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MEASUREMENT TECHNIQUES USED TO VERIFY THE CAUSE AND NATURE OF LOW-FREQUENCY NOISE IN ROOMS

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Measurements in small rooms proposed for use as research laboratories indicated the presence of high amplitude infrasonic (i.e., at frequencies below 20 Hz) noise. Concern about this noise, which the author has further discovered to be common in many types of rooms, is due to the sensitivity to infrasound of the experiments proposed to be carried out in these spaces. This report describes measurement techniques used to discover the nature of this noise as the necessary first step in a mitigation program. Essentially, it was necessary to know whether the noise was due to air flow turbulence or was a pressure phenomenon coherent over the room volume such as would be found if the room behaved as a Helmholtz resonator. Measurements of the coherence of the pressure wave over large spatial areas within the room demonstrated the latter case. Data from measurements to demonstrate the coherence in turbulent flow are also shown for contrast.

1. Introduction

In the process of commissioning a laboratory building, relatively high levels of infrasound were discovered. While subsequent measurements of other lab and office spaces using various types of forced air systems have revealed that this phenomenon is quite common, in this particular case the infrasound was detrimental due to the sensitivity of the research equipment and processes that were to be used in the labs. These particular processes employed open beam-path techniques similar to interferometry, which can be particularly sensitive to low frequency pressure fluctuations. At high amplitudes, infrasound can also affect people,[1,2] and other types of equipment (e.g., equipment with components of large dimensions, flexible air bladders,[3] etc.).[*] The present article specifically focuses on measurement techniques used to characterize the infrasonic noise; other details and characteristics of the phenomenon itself are the subject of a separate study,[4] and ongoing research. Fig. 1 shows typical time-averaged spectral data from infrasonic noise measurements in several rooms served by forced air systems.

The measurement system used has a relatively flat frequency response (± 3 dB) down to 2 Hz. Note that most of the rooms represented in Fig. 1 show a clear infrasonic peak in the 2 to 10 Hz range, presumed to be a resonance associated with dimensions of the room, the dimensions of ductwork serving the room and other openings into it, and other details.

[*] Although this phenomenon is quite common, at common amplitudes it is not often detrimental to people and small-scale research equipment, and is thus often of no concern. Unusual fan operating conditions, such as stall, can worsen infrasonic noise; however this is not the specific focus of this paper.

In an effort to reduce the infrasonic noise level, it is useful to know more about the nature of the noise. At the outset of this investigation, it was considered that the phenomenon might be due either to wind interference with the measurement equipment, such as can be produced by relatively small-scale eddies in the air flow in the room (in this case the lab is supplied with air at relatively high velocity for precise temperature control), or due to fluctuating uniform pressure variations, such as would occur inside a Helmholtz resonator. The infrasonic resonance frequency is well below those which would be associated with the normal modes in these relatively small rooms, and this third possible mechanism was therefore disregarded.

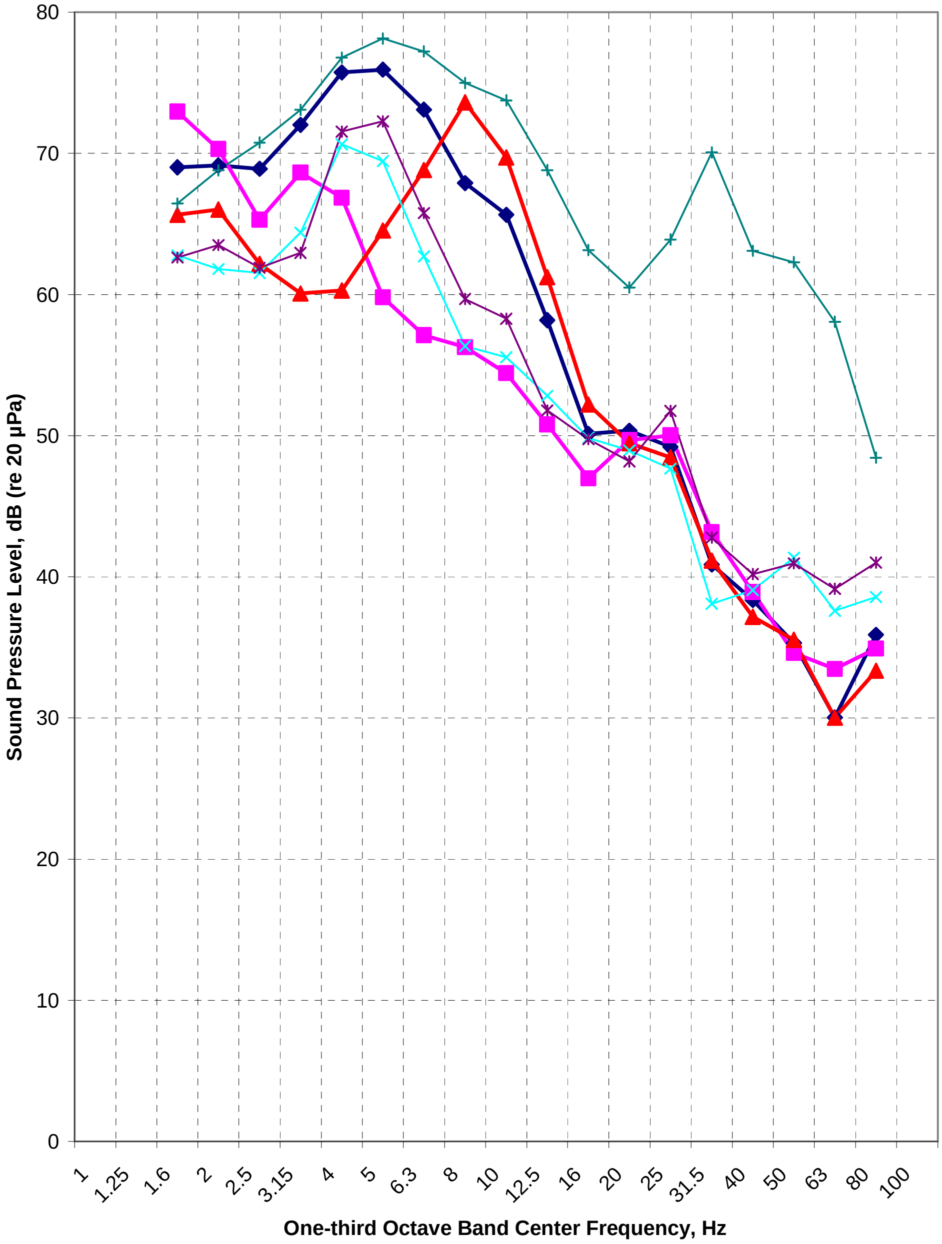

Figure 1. Sound pressure measurements in several laboratories served by forced air systems, infrasonic range (1.6 to 80 Hz), 60s equivalent-energy average (L_{eq}), “slow” time weighting.

2. Measurement techniques

The basic challenge in this project was to determine if the infrasonic pressure is due to coherent low-frequency wave phenomena or uncorrelated turbulence, such as due to air flow. Our study used a relatively simple 2-channel measurement technique and cross-correlation analysis to determine if there is coherence in the pressure over large areas in the room. The basic technique is based on multi-channel array analysis which is commonly used in measurement of atmospheric infrasound.[5]

3. Results

Fig. 2 shows sound pressure, transfer function, and coherence data for two microphones separated by various distances and located at the floor level in a room. Several features may be distinguished in these data:

- The peak pressure in the particular room analyzed in this exercise is in the 2 to 3 Hz range.[†]
- There is a high degree of coherence at low frequency. This extends well above the infrasonic resonance frequency of the room, which indicates that this peak frequency is due to a pressure wave that is coherent across a large area of the room, and not due to local turbulence.
- There is a cut-off frequency above which the noise data become incoherent, and this is a function of the microphone spacing. The coherence cut-off frequency as a function of the microphone spacing is summarized in Fig. 3.[‡] Identification of the cut-off frequency requires some judgment, so this factor is considered approximate. In any case, the coherent frequency range is inversely proportional to the microphone spacing, and appears to follow a logarithmic trend.

Thus, the most important query at the outset of this exercise, regarding the nature of the infrasonic noise source, is answered. The supplementary result showing the relationship between good coherence and microphone separation is also interesting, and requires some elucidation. It is likely that this is related to the wavelength and appearance of cross-modes (interference from non-planar or reflected waves) in the room, a similar limitation as seen, for example, in active noise cancellation systems.

The foregoing data show the behaviour at a single elevation, but we would not expect variations in elevation to affect the results significantly. This is demonstrated by the data shown in Fig. 4, comparing the results of a vertical separation of 2.75m with those of a similar horizontal separation. Coherence at infrasonic frequencies is maintained. As indicated by the square data point in Fig. 3, there is a small variance from the trend line in the relationship between coherence cut-off frequency and horizontal microphone separation, which may or may not be significant. We have used the term “plane wave” in reference to waves much larger than the space in which they propagate; this may be misleading because apparently the infrasonic pressure varies coherently in the entire volume of the room.

The conclusions of the foregoing paragraphs are supported by two other data sets. First, Fig. 5 shows the results measured with the microphones placed side-by-side. In this case there is apparently no high-frequency coherence loss, at least within the measured frequency range.[§]

More interesting is the data set shown in Fig. 6. This is the result from using the same two-channel analysis system, with the microphones separated by 10cm and placed in the opening of an

[†] There may be higher amplitudes at lower frequencies, below the calibrated range of the microphone and preamplifier, but the presence of these does not impact the basic analysis and conclusions of this study.

[‡] The significance of the data point of unusual shape is discussed below.

[§] This figure also demonstrates the similarity in frequency response of the two microphones.

air extract duct. In this case we would assume no correlation between microphones at infrasonic frequencies due to the turbulent flow, and this is verified by the measurement results.

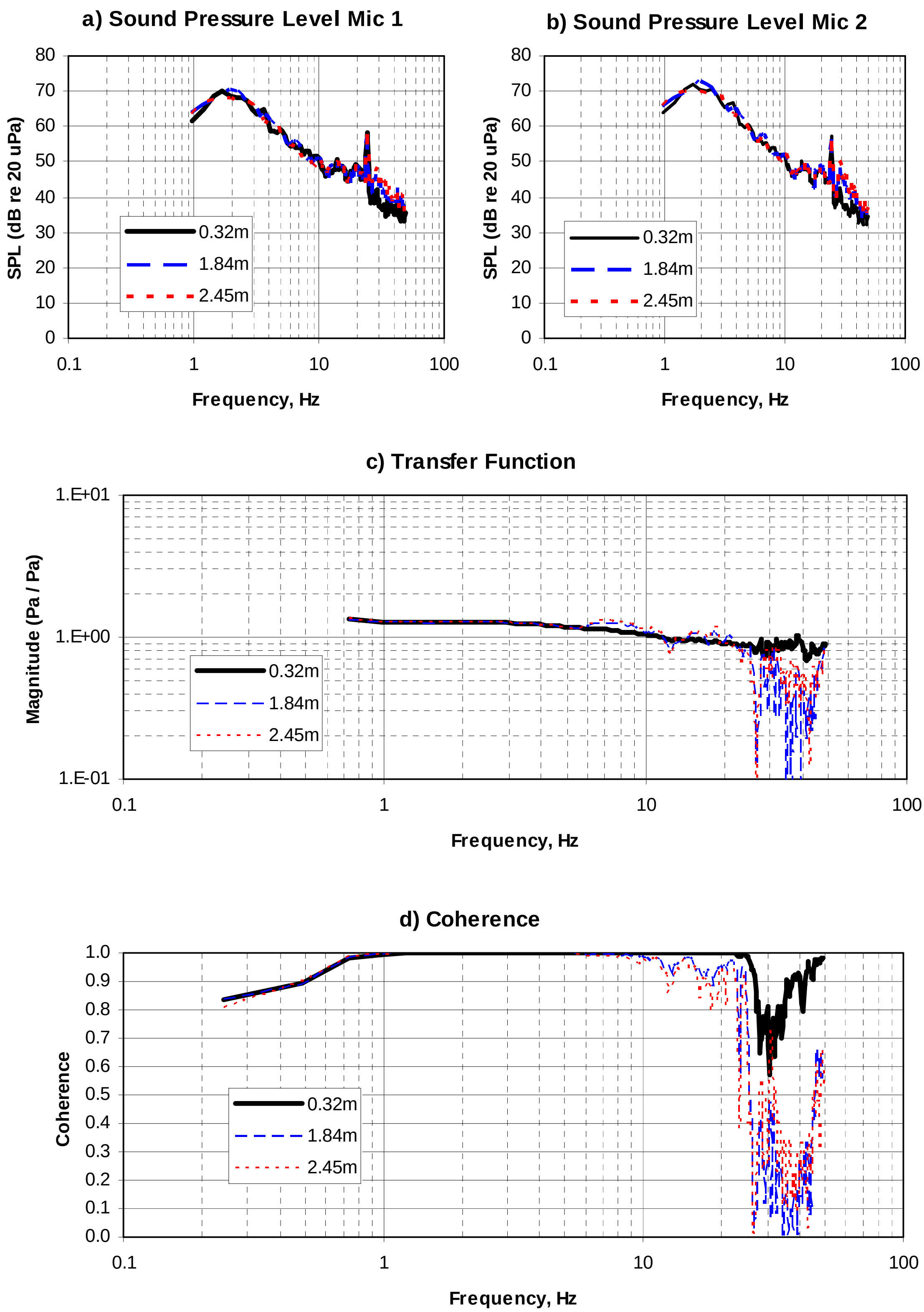

Figure 2. Sound pressure, transfer function, and coherence between two microphones separated by various horizontal distances in room (effective bandwidth = 0.366 Hz).

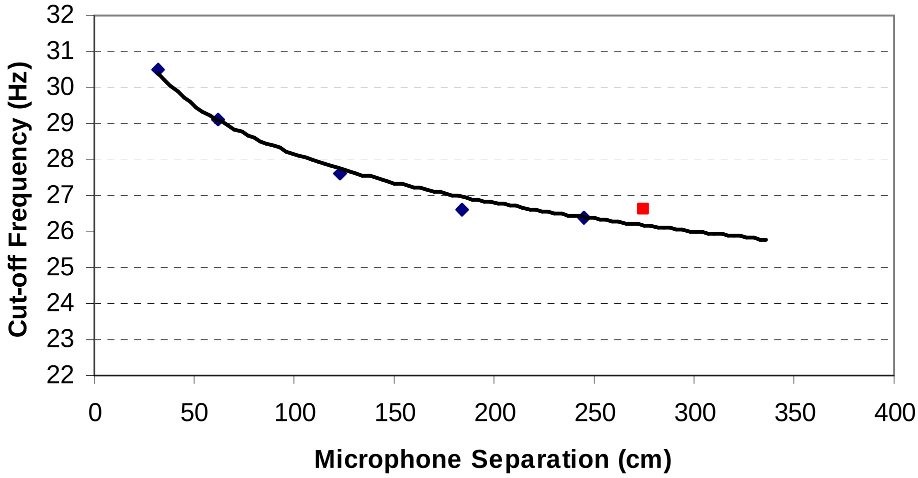

Figure 3. Coherence cut-off frequency versus microphone separation with logarithmic trend line.

4. Conclusions

There can be a significant amount of infrasonic sound pressure in rooms served by external forced air systems. Since this energy tends to be below the human hearing range, it may not be problematic for normal human occupancy. Some advanced technology experimental work, however, is sensitive to infrasonic pressure fluctuations, and in this case it is important to acknowledge and control the phenomenon. In order to control this noise, it is necessary to understand how it is generated and supported in the room, or by the configuration of the room, supply ductwork, etc.

It has been shown that the infrasonic noise in the tested rooms is a volume pressurization effect, such as occurs inside a Helmholtz resonator, rather than due to turbulent air motion, because the pressure fluctuation is coherent over the room volume. This points to consideration of control methods similar to those used in the design (and suppression) of Helmholtz resonance.

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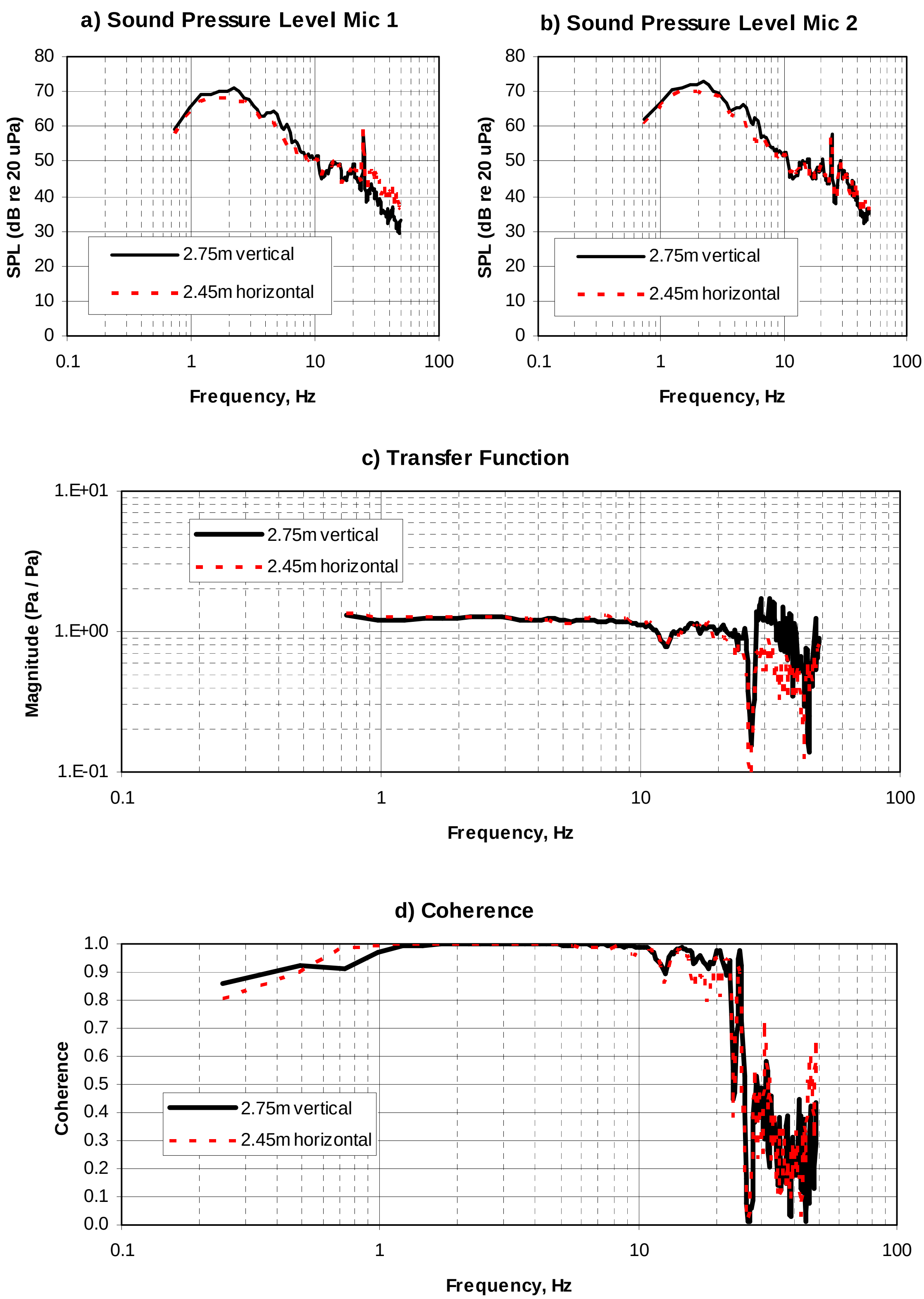

Figure 4. Sound pressure, transfer function, and coherence between two microphones separated by similar vertical and horizontal distances in room (effective bandwidth = 0.366 Hz).

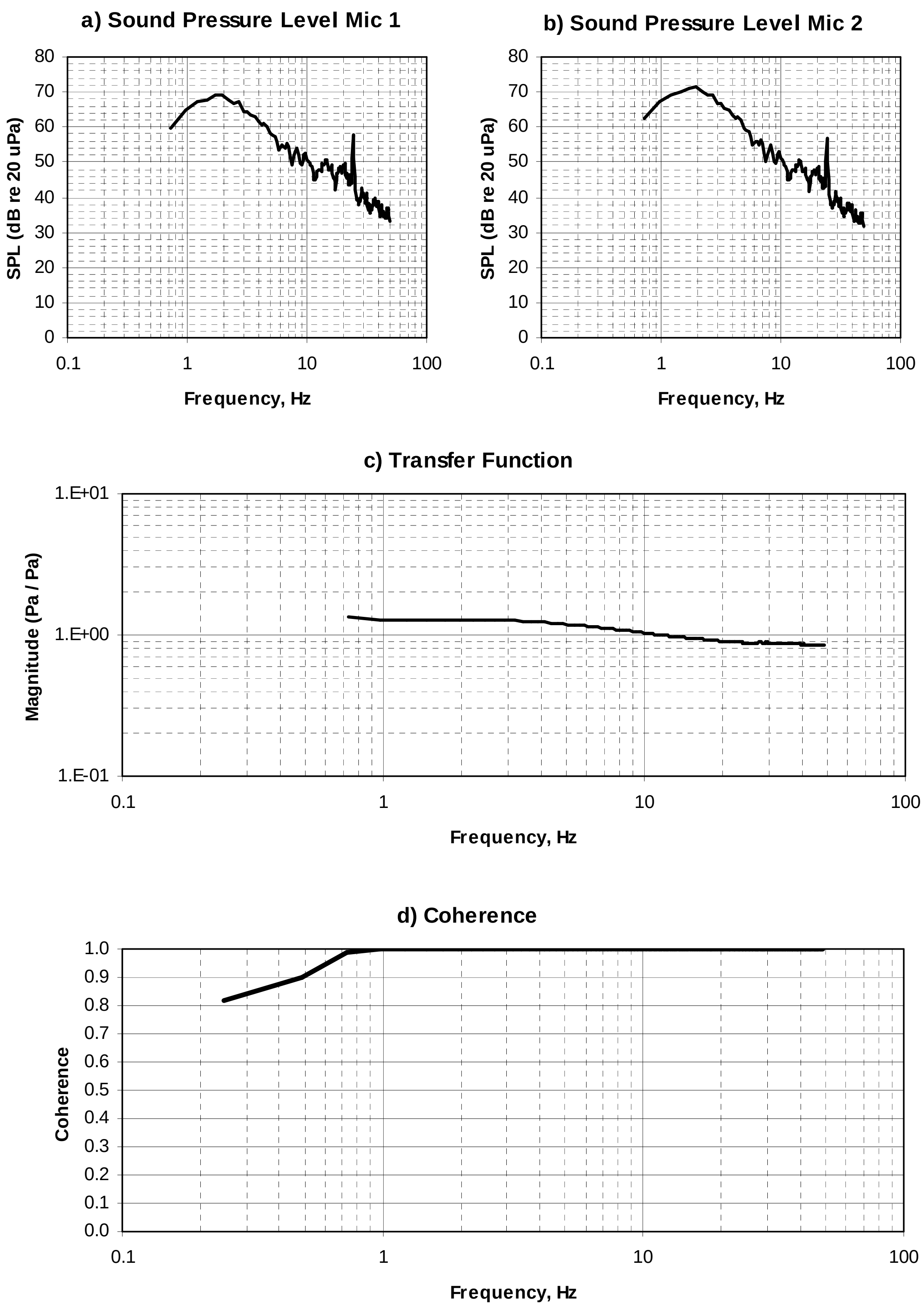

Figure 5. Sound pressure, transfer function, and coherence between two microphones placed side-by-side in room (effective bandwidth = 0.366 Hz).

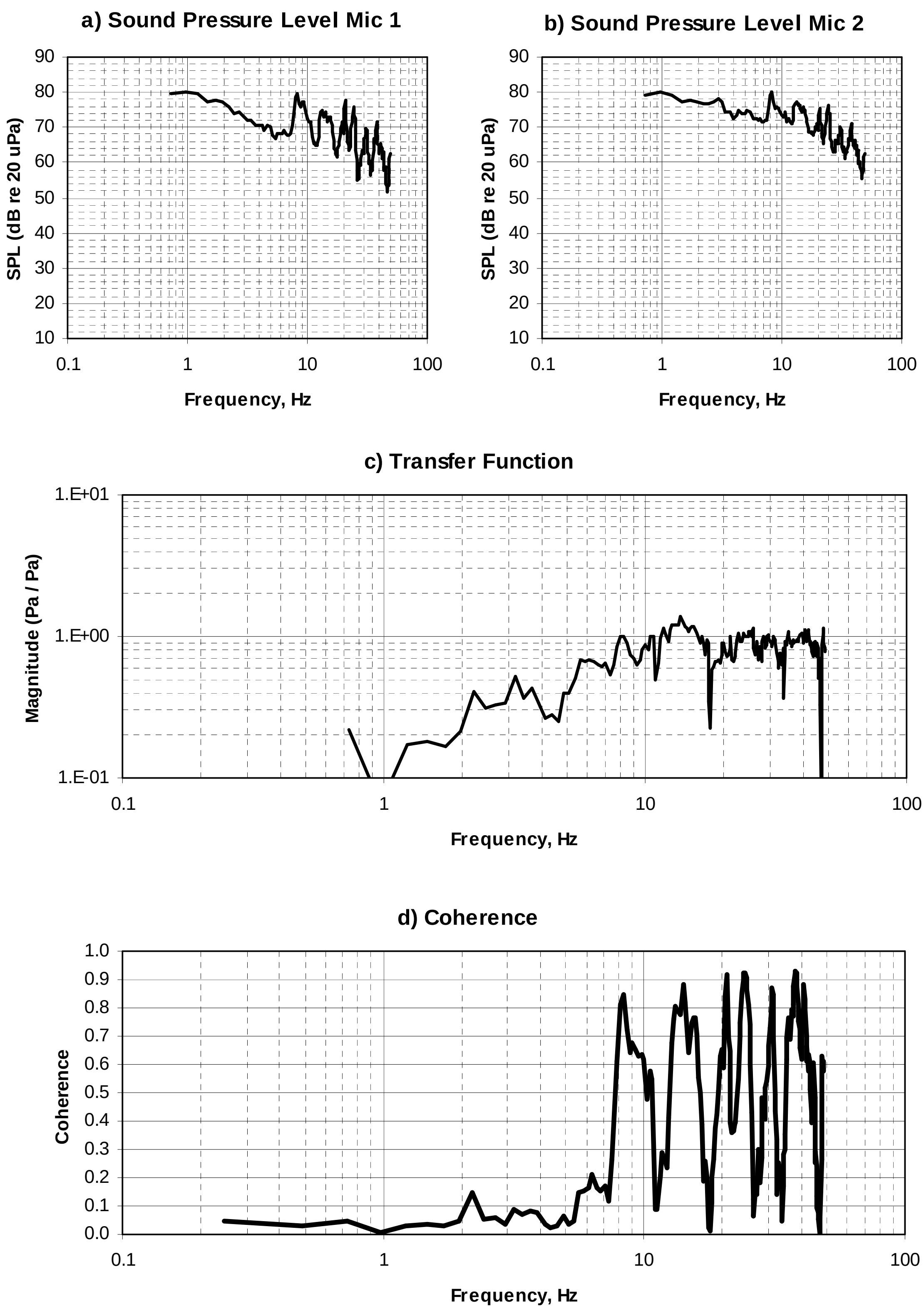

Figure 6. Sound pressure, transfer function, and coherence between two microphones separated by 10cm in room extract duct (effective bandwidth = 0.366 Hz).