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ANALYSIS OF PRESSURE MEASUREMENTS THROUGH TUBING SYSTEMS USING "MATLAB"

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INTRODUCTION

Measurements of fluctuating pressures such as those commonly performed for wind tunnel studies of wind pressures on buildings typically use a length of tubing to connect the pressure transducer to a pressure tap where the pressure is to be measured. A simple length of tubing distorts the pressure signal, with the signal being strongly amplified at the resonant frequencies of the tubing. A means of correcting this distortion is therefore required.

A commonly applied solution has been the use of a restrictor to damp out the resonant frequencies and achieve reasonably undistorted pressure measurements. The procedure has been described by Holmes and Lewis (1987). The disadvantages of this method are that careful design, construction and maintenance of the tubing system with restrictors is required, and the resulting tube is likely to be undesirably short in order to achieve the required frequency response. A tube length of about 400 mm for a wind tunnel measurement system is typical.

The use of a controlled leak in the tubing to achieve a similar effect to the use of a restrictor has been described by Gerstoft and Hansen (1987). The leak allows the use of a longer length of primary tubing, but also introduces an additional degree of complexity in the equipment.

Procedures for measuring a distorted signal with the pressure transducer, and then subsequently correcting the measurements either electronically or numerically have been available for some time. Irwin et al (1979) described the inverse transfer function method of numerically correcting the signal, which was shown to provide satisfactory undistorted pressure measurements. However, the computational requirements of the numerical procedure were, at that time, believed to be excessive.

With current PC computer equipment, the costs of the numerical correction procedure are no longer excessive, and commercial software to perform the correction is readily available. This paper describes the use of the software package "MATLAB" to perform the analysis.

ANALYSIS PROCEDURE

It was proposed to design a system to measure pressures through a simple 1 m long, 1.6 mm internal diameter vinyl tube, with sampling frequency of 1000 Hz. The amplitude and phase response of the system should be linear within the frequency range 0 to 500 Hz. The gain and phase non-linearity of the simple tube can be calculated, and are shown in Figures 1a and 1b.

The procedure in MATLAB involves calculating the inverse of the tubing gain, and entering this as the input data for the Yule-Walker filter function "yulewalk" which is provided in the software. This function calculates a set of filter coefficients, and the function "filter" is then used to correct the measured data. Some iteration is required to optimise the coefficients to achieve the best linearity.

The calculated gain and phase non-linearity of the corrected signal is shown in Figures 1c and 1d. The maximum gain has been reduced from 2.4 for the uncorrected tube to 1.001 over most of the frequency range. The majority of the phase non-linearity has also been removed, despite no specific attempt being made to correct the phase. With additional effort it is possible to correct the phase independently, but this does not seem to be necessary to achieve sufficiently accurate measurements. After setting up the coefficients, the filtering requires only an additional line in the operating software, and typically takes a few seconds to run.

MEASUREMENT OF SIGNAL SPECTRA

To measure the amplitude response of a tubing system we typically calculate a standard spectrum using the turbulent wind tunnel dynamic pressure as the random pressure source.

Figure 2a shows the wind tunnel velocity spectrum measured by a hot film anemometer. It can be seen that the spectrum is essentially straight on the log-log plot for frequencies from 5 to 500 Hz. Ideally the pressure spectrum should look the same.

Figure 2b shows the pressure spectrum for a short tube with a restrictor and a Scanivalve, which is the equipment we have previously used for wind tunnel pressure measurements. This equipment has adequately linear gain up to 270 Hz. (The spikes on the spectrum at multiples of 100 Hz are caused by the wind tunnel fan.)

Figure 2c shows the uncorrected spectrum for the 1 m tube, with the same distortion of the measured pressure as calculated for Figure 1a. An analogue low pass filter of 450 Hz has been used, which causes the rolloff in response at that frequency.

Figure 2d shows the same data measured using the 1 m tube after it has been corrected using MATLAB. The measured linearity is clearly better than that in Figure 2b (for the short tube with restrictor and Scanivalve) and remains essentially linear up to the 450 Hz analogue filter cutoff. The measured linearity is not as perfect as was predicted (in Figure 1c) and this may be because the calculated tubing response and/or the tube size is not exactly correct.

COMPARISON OF PRESSURE MEASUREMENTS ON A WIND TUNNEL MODEL

To compare the representative pressures measured by the short tube with restrictor and Scanivalve, and the new corrected 1 m tube, a pair of pressure taps were located near the leading edge of the roof on a wind tunnel model building. The taps were close together (1 mm apart) so that the pressure signal at each tap was very similar. The two taps were then sampled simultaneously using the two systems.

Figure 3a shows a typical second of data from the short tube with restrictor and Scanivalve. Figure 3b shows the uncorrected data from the 1 m tube. Figure 3c shows the corrected data from the 1 m tube. It can be seen that Figures 3a and 3c are very similar, except that Figure 3c shows some additional high frequency information due to the greater frequency range of the 1 m tube system.

CONCLUSIONS

It has been shown that the signal processing capability of the data analysis software package "MATLAB" provides a practical method of correcting pressure measurements through simple tubes. The analysis for a 1 m long simple tube has been presented. The method can also be applied to longer tubes, to tubing systems which include a Scanivalve, and to pneumatically averaged multiple tube systems.

ACKNOWLEDGEMENT

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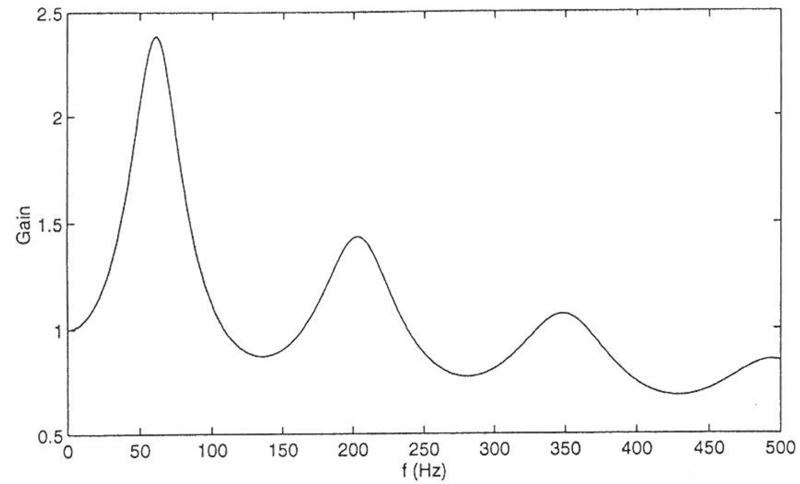

Figure 1a. Gain of 1m long tube, i.d.=1.6mm.

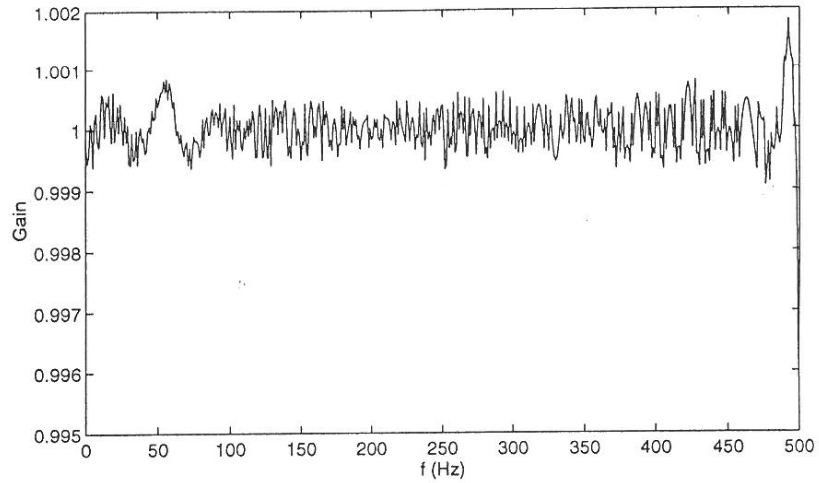

Figure 1c. Gain of corrected signal from 1m long tube, i.d.=1.6mm.

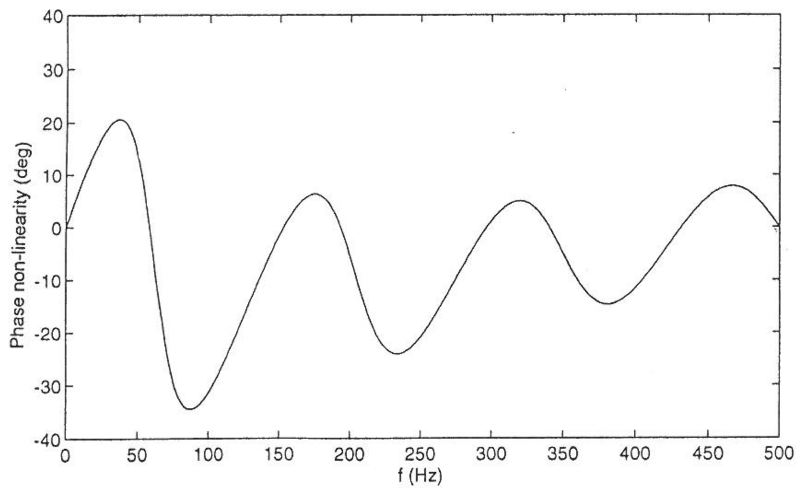

Figure 1b. Phase non-linearity of 1m long tube, i.d.=1.6mm.

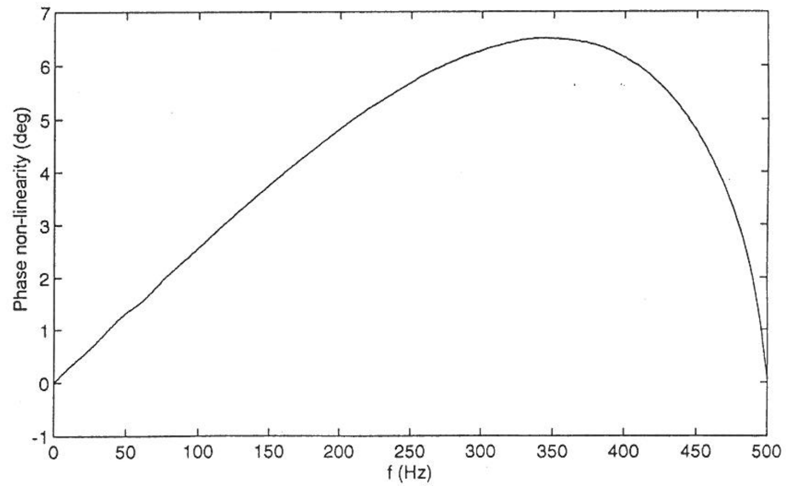

Figure 1d. Phase non-linearity of corrected signal from 1m long tube, i.d.=1.6mm.

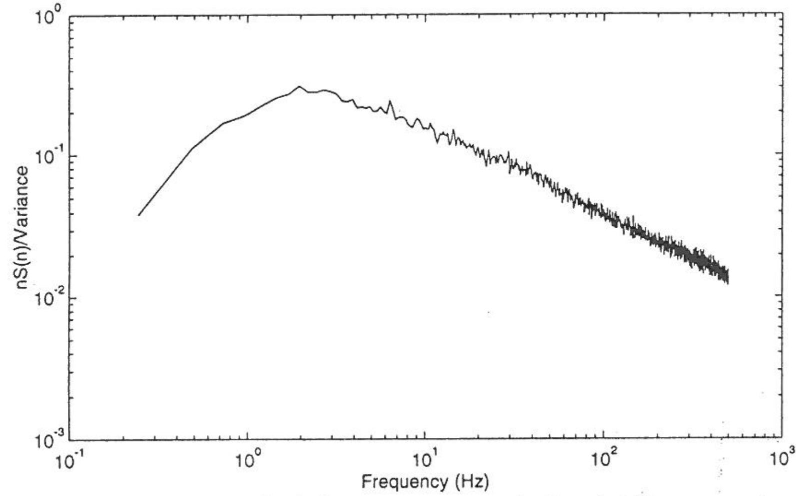

Figure 2a. Wind tunnel velocity spectrum measured using a hot film anemometer.

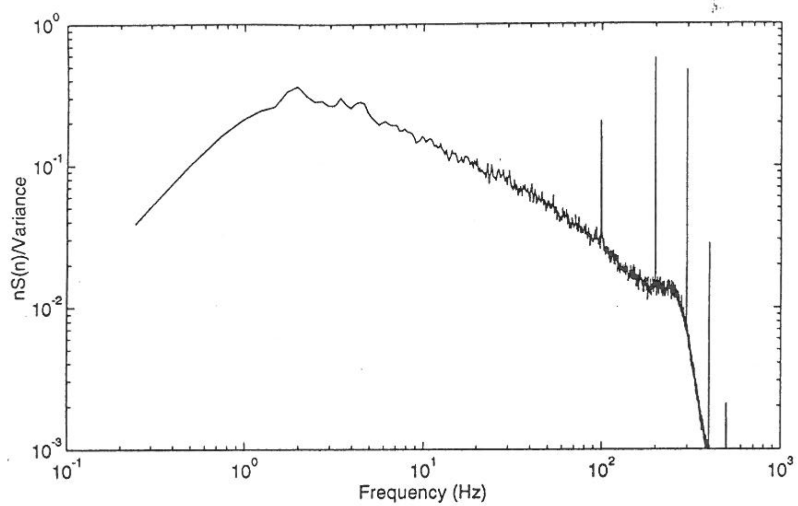

Figure 2b. Wind tunnel dynamic pressure spectrum measured using the short tube/restrictor/Scanivalve measurements.

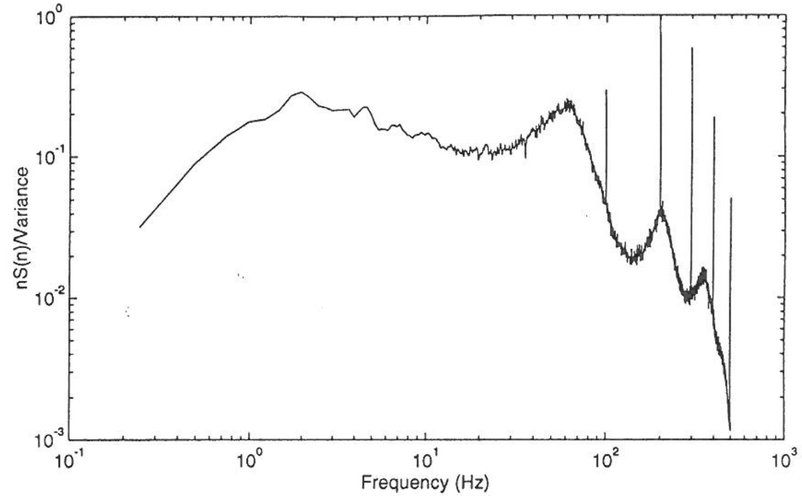

Figure 2c. Wind tunnel dynamic pressure spectrum for uncorrected measurements from1m tube.

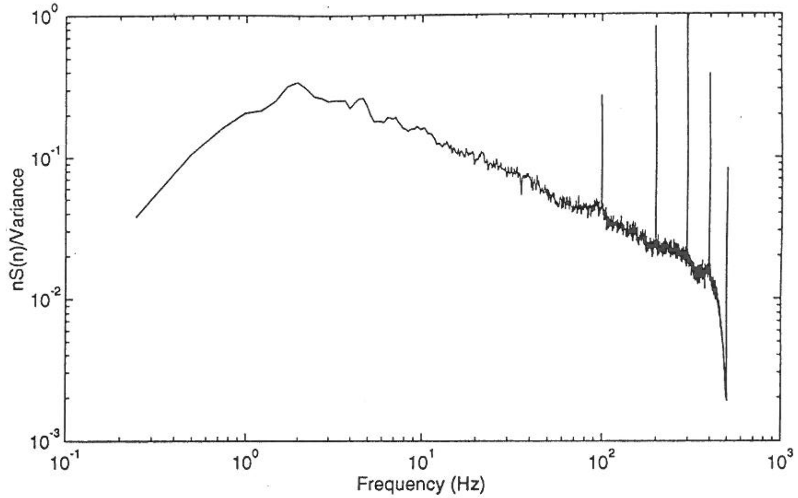

Figure 2d. Wind tunnel dynamic pressure spectrum for corrected measurements from 1m tube.

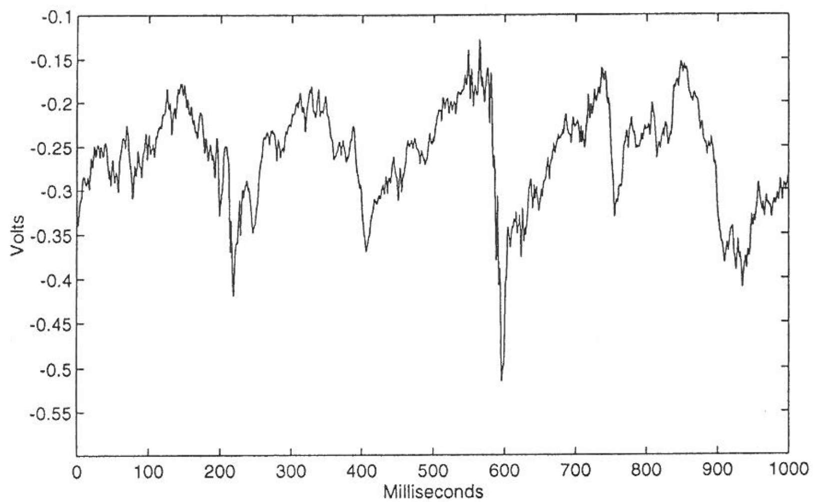

Figure 3a. Typical time history of short tube/restrictor/Scanivalve data.

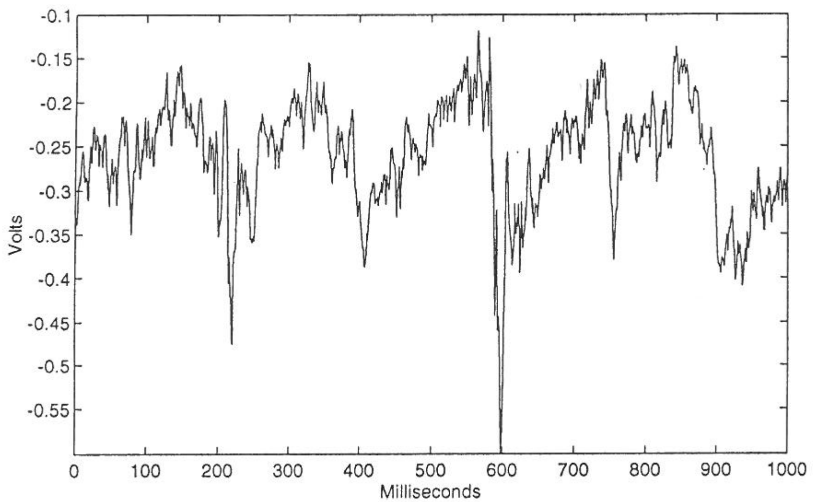

Figure 3b. Typical time history of uncorrected 1m tube data.

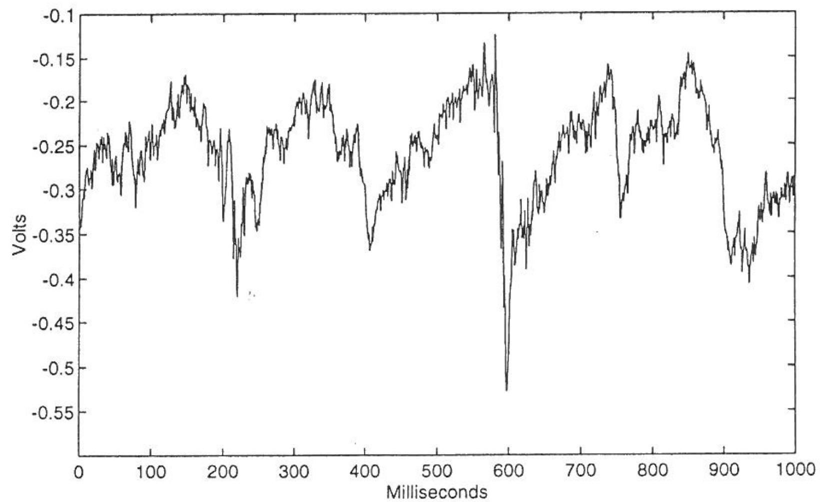

Figure 3c. Typical time history of corrected 1m tube data.