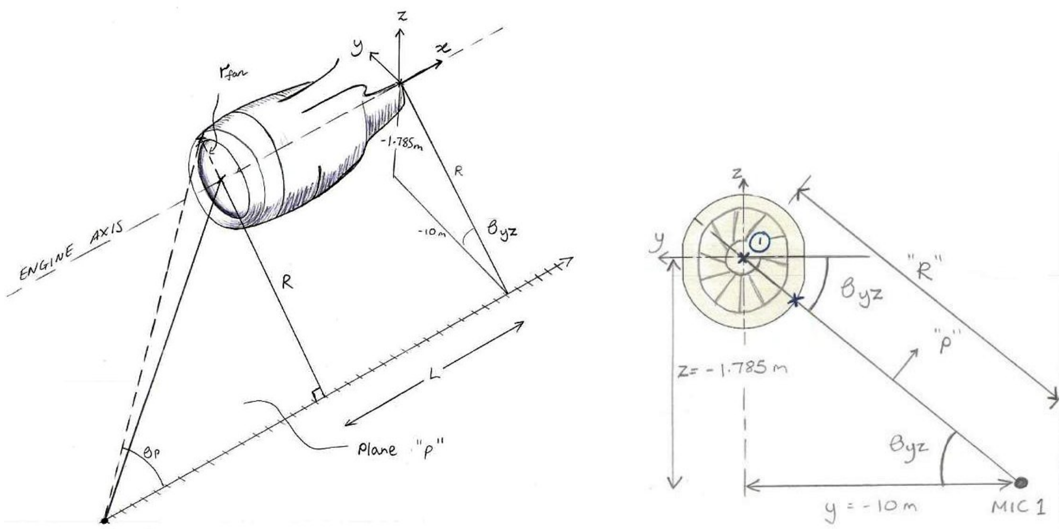
The acoustic measurements with the microphone array under free field conditions were performed in June 2013 on the airfield in Cochstedt. The main measurements were performed in September 2013 in the noise protection hangar of Lufthansa Technik at Hamburg airport. This paper describes both array measurements and compares the results with a focus on the differences induced by the different acoustic environments. Standard spectral measurements are used to analyse the directivity of the noise field and the SODIX (Source Directivity in the Cross Spectral Matrix) method [2–6] is used to analyse the sound field of the engine by calculating equivalent noise source distributions for different frequencies and emission directions.

*Figure 2: The starboard side IAE V2500 engine of the DLR research aircraft ATRA*

## 2 EXPERIMENTAL SET-UP

The objective of these experiments was to measure the sound field of an aircraft engine during ground operations. The DLR research aircraft ATRA was parked and a linear microphone array was set up parallel to the axis of one engine, measuring the sound field from a sideway distance of 10 m. The microphone array extended up to about 22 m up- and downstream of the engine nozzle.

The engines of the ATRA are IAE V2500 engines[1]. They are long cowl engines, see figure 2. The hot core jet and the cold bypass jet start to mix inside the nacelle and exit through the common nozzle, which has an inner diameter of 1.067 m.




(a) Schematic (b) *y*-*z*-plane

*Figure 3: Schematic of the set-up and definition of the coordinate system in the engine test hall of Lufthansa Technik at Hamburg airport.*

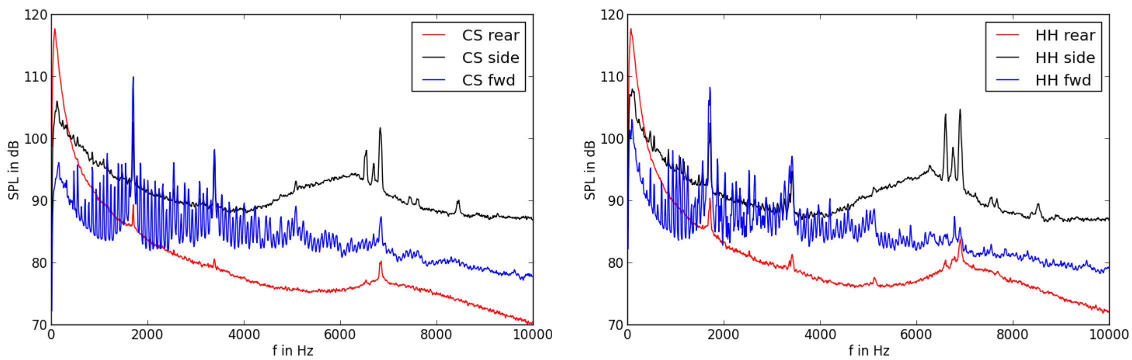



*Figure 4: Frequency spectra from the free-field measurements at Cochstedt (left) and the in-door measurements at Hamburg airport (right).*

The measurements were repeated for different engine shaft speeds between idle and maximum continuous thrust ($30\% \leq N1 \leq 83\%$, where $N1$in Hz $\approx 0.946\,N1$in $\% - 0.045$) with both engines operating at the same speed. The aircraft was held in position by the brakes on the landing gear only. The highest engine speed that could be achieved with the aircraft in a parking position was *maximum continuous thrust* with a shaft speed of $N1 = 83\,\%$.

The backward movement of the aircraft at different engine thrusts, which occured due to movements of the landing gear suspension systems, was monitored optically and remained below 20 cm for the highest engine speeds.

During both experiments, the data from the 248 array microphones were recorded simultaneously at a sampling frequency of $f_s = 40\,\text{kHz}$. When a particular constant engine shaft speed had been established, data were acquired for a period of 40 s.

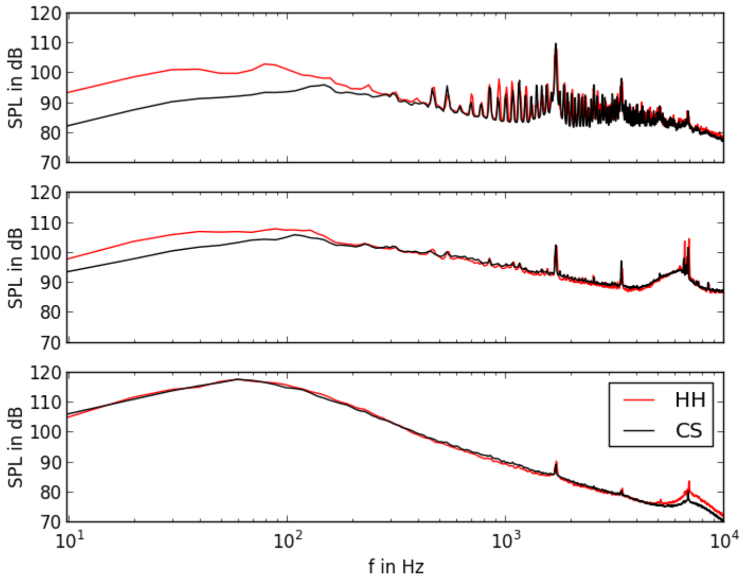



*Figure 5: Frequency spectra from the free-field measurements at Cochstedt compared with the in-door measurements at Hamburg airport. Top: forward arc; centre: side line; bottom: rear arc.*

### 2.1 General set-up of the array

Both experiments were performed using the same equipment. The linear microphone array was a modular set-up with 248 microphones mounted on rail segments. The microphone spacing was constant in the centre of the array and increased towards both ends from 150 mm up to 400 mm.

The coordinate system was centered at the nozzle exit plane on the engine axis (see figure 3) with the $x$-axis pointing in the direction of the jet, the $z$-axis pointing upwards and the $y$-direction according to the convention of a right-handed coordinate system.

The microphones were mounted on rail section with groups of 4, 8, or 16 microphones, depending on the length of the particular section. The microphones were organised in groups of

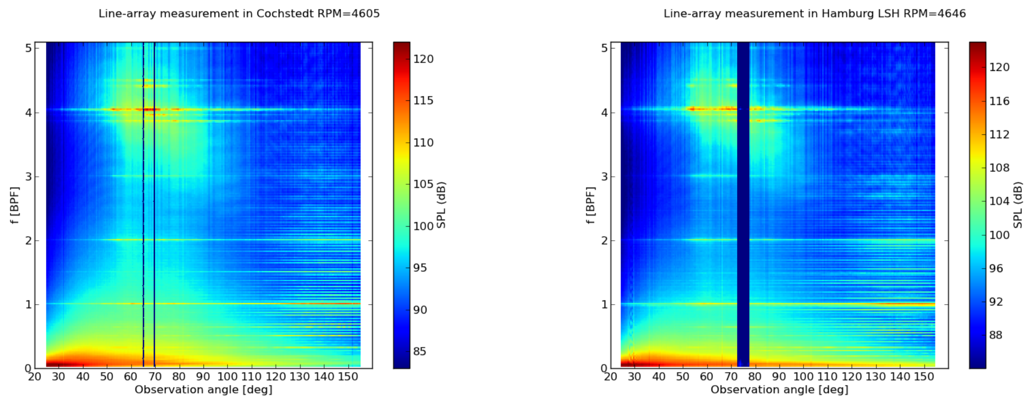



*Figure 6: Waterfall diagrams of the sound field directivity measured at the Cochstedt airfield (left) and in the noise protection hangar at Hamburg airport (right). The dark blue vertical lines correspond to microphone channels that were not considered in the analysis.*

eight which were connected to one concentrator box. The concentrator boxes were connected to the 32 channel AD converters in groups of four. The eight AD converter boxes were connected with digital cables of 50 m length to the data acquisition unit which in turn was remote controlled over an optical fibre link in order to get the personnel as far away from the aircraft engines as possible. In the free field experiment, sound pressure levels up to 100 dB were measured using a hand-held sound level meter at a distance of approximately 30 m away from the aircraft.

At Cochstedt, the array was set up on the starboard side of the aircraft due to several constraints which prevented using the planned set-up for the experiments in Hamburg, where the port side engine was supposed to be measured. This meant that at Cochstedt, the $y$-axis of the coordinate system pointed from the engine towards the array. In the engine test hall at Hamburg airport, the array was set-up as shown in figure 3 with array was on the port side of the aircraft.

## 3 DATA ANALYSIS AND FIRST RESULTS

The microphone array data from both experiments was verified and calibrated. During both experiments, some of the 248 microphones were not operating and were therefore not considered during the data analysis.

For the analyis shown in this paper, the case with the highest engine speed (*maximum continuous thrust* with $N1 = 83\%$) was chosen and analysed with classical methods and the SODIX method. This high engine speed provides a particular challenge for the SODIX method, because the sound field is dominated by the jet noise, which radiates towards the rear arc, but there are also strong tonal sources from the *buzz-saw-noise* mechanism that radiate forward from the inlet duct.

Frequency spectra measured at this engine speed during both campaigns are presented in 4. From the data, the three microphone positions far upstream, to the side, and far downwstream of the engine are presented. The frequency spectra, which were measured at different times, locations, and even for the two different engines of the ATRA (the starbord side engine at

Cochstedt, the port side in Hamburg), nevertheless show a remarkable similarity. The direct comparison of the spectra in the three directions is shown in figure 5: in the forward arc and to the side, the sound pressure levels measured indoors are significantly higher for frequencies below 300 Hz. This can be attributed to the low-frequency jet noise from both engines being reflected off the roof and side walls of the Hamburg hangar. In the rear arc, where the jet is the strongest source, the direct jet noise is strong enough to mask the impact of the reflections. In the forward arc, the distribution and strength of the buzz-saw noise peaks is different in both measurements, however this is not unusual for different engines of the same production type. These differences are most likely independent of the measurement conditions.

Figure 6 shows the the directivity of the measured sound field. It presents the frequency spectra of all array microphones for the Cochstedt and Hamburg experiments for an engine speed of $N1 = 83\%$. On the horizontal axis is the emission angle, which is the angle between the engine axis and a direct line from the microphone position to the axis of the engine at the position of the nozzle. The $\theta = 90°$ position is directly to the side of the engine nozzle, smaller angles are in the rear arc towards the jet and angles $\theta > 90°$ lie forward in the direction of flight. The vertical axis is the frequency axis. The frequency is scaled with the engine $N1$ shaft frequency and 22, the number of fan blades of the V2500 engine, in order to obtain the non-dimensional blade passing frequency (BPF). A BPF of 1 is 22 revolutions of the low pressure shaft ($N1$). The tonal components at the blade passing frequency and its higher harmonics show as horizontal lines in Figure 6. These fan tones radiate strongest in the forward arc (i.e. for $\theta > 90°$. The blade passing frequency (BPF 1) and its fourth harmonic (BPF 4) also propagate through the by-pass duct of the engine and radiate into the rear arc. The BPF 4 and a lower interaction tone radiate strongly towards the side, around $\theta = 90°$. The low frequency noise from the jet is strongest in the rear arc for $\theta < 90°$.

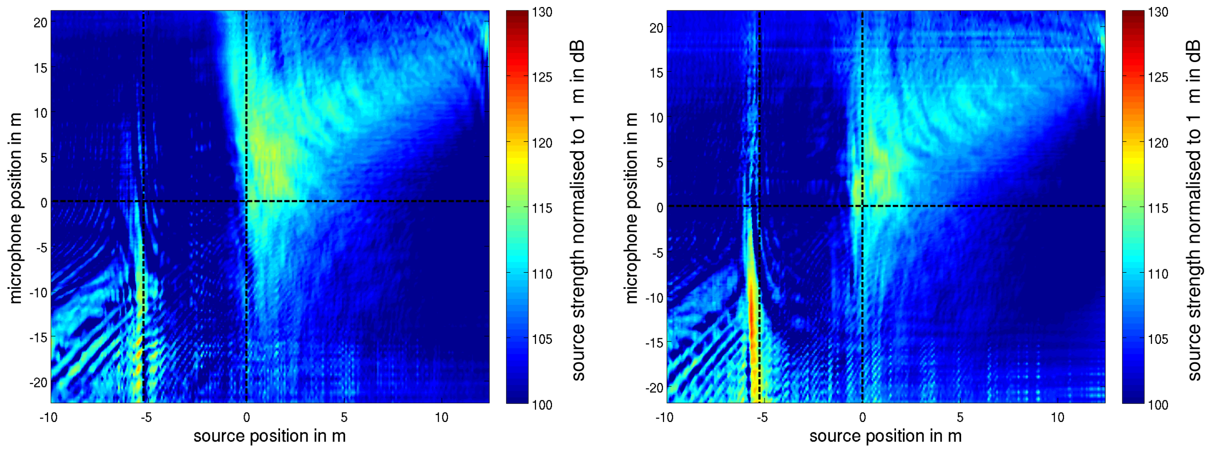



*Figure 7: SODIX sound source directivity map for the 1 kHz one-third-octave-band. Left: Cochstedt, right: Hamburg experiment. The engine inlet and nozzle positions are marked with vertical dotted lines.*

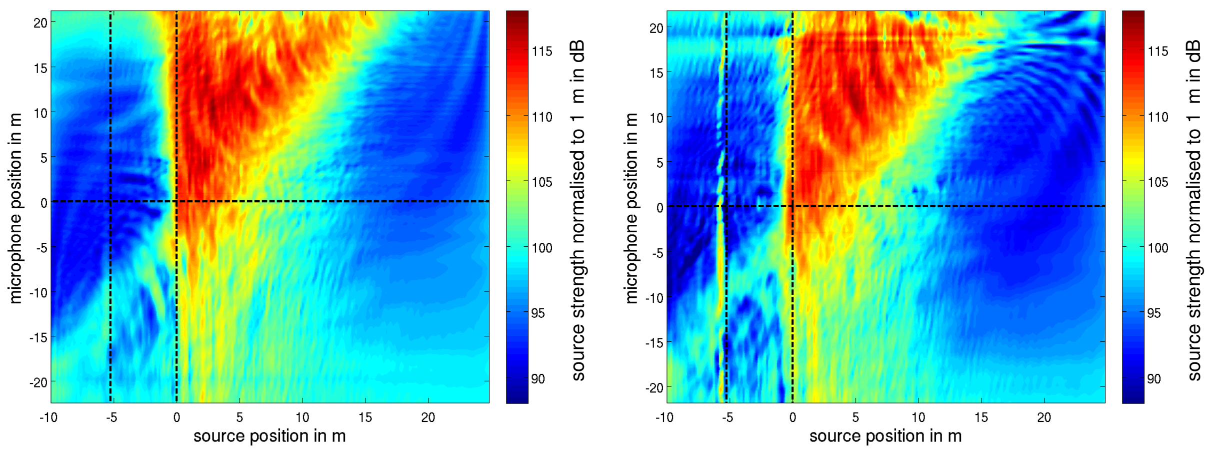



*Figure 8: SODIX sound source directivity map for the 500 Hz one-third-octave-band. Left: Cochstedt, right: Hamburg experiment.*

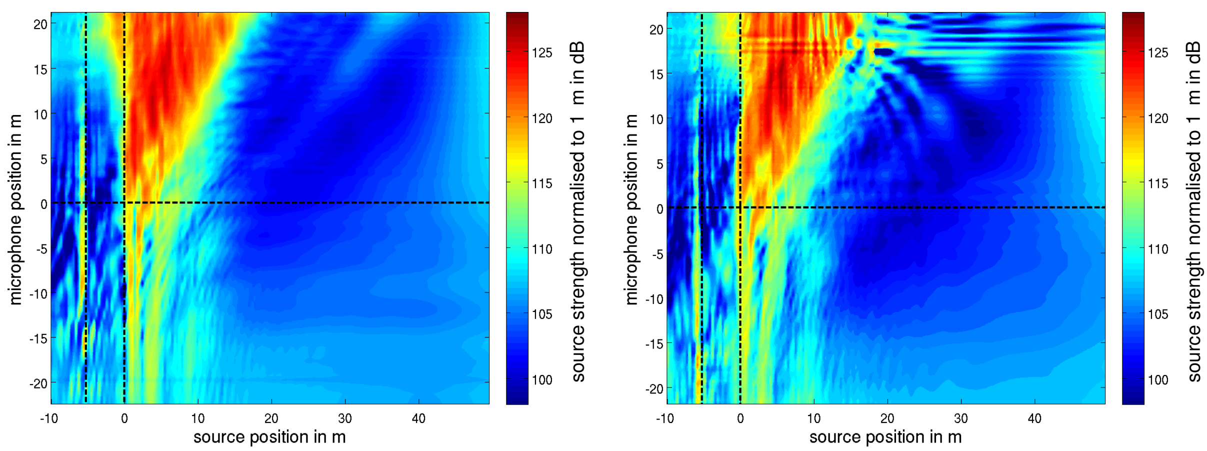



*Figure 9: SODIX sound source directivity map for the 250 Hz one-third-octave-band. Left: Cochstedt, right: Hamburg experiment.*

## 4 FIRST RESULTS OF THE ACOUSTIC SOURCE ANALYSIS WITH SODIX

A prelimiary analysis of the data for the shaft speed of $N1 = 83\,\%$ was performed using the SODIX algorithm. SODIX was used to calculate a distribution of directive point sources that best reproduces the cross spectral matrix from the experimental microphone array data. The cross spectral matrices were calculated from the calibrated array data. The point sources were located on the engine axis. A different distribution of sources was used for every one-third-octave frequency band. The sound source model in SODIX is a set of incoherent point sources. The directivity of the sound field is taken into account by calculating a different point source amplitudes for every microphone position. The results of the SODIX analysis are distributions of equivalent sources in every one-third-octave band and for every microphone position.

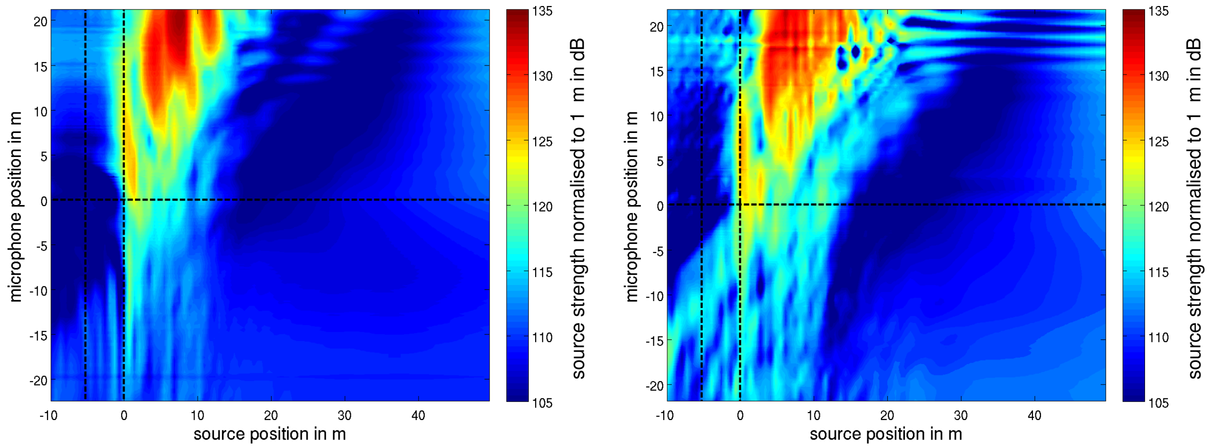



*Figure 10: SODIX sound source directivity map for the* 125 *Hz one-third-octave-band. Left: Cochstedt, right: Hamburg experiment.*

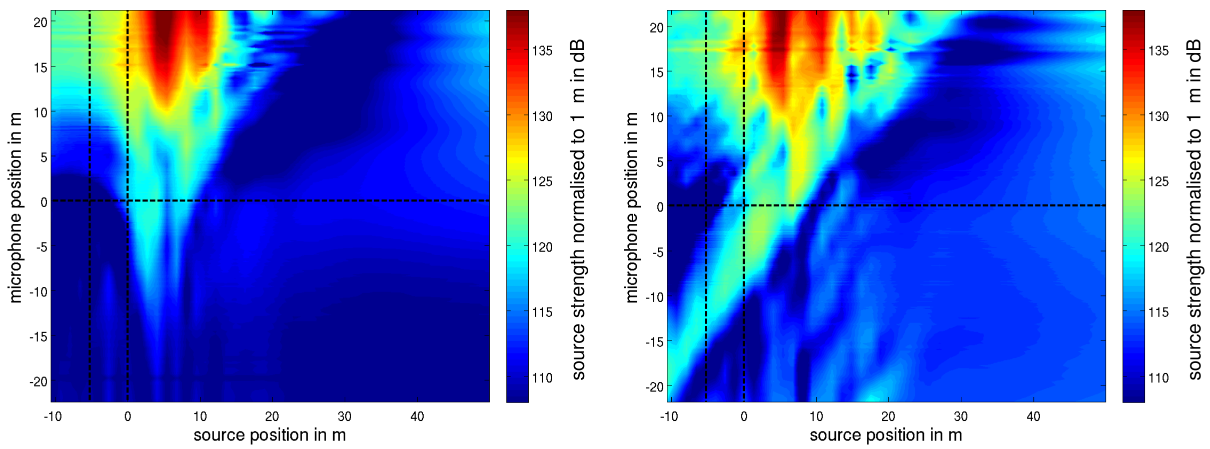



*Figure 11: SODIX sound source directivity map for the* 63 *Hz one-third-octave-band. Left: Cochstedt, right: Hamburg experiment.*

### 4.1 The size of the source region and source spacing

In order to match the spatial resolution to the acoustic wavelength, a different set of source positions was used for every one-third octave band. The sources were placed on a linear grid on the engine axis. Generally, the distance between the sources was set to $\Delta x = 0.25\,\lambda$, however some adjustments had to be made for the jet region downstream of the engine, the engine nacelle, and the region upstream of the engine inlet such that point sources were placed directly at the engine inlet and nozzle positions.

The length of the source grid downstream of the engine was also adapted to the freqency: for one-third octave bands up to and including 250 Hz, it reached 40 nozzle diameters downstream of the nozzle. For higher frequencies, the length of the source region was reduced by a factor of two for a doubling of the frequency.

The reasoning behind reducing the length of the source region downstream of the nozzle with increasing frequency is that the jet noise is dominated by low frequencies. By reducing the length of the jet region at higher frequencies, the increase of the computational effort is controlled. This approach resulted in using 206 sources for the 500 Hz one-third octave band, and 265 sources for the 1 kHz band.

### 4.2 SODIX results for maximum continuous thrust

For the free-field experiments in Cochstedt, first results with SODIX have been obtained for the highest engine speed of the test ($N1 = 81.3\%$) for frequencies in the one-third-octave bands of $f = 63$ Hz, 125 Hz, 250 Hz, 500 Hz, and 1000 Hz. These frequency bands were chosen because they contain no or very few dominant tonal noise contributions originating from the fan. This is important, because the source model of SODIX may not be suited for engine tones which originate from the modes of the in-duct sound field of the turbomachinery sources and radiate from the inlet and the nozzle.

Figures 7 to 11 present the results of the SODIX analysis of the broadband noise component for the different one-third octave bands. The source postions are mapped to the horizontal axis and the microphone positions to the vertical axis. Vertical lines in the contour plot represent the sound source strength that a particular source contributes in the direction of a specific microphone position. Horizontal lines show the distribution of source strenghts seen by a particular microphone.

The engine inlet and nozzle positions are indicated in Figures 7 to 11 with vertical dotted lines. A horizontal dotted line marks the $\theta = 90^\circ$ position relative to the nozzle exit on the array.

In the $f = 1$ kHz band, see figure 7, there is a strong source at the engine inlet position that radiates forward.

Figure 12 presents the directivities of the sources at the engine inlet and nozzle, which have been extracted along the vertical dotted lines in figures 7 to 11. For both sources, the source strength was integrated over all source positions between two positions up and down from the reference source. This is equivalent to integrating over an area of the size of $-0.5 \leq x/\lambda \leq 0.5\lambda$. Figure 12 only presents these two sources, the sources in the jet are not included. Both sources show strong directivities over a dynamic range of up to about 15 dB.

The inlet source is generally weaker than the nozzle source, it is only stronger than the jet in the 1 kHz band. It radiates mainly into the forward arc and drops by more than 10 dB downstream of the inlet. The source at the nozzle radiates strongest into the rear arc.

## 5 CONCLUSIONS

The two experiments in Cochstedt and Hamburg were analysed with classic methods, by calculating frequency spectra, as well with a source localisation calculated with SODIX. Considering that the measurements were performed at very different conditions with different engines, the agreement is rather good. The data from the Hamburg hangar is only influenced in the forward arc by reflections of the low frequency jet-noise.

The present data is very well suited for a further analysis of jet noise and especially the combination of the acoustic data from the microphone array with the laser-optical flow measurement

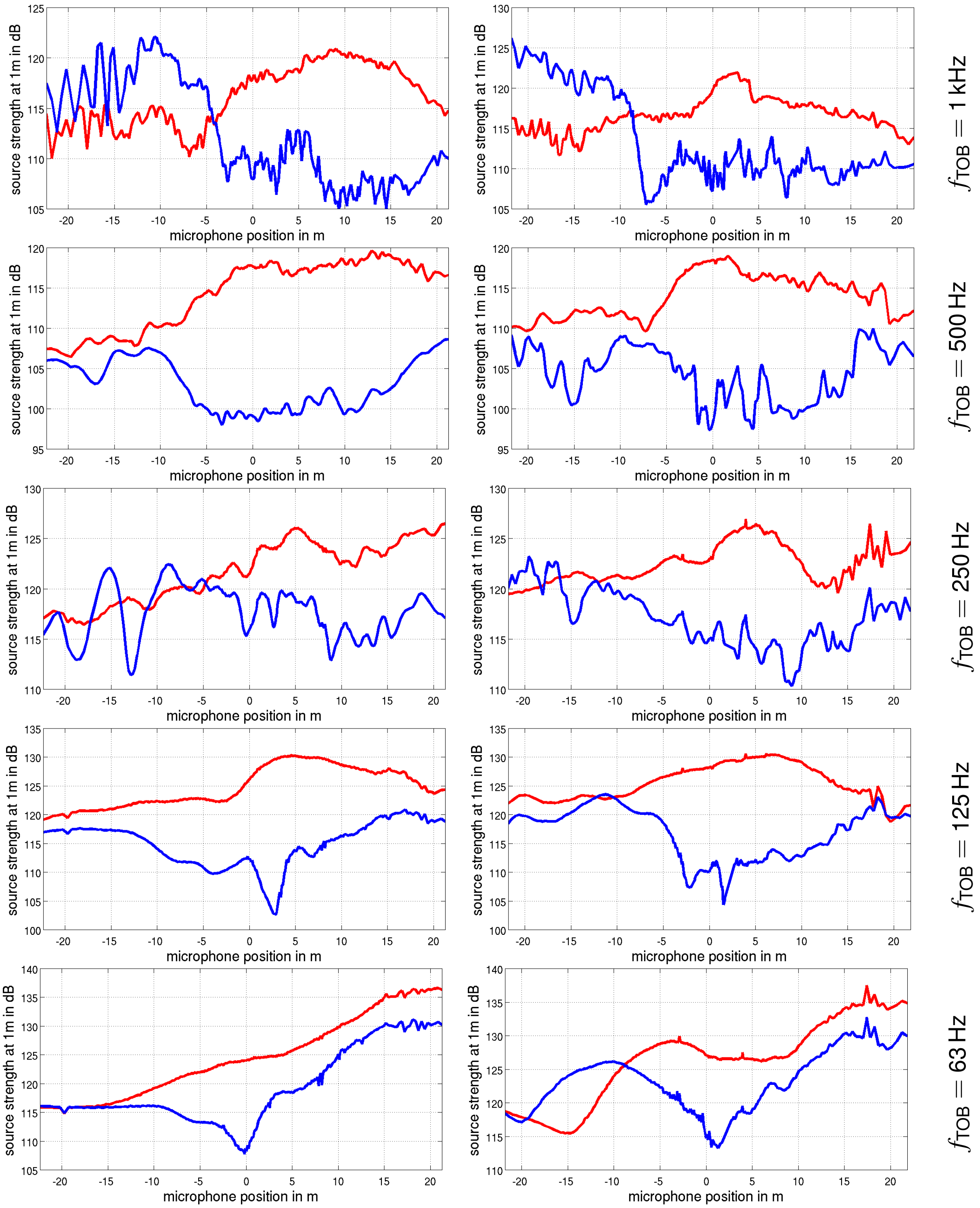



*Figure 12: Directivity of the sources at the engine inlet (blue) and nozzle (red), from top to bottom in the 1 kHz, 500 Hz, 250 Hz, 125 Hzm and 063 Hz one-third octave bands. Left: Cochstedt, right: Hamburg experiment.*

data from the other experiments in Hamburg within the framework of the project SAMURAI.

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