inter-noise 2009
innovations in practical noise control
2009 August 23-26
Ottawa, Canada

Reduction of tonal noise in lecture room air conditioning supply ducts

Jack B. Evans[a]
JEAcoustics
Engineered Vibration Acoustic & Noise Solutions
1705 West Koenig Ln
Austin, Texas 78756-1206 USA

ABSTRACT

A multipurpose room in a university teaching facility, which can be used for lecture, presentation or meetings, had an audibly tonal background noise. On-site observations and measurements were conducted to determine the nature of the noise and potential solutions. Measurements showed that with air conditioning on, broadband ambient noise slightly exceeded allowable background noise criteria, but the 500 Hz 1/3 octave level exceeded sidebands by 9 and 6 dB, respectively. Measurements in the mechanical equipment room indicated no air handler fan noise that contributed to the 500 Hz band. Observations of the ductwork above the ceiling indicated a potential turbulence-generating geometry near the vane in a tee fitting. This paper addresses the potential for aerodynamic and duct geometry contributions to noise generation and solutions proposed to mitigate the tonality. Graphic diagrams of ductwork configuration and results from on-site measurements will be presented along with the alternate ductwork solutions proposed. The effectiveness of fan and duct fitting noise treatments is discussed.

1. INTRODUCTION

A university academic teaching and faculty office building was planned with a multipurpose lecture and assembly room, to be included as an alternate if the bid-budget allowed. The space was designed as a stand-alone addition, including a dedicated air conditioning and heating unit. When the space was built and building systems were commissioned, an audible tone was noted in the background sound spectrum. Acoustical measurement and evaluation were commissioned.

Measurements confirmed tonality in the supply air ducts, but not in the air handler mechanical equipment room. Observations of the ducts revealed minor changes from the design to avoid conflicts in the ceiling plenum. The field changes in duct geometry may have caused conditions that generate tones in the duct. The evaluation focused on this issue.

Alternate noise control recommendations that were offered to the design engineers for consideration are discussed below. One solution was selected and implemented after additional detail development. We have subjective evaluation response from the user/occupants that indicate tone reduction and satisfaction with the renovated duct installation.

[a] Email address: Evans<at>JEAcoustics.com

2. EXISTING CONDITIONS

A. Initial Determination of Issue

Project design criteria for a mixed-use space (lecture, assembly and reception) was NC 30-35, which is somewhat more relaxed than for a pure teaching space. At substantial completion of construction (just prior to initial occupancy), the owner's representative noted a tonal sound in the room. An octave spectrum analysis measurement of background sound requested for comparison with the allowable sound criteria showed broadband non-conformance in the mid-part of the audible spectrum. Following a review by design engineers, it was noted that the AHU was rotated 90° from the position shown on engineering drawings and approved shop drawings, but the cause or reason was not known,[1] but later was found to be due to space conflict with pump installations. The report indicated that the AHU rotation resulted in additional duct fittings, including the supply duct offset discussed above.

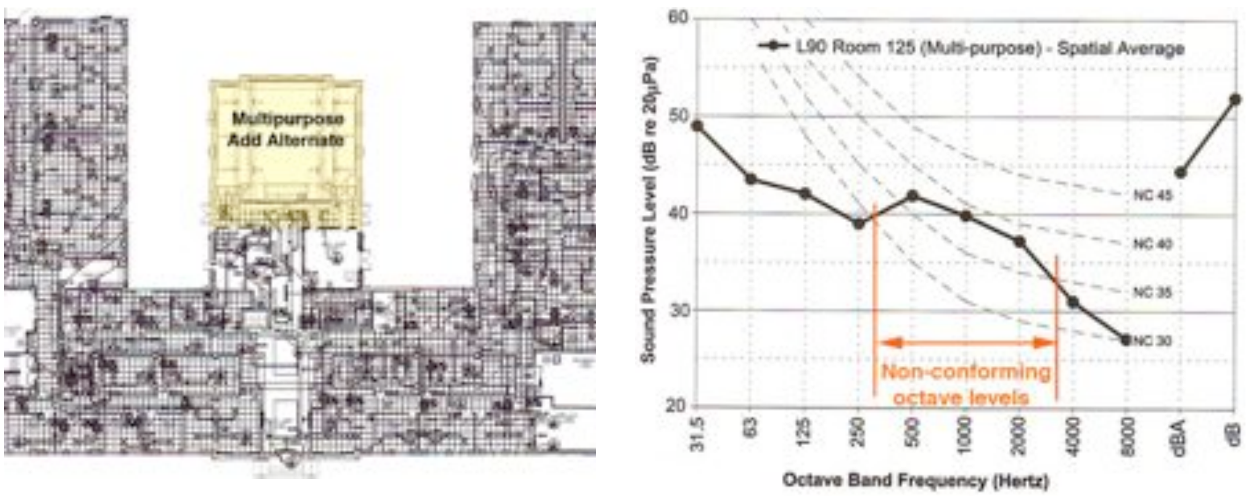

Figure 1: Multipurpose Room Addition to Academic Building (left) with Background Noise vs. Criteria (right)

B. HVAC System Design

The multipurpose lecture room was designed as a "stand-alone" facility that could be constructed as an "add alternate" concurrently with the building or as a future expansion. A dedicated heating and cooling air handling unit (AHU) in it's own mechanical equipment room (MER) was planned immediately across a corridor/pre-function space from the multipurpose room. The heating, ventilating and air conditioning (HVAC) ducts included a primary or trunk supply duct with a "tee" fitting to create two branch ducts that would serve both sides of the room. There was a return air duct from the rear of the multipurpose room back to the MER. Space conflicts during construction caused the constructor to make a minor field modification to offset the supply duct just before the tee fitting, as shown on Fig. 2 below.

Conditioned air is supplied to the multipurpose room via slot diffusers along the sidewall perimeter soffit and via side-throw (lateral discharge) diffusers on vertical furring surfaces. Small branches at ends of main branches serve the slot diffusers. Individual insulated flexible ducts connect the slot diffusers and coincidently provide supplemental attenuation. Larger branches serve the sidewall diffusers. They are on 45° shoe fittings tapped off the branches, and lack any supplemental duct attenuation. The objectionable tonal noise is measurably and audibly greater at the sidewall diffusers than the perimeter slot diffusers. Similarly, the tonal sound is greater at diffusers on the branch that is closer (shorter duct length) to the tee branch fitting and a few dB less at diffusers on the opposite branch (longer duct).

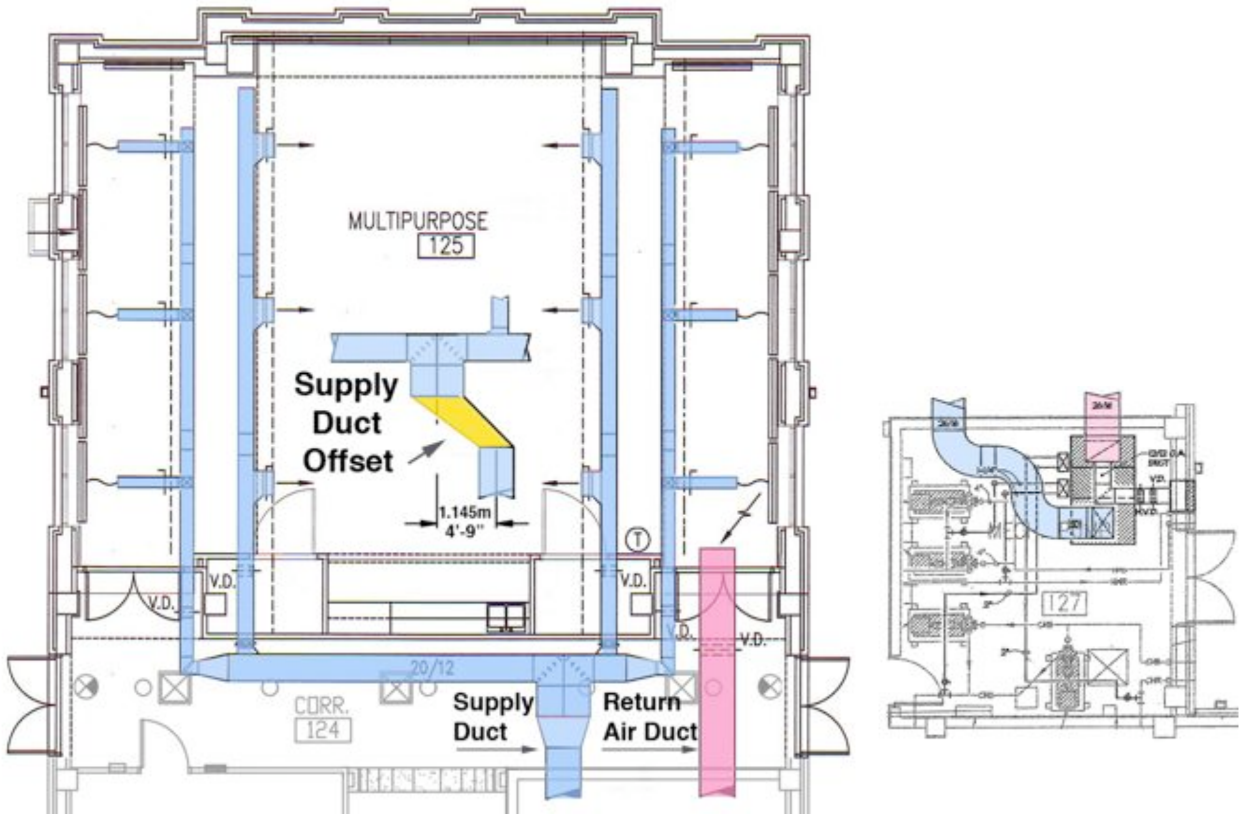

Figure 2: HVAC duct plan of the Multipurpose Room with inset of supply duct installed configuration (left) and plan of AHU MER as designed (right).

The return air transfer duct has an open inlet above the soffit ceiling at right rear of the room. It is routed above the corridor ceiling to the AHU MER, where it connects to the AHU inlet.

C. Architectural Acoustics

The multipurpose room is oriented with space for speaker podium and projection or video monitor screen at the front. Entry/exit doors and a serving bar are at the rear. Sidewalls have exterior windows. All of the wall and window surfaces are acoustically reflective. The acoustically absorptive ceiling has lower elevation soffits over the sides and a higher elevation ceiling above the center of the room. Moderate room reverberation caused some noise build-up. The room has good sound isolation from exterior or adjacent space interior intrusive noise.

3. OBSERVATIONS AND MEASUREMENTS

A. Observations

An acoustical consultant was retained to evaluate the existing conditions and develop recommendations to reduce noise level and if possible, the tonality in the sound spectrum also. Subsequent to review of the design and the post-construction test and balance report the Acoustician visited the site to conduct visual observations and acoustical measurements for evaluation.

By observation, it was noted that the tonal noise was most noticeable near the rear of the room on the side closest to the AHU MER. Reflection from the nearby rear wall slightly amplified the diffuser discharge noise. The return air duct inlet had a barely audible tone, but at a lower pitch than the tonality of the supply air. Removal of supply diffusers did not seem to change tonality, indicating that the source must be upstream in the ducts or air handler. Very little was visible above the hard, solid corridor ceiling, but the supply duct offset was observed. The geometry of the duct installation, which had been altered to accommodate physical obstructions in the crowded ceiling plenum, caused the air to flow in a diagonal direction as it approached a 90° tee fitting. The multiple direction changes and internal duct fittings appeared capable of producing several small areas of turbulence.

B. Measurement Results

Measurements were conducted at multiple locations, including near each sidewall supply outlet, near the return air open inlet, and in the MER near AHU inlet and discharge ducts. After reduction and analysis of the data, results indicated:

1. A tone[2] in the supply air (at diffuser nearest tee fitting) in the 500 Hz 1/3 octave, which exceeded the 400 Hz and 630 Hz sidebands by 9 and 6 dB, respectively, as shown in Fig. 3 (left). A similar tone was measured at the diffuser on the opposite side of the room (farther from tee fitting) with 7 dB and 6 dB sideband differentials (not illustrated below).
2. Removal of the side-throw supply air diffuser from the first outlet did not change the 500 Hz tone (Fig. 3, spectrum with diffuser vs. without is not illustrated below). Removal of the trim damper on the face of the diffuser did not change the tone (after the diffuser was replaced).
3. A tone was measured in return air (at duct inlet) in the 630 Hz 1/3 octave, which exceeded the 500 Hz and 800 Hz sidebands by only 2 and 5 dB, respectively, re: Fig. 3, but there was no evidence of the 500 Hz tone found in the supply duct.
4. The noise spectrum in the MER showed no prominence in the 500 Hz or the 630 Hz 1/3 octaves. If anything in the MER contributed to the supply duct tone, it was neither audible nor measureable above the ambient MER level with the AHU on. Comparison of AHU fan noise spectrum versus the tonal spectra in supply and return ducts are shown in Fig. 3 (right).
5. The noise spectrum within the AHU fan module showed a slight prominence in the 630 Hz 1/3 octave, but no similar prominence in the 500 Hz 1/3 octave, indicating that the fan might be the source of the slight tone in the return air. Nothing was audible or measureable above the AHU fan noise that appeared to contribute to the tone in the supply ducts.
6. A peak level in the 315 Hz 1/3 octave in the fan noise spectrum, thought to be the blade passage frequency, is also visible in the MER and return air duct spectra, but not in the supply duct spectrum. The 630 Hz tone in the R/A duct is possibly a harmonic of the 315 Hz fan tone.

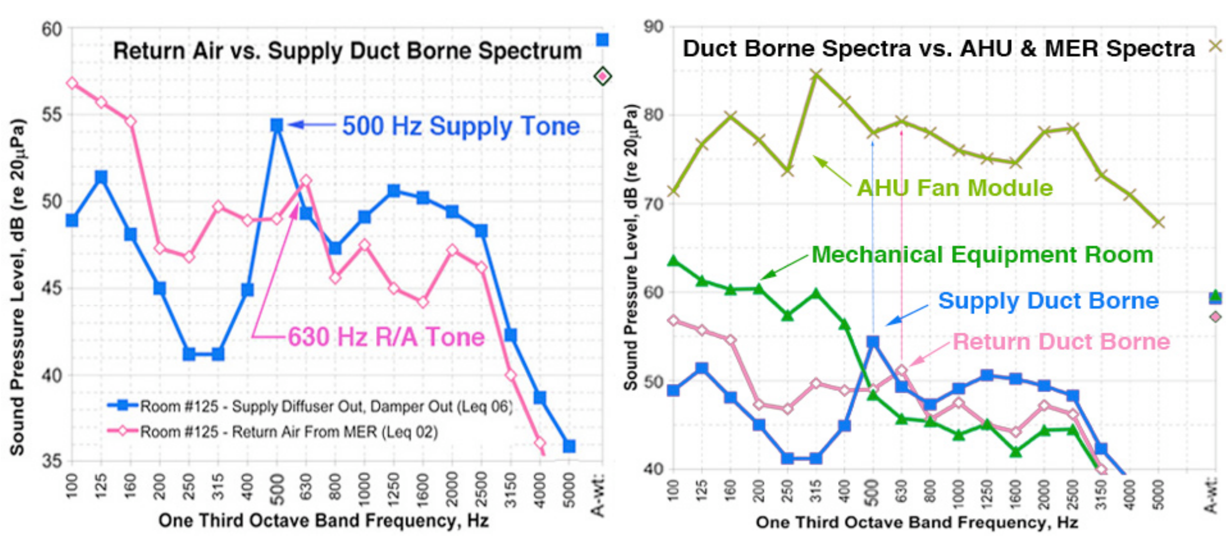

Figure 3: Tonal supply and return duct noise spectra (left) and duct borne versus AHU & MER spectra (right).[3]

4. FINDINGS AND RECOMMENDATIONS

A. Findings

After consideration of other potential sound source locations and spectra, the 500 Hz tonal sound appears to be generated within the supply duct. There are no unusual duct characteristics or fittings that would normally generate narrow band noise, except for the approximately 45° duct offset before the tee fitting. The airflow from the offset duct would flow across the edge of the internal vane that splits the duct flows going into each elbow segment of the tee fitting as illustrated in Fig. 4. The diagonal flow relative to the vane appeared to shed vortex turbulence behind the vane, which could generate noise at frequencies proportional to the size of the vortex.[4, 5]

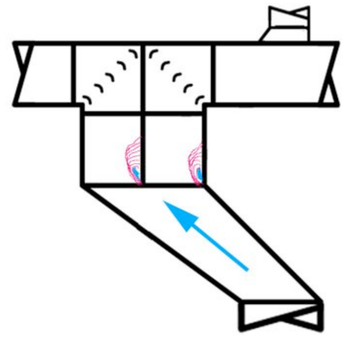

Figure 4: Eddy pattern at vane.

The first diffuser on each main branch is near a rear-wall reflecting surface, causing 2-3 dB amplification[6] reinforcement of the duct noise from diffusers, including the 500 Hz tone. The room is also somewhat reverberant and harsh in characteristic due to predominance of reflective wall surfaces, in contrast with the quantity of ceiling surface area that is acoustically absorptive.

B. Recommendations

It was necessary to implement effective modifications that were feasible with minimal disturbance to the as-built conditions to avoid disruption and downtime for the occupants and excess expense to the owners. The consultant focused on modification or replacement of the offset supply duct and/or tee fitting and surface changes in the multipurpose room in lieu of changes above the ceiling or behind walls that might require demolition and rebuilding.

1. Eliminate the offset duct and the diagonal approach to the tee fitting for the purpose of reducing the tee-fitting vane's vortex shedding turbulence. Three variations were proposed:

- Fabricate an acoustically lined expansion-chamber plenum to replace the offset duct and tee.
- Fabricate an expansion-chamber plenum to replace offset duct only with the tee fitting at exit.
- Replace the offset duct with two 90° elbows to accommodate the duct misalignment.

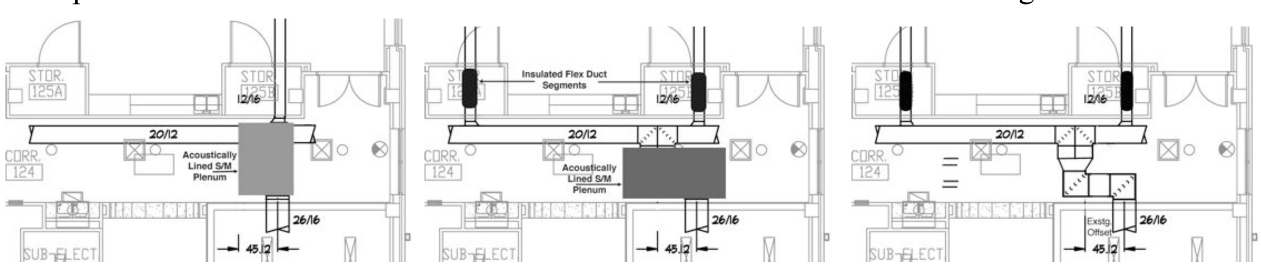

Figure 5: Three offset duct replacement variations, lined plenum in lieu of duct and tee (left), plenum in lieu of offset duct only (center) and two 90° elbows in lieu of offset duct (right). Duct attenuator locations are shown also.[7]

2. Either in lieu of or in addition to the modifications described above, insert duct attenuators in the duct branches downstream of the tee fitting, and before the first diffusers.
3. Insert a low-pressure duct attenuator at the return duct inlet or place acoustically absorptive finishes on surfaces adjacent to the return duct inlet to reduce marginal room noise contribution.
4. Minor recommendations were offered for the secondary issue of broadband noise in speech frequencies to increase supply duct sizes and reduce air velocity (not discussed here).
5. Install acoustically absorptive surfaces on rear wall of room at elevation near sidewall diffusers to (a) reduce reverberation and harshness and (b) to reduce reflective amplification.

5. IMPLEMENTATION

Subsequent to discussions about cost and feasibility for the various alternatives and affects on operations in the occupied space, the mechanical engineer and architect elected to pursue the acoustically lined expansion chamber plenum replacement of the offset duct and tee fitting. Difficulty of working in the crowded ceiling plenum above the corridor and pressure drop considerations for various configurations and fittings favored the more simple solution.

The lined expansion plenum solution solved multiple problems: i) expansion chamber plenum attenuates broadband noise over a wide frequency span[8], ii) by eliminating the diagonal flow over the tee vane, the tone should be eliminated, iii) by eliminating the tee fitting, additional broadband fitting noise should be reduced in the speech frequencies and iv) the acoustical liner in the plenum improves mid to high frequency attenuation of fan and duct noise entering the chamber. Therefore, implementation of the lined expansion plenum prevented the need for any other duct modifications or duct attenuator insertions.

Product and installation information were provided to the Owner's representative, but the additional absorption recommendations were not implemented as part of this post-construction adjustment. The owner may adjust room absorption in the future, it they find the need or desire.

6. CONCLUSIONS

Although the Consultant was not retained to conduct post-installation performance validation measurements (due to expense of travel and consulting fees), the project is considered a success.

Replacement of the offset duct and tee fitting did reduce noise and tonality, although an exact amount may not be reported due to lack of validation measurement data. The owner is satisfied, and the multipurpose room is in use by the institution for its intended functions.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the mechanical engineer, HMG Associates and Architect, PBS&J-Croslin for permission to publish and assistance with production of this case study.

REFERENCES

[1] T.I. Irwin, unpublished construction report, "Multipurpose Room 125 Noise Issue," HMG & Assoc., Inc., Austin, Texas, 29 Jan 2008, pg. 2.

[2] C.M Harris, "Definitions…," Chapter 2 in *Handbook of Acoustical Measurements and Noise Control, 3rd ed.,* C.M Harris, Ed., McGraw-Hill, New York, pg. 2.16, 1979.

[3] J.B. Evans, unpublished consultation report, "Multipurpose Room 125 HVAC Background Noise," JEAcoustics, Austin, Texas, 20 March 2008, pg. 2.

[4] ASHRAE. "Sound and Vibration Control," *ASHRAE Handbook of HVAC Applications.* Atlanta, GA: American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc., Chap. 47, Aerodynamically generated sound in ducts / fixed duct fittings, pp. 47.7-47.9, 2007.

[5] A.G Davenport, M. Novak, "Part II: Vibration of Structures Induced by Wind," Chapter 29, Excitation due to Turbulence / Vortex shedding in *Shock & Vibration Handbook, 3rd ed.,* C.M Harris, Ed., McGraw-Hill, New York, pp. 29.23-29.33, 1988

[6] Sound research Laboratories, Ltd. "Sound In Rooms," Chap. 3 in *"Noise Control in Building Services"* A. Fry, Ed., Pergammon Press, Oxford (1988), 3.3.1 surface directivity, pg. 47.

[7] *Ibid.,* Evans unpublished report, pg. 4.

[8] *Ibid.,* ASHRAE., Chap. 47, Duct element sound attenuation / Plenums, pp. 47.12-47.13.