Citation:

Davy, J, Baade, P and Halvarsson, J 2003, 'An improved sampling tube for in-duct fan sound measurement', in J. Tourret, A. Guedel (ed.) Fan Noise 2003, Senlis, France, 23-25 September 2003.

AN IMPROVED SAMPLING TUBE FOR IN-DUCT FAN SOUND MEASUREMENT

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SUMMARY

A number of researchers have shown that the currently available commercial sampling tube (microphone turbulence screen) suffers from excessive self-noise, poor turbulence rejection and non-smooth frequency response. This paper describes the development of an improved sampling tube by Baade. In particular, it discusses the difficulties encountered by Halvarsson and Davy when measuring the pure tone frequency response of sampling tubes in an anechoic room. This research is still in progress, but results to date are presented. It is planned that the design resulting from this research will be included in ASHRAE Standard 68 and ISO 5136.

INTRODUCTION

During the most recent update of the US counterpart (ASHRAE Standard 68-1997 [1]) to ISO Standard 5136 [2], evidence was discovered that the only commercially available sampling tube (Brock [3]) suffers from excessive self-noise. Brock concluded that this device was useful only in highly turbulent flow and should never be used "just in case". Von Heesen [4,5] measured the self-noise of this device and also reported that the irregularities of its narrow band frequency response curve cause errors when investigating the tonal components of fan noise. Rainey [6] found that, when testing a comparatively quiet fan, the self-noise caused errors as high as 18 to 22 dB in some frequency bands (see figure 1). This figure also shows that use of an experimental "Friedrich" tube with a very smooth outer surface eliminated these errors. Guedel [7] and Tooley [8] (see Figures 2 and 3) have also both reported that the current Brüel and Kjær sampling tube does not perform as well as claimed.

Based on these findings, the ASHRAE Project Committee decided that, in the next update of ASHRAE Standard 68, information should be included to enable the user to construct a better performing sampling tube. Baade has constructed a number of tubes. The frequency response of the initial design was disappointing. Several causes have been identified and corrected one at a time. The fourth generation design was tested by Davy and found to be significantly better but still not fully acceptable. Based on these tests, improved tubes were constructed and tested by Halvarsson. The results of these tests are discussed in this paper.

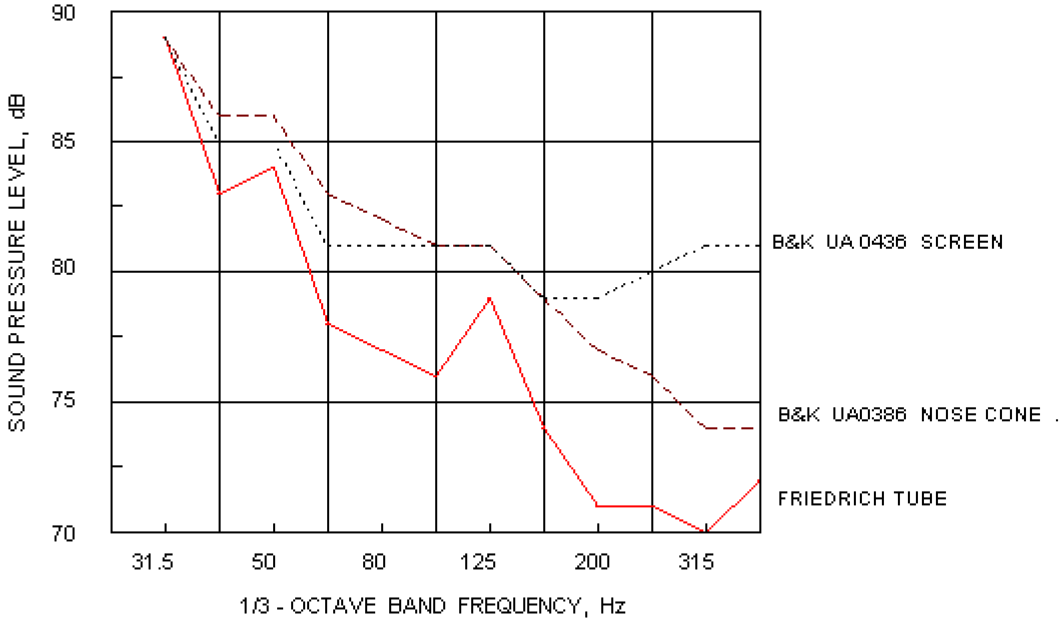

Figure 1: Performance comparison of various microphone attachments for use in flow ducts (after Rainey [6])

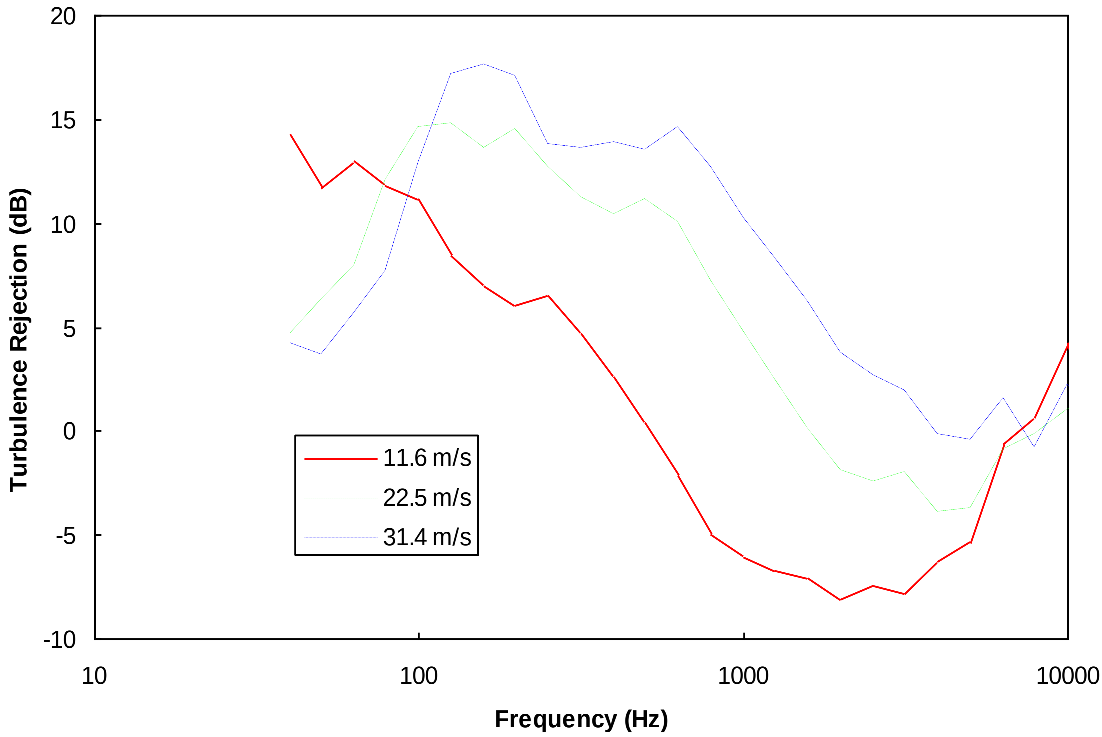

Figure 2: The third octave band turbulence rejection of a pristine Brüel and Kjær type UA 0436 sampling tube (Tooley [8])

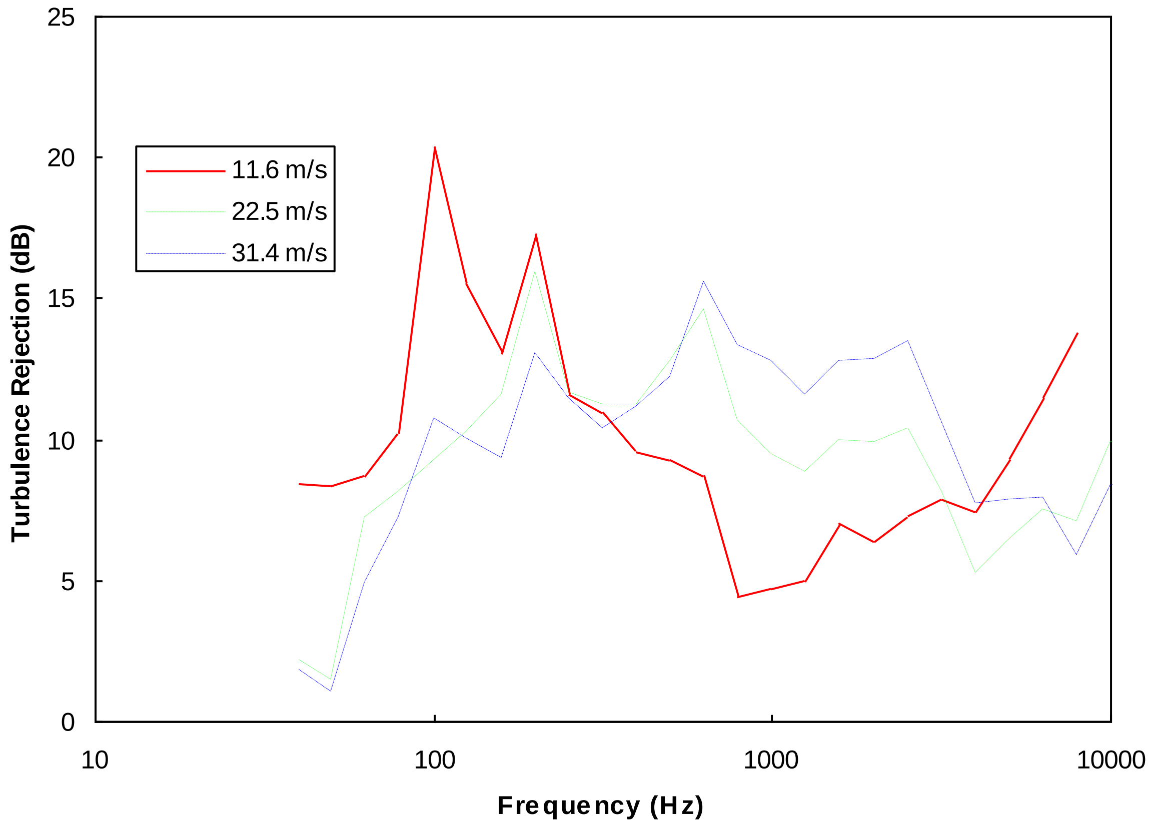

Figure 3: The third octave band turbulence rejection of a damaged Brüel and Kjær type UA 0436 sampling tube (Tooley [8])

The general conclusion to be drawn from these efforts is that the design information to be included in the next revision of ASHRAE Standard 68 will have to be much more detailed than the information in Annex G of the currently pending revision of the ISO Standard 5136. A complete record of the design problems and solutions is planned to be published in the ASHRAE Transactions in 2004.

BAADE'S PROTOTYPE SAMPLING TUBES

When the work for updating ISO 5136 was started in 1998, the USA proposed at the first meeting of the working group (WG47) that detailed instructions be included for building a sampling tube. This was because Brüel and Kjær had refused repeated requests to improve their sampling tube to remove the well known deficiencies regarding self-noise, frequency response and turbulence rejection referred to above. Baade had already started to design, construct, and test a better tube with parts to be fabricated by other members of the USA counterpart to WG47 and with test facilities to be provided by other members of the USA committee.

Naively, Baade had thought that this would be simple task. In June 1999, he submitted to WG47 a detailed drawing representing the second revision of his original design and subsequently submitted updates as further changes became necessary. In preparing the Final Draft for the ISO 5136 revision [9], the Working Group decided not to include any of his design details for the sampling tube in Annex G. In retrospect, this was a blessing in disguise since it has been found that quite a few more changes had to be made.

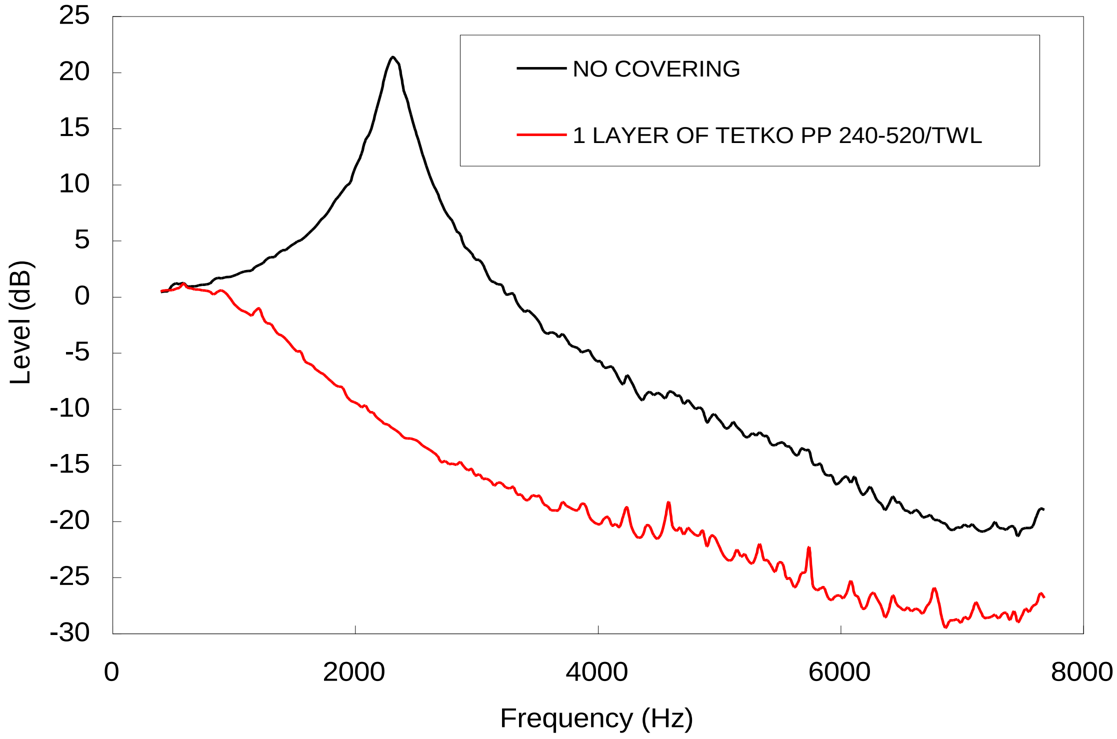

Figure 4: The frequency response of a resonator with no covering and covered with one layer of Tetko PP 240-520/TWL woven plastic cloth

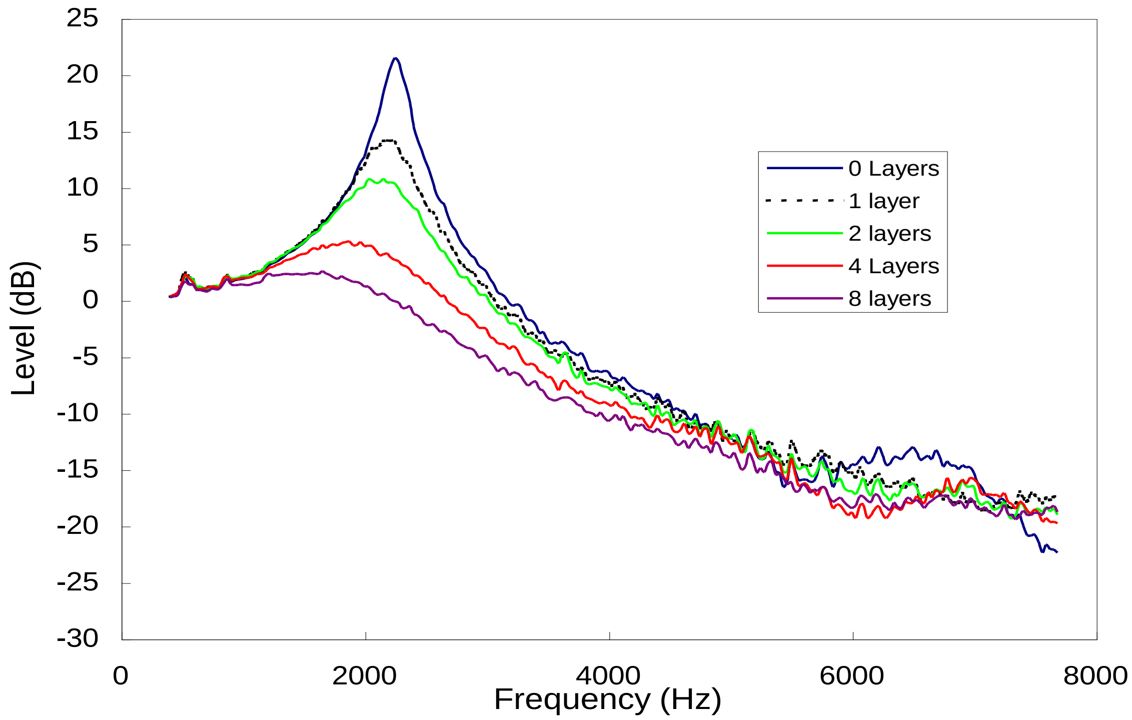

Figure 5: The frequency response of a resonator with no covering and covered with varying numbers of layers of woven wire cloth

In revision 3, Baade changed the covering material, from the cloth that he had been sent by Davy, to 4 layers of the same wire mesh that is used in the Brüel and Kjær sampling tube and made the internal absorber tube 28 mm shorter to accommodate a longer gradual end plug. The frequency response results still were not good enough. In particular, there was a frequency response peak at about 2300 Hz, which Baade attributed to the damping of the 4 layers of wire mesh being too low. Therefore, Baade constructed the tube that is referred to in this paper as "Baade’s old tube". This was revision 4. It used 8 layers of wire mesh but the peak was still there. From Halvarsson’s measurements, it is now known that this has nothing to do with the covering, but is due to reflections from the end of the absorber.

Subsequent to the original CSIRO tests of "Baade’s old tube", Baade ran tests to compare the damping provided by various numbers of layers of wire mesh to that of one layer of the fabric that, from Davy's flow resistance measurements some years ago, was known to have a specific flow resistance of about 456 mks rayl. These tests are shown in figures 4 and 5. To Baade’s surprise these tests showed that even 8 layers of wire mesh had much less damping than 1 layer of the cloth. This led to revision 5 which is referred to as "Baade’s new tube" in this paper. It was covered with the cloth provided by Davy.

INITIAL CSIRO FREQUENCY RESPONSE MEASUREMENTS

The initial CSIRO frequency response measurements of “Baade’s old” sampling tube showed unexpected ripples of up to 3 or 4 dB peak to peak. The frequency response was measured in two different ways. In the first method, the frequency responses of the reference microphone and the sampling tube were measured simultaneously with a dual channel analyser by placing the reference microphone close to the sampling tube. This removes variations in the sound source with time. In the second method, frequency response of the reference microphone is measured before or after that of the sampling tube, by removing the sampling tube and placing the microphone where the centre of the sampling tube slit would normally be positioned. The same microphone and analyser channel is used for the sampling tube and reference microphone. Surprisingly these two methods produced different measured sampling tube frequency responses. Both swept sine and Fast Fourier Transforms (FFT) were used to determine the frequency responses. After frequency resolution issues were sorted out, the swept sine and FFT measurements agreed for the same experimental setup.

Why did the two methods give different results, and was the ripple due to the sampling tube? A room is said to be anechoic if its lining reflects less than 1% of the incident sound energy. Because the sound energy is proportional to the square of the sound pressure, an anechoic room lining must reflect less than 10% of the incident sound pressure. If a 10% reflected sound pressure is in phase with the incident sound pressure, the total sound pressure is increased by 1 dB. If it is 180° out of phase, it reduces the total sound pressure by 1 dB. A rectangular parallelepiped room has 6 primary image sources, but they are all further from the receiver than the real source and their contribution is reduced by inverse square law. Free field microphone calibration takes advantage of the inverse square law by placing the source and receiver fairly close together in the centre of the anechoic room. It also reduces the effect of the reflections and the uncertainty of where the acoustic centres are positioned by averaging over a number of source and receiver spacings. Because sampling tube slits are 400 mm long, ISO 5136 [2] attempts to reduce the variation of sound pressure due to inverse square law along the length of the slit when the sampling tube frequency response is being measured in an anechoic room. It does this by requiring that the minimum distance between the sampling tube and the sound source shall be 3 m. The working space of the CSIRO Highett anechoic room is 5 m long by 4 m wide by 4 m high. Thus both the sound source and the sampling tube have to be fairly close to the anechoic lining. Thus it is not surprising that ripple of 3 to 4 dB peak to peak was observed (see figure 6).

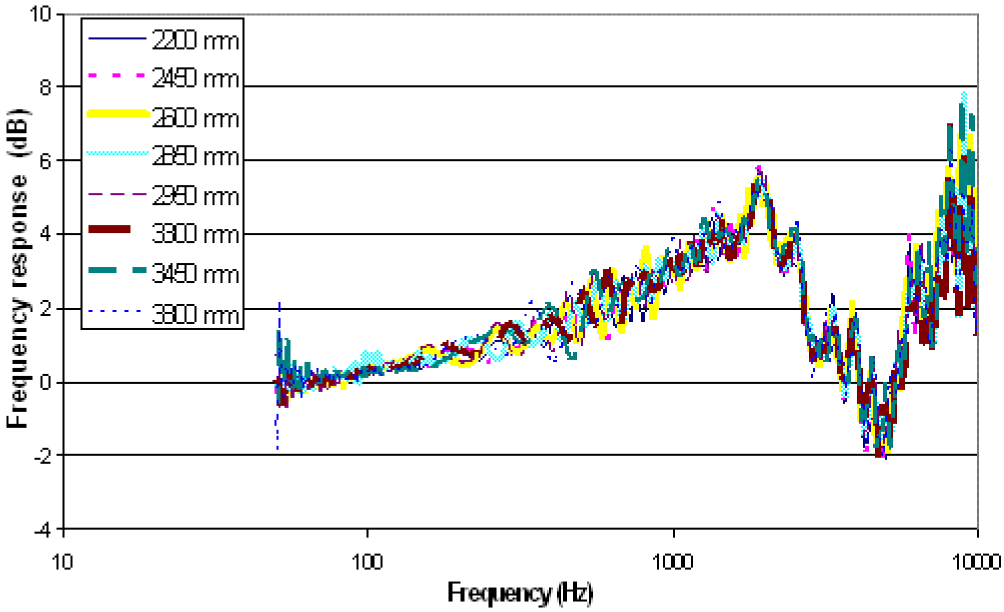

Figure 6: Comparison of measured frequency response of Baade's old sampling tube at 8 different positions (Pavasovic and Davy [10])

For normal microphone or sound source comparative calibrations, the sound sources and receivers can be put in essentially the same positions and the effects of the reflections are cancelled out. However this is not the case with a sampling tube which averages over 400 mm, while the reference microphone samples at essentially a single point location. The reflections also cause measurement problems if deep nulls have to be measured in certain directions from the source or the receiver. A survey of positions approximately 3 m from the sound source with two microphones placed 183 mm apart failed to find any positions where the ripple in the relative frequency response of the two microphones when in line with the centre of the sound source was significantly less than 2 dB peak to peak. Because of this observation, the ripple in the measured frequency response was reduced by averaging over eight different positions of the sampling tube in the anechoic room.

FREQUENCY RESPONSE RIPPLE AT HIGH FREQUENCIES

After the cause of the frequency response ripple at low frequencies was discovered and overcome, there was some evidence of frequency response ripple at high frequencies. The Brüel and Kjær sampling tubes had definite harmonically related resonances at high frequencies and it was possible that the prototype sampling tubes were exhibiting similar effects. Another possibility was that the high frequency ripple was due to reflections off the microphone stands that were used to mount both the source and the receivers. To find out if this was the case, the microphone stands were removed from the room and replaced with thin threads of sewing yarn which were hung from existing steel hooks which are recessed amongst the lining wedges on the ceiling of the anechoic room. Two threads of sewing yarn were used to mount the sampling tube. The reference microphone was hung on sewing yarn from the centre of the sampling tube. One or more sewing threads were used to mount the sound source. The difference was dramatic and is shown figure 7. The ripple below 1 kHz is greater for the sewing yarn case because the average is over 4 rather than 8 tube positions.

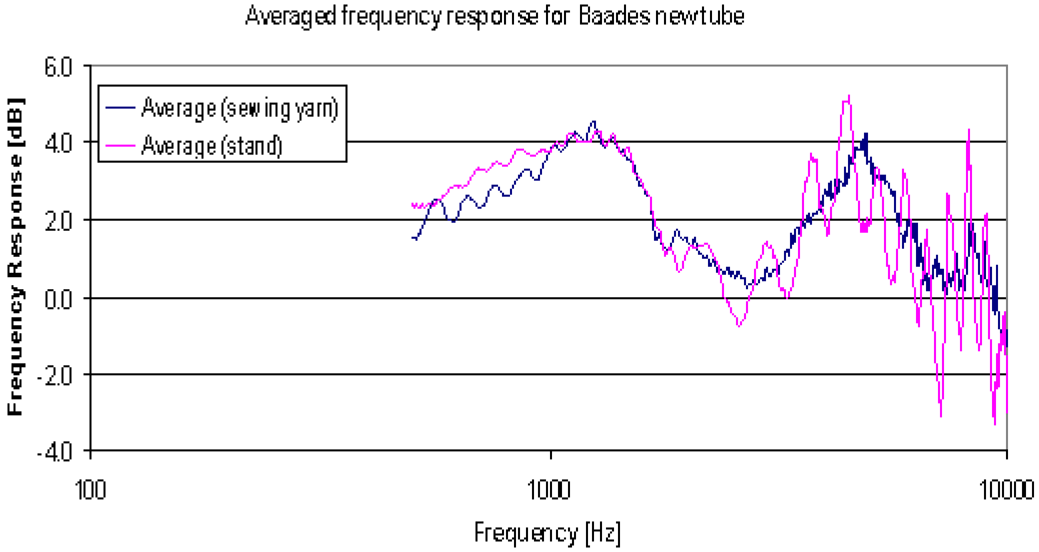

Figure 7: Comparison of mounting with microphone stands or sewing yarn (Halvarsson [11])

COMPARISON OF THE FREQUENCY RESPONSE OF SAMPLING TUBES

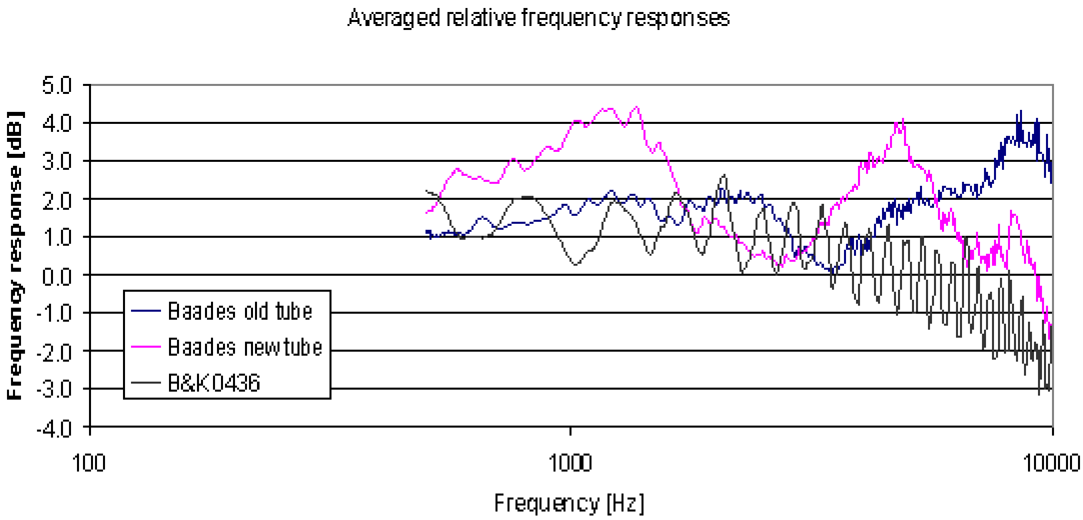

Figure 8: Comparison of the frequency responses of 3 different sampling tubes from 500 Hz to 10 kHz

Figure 8 shows a comparison of the frequency responses of two of Baade's prototype sampling tubes with the frequency response of a commercial Brüel and Kjær sampling tube. The Brüel and Kjær sampling tube shows pronounced resonances because it has no internal absorber like that inside Baade's prototype sampling tubes. Baade's new prototype sampling tube is now being tested with an impedance transformer as suggested by Wang and Crocker [12], rather than the internal absorber used to obtain the results in Figure 8. The initial results look promising. The dip between 2 and 4 kHz appears to have been eliminated.

CONCLUSIONS

The narrow band frequency response of a sampling tube can be reliably measured in an anechoic room if averaging is performed over a number of source or receiver positions, and if reflections from supporting hardware are minimized. Baade's prototype sampling tubes have a smoother frequency response than the Brüel and Kjær type UA 0436 sampling tube because of their use of an internal sound absorber or an impedance transformer. Baade's prototype sampling tubes should be able to be evolved into a satisfactory sampling tube whose design details can be included in ASHRAE Standard 68 and ISO 5136.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the work of Daniel Tooley, Vladimir Pavasovic and Willem Gouthro who performed some of the measurements used in this paper.

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