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Automated transmission loss measurement in the Structural Acoustic Loads and Transmission facility at NASA Langley Research Center

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Abstract

A technique to measure the radiated acoustic intensity and transmission loss of panels is documented in this paper. This facility has been upgraded to include a test fixture that scans the acoustic intensity radiated from a panel on the anechoic receiving room side of the transmission loss window. The acoustic intensity incident on the panel from the reverberant side of the transmission loss window is estimated from measurements made using six stationary microphones in the reverberant source room. From the measured incident and radiated intensity, the sound power transmission loss is calculated. The setup of the facility and data acquisition system are documented. A transmission loss estimate of a typical panel is shown. The measurement-to-measurement and setup-to-setup repeatability of the transmission loss estimate are assessed. Conclusions are drawn about the ability to measure changes in transmission loss due to changes in panel construction.

1. Introduction

In aircraft, the main source of interior noise is sound that is transmitted through the aircraft fuselage from noise sources outside the aircraft. Thus, it is desirable to quantify and reduce the sound transmitted through the fuselage wall. The Structural Acoustic Loads and Transmission (SALT) facility [1] was recently upgraded. Intensity probes and a traverse mechanism were installed to measure the spatial intensity distribution radiated from panels mounted in the transmission loss window. The spatial intensity can be integrated to find the total sound power radiated from the panel due to an excitation of the panel [2]. In the case of a reverberant excitation, the transmission loss (TL) of a panel can be evaluated. In the case of single or multiple point force excitations, the radiated sound power and the spatial distribution of the intensity due to the excitation can be evaluated. These data can be used to determine the effectiveness of noise control treatments applied to the panel and to validate structural acoustic models. This paper serves to document the setup, procedure and typical results of transmission loss and radiated sound power measurement using the SALT facility.

2. Facility Setup And Data Reduction

All of the measurements presented here are made in the Structural Acoustic Loads and Transmission (SALT) facility at NASA Langley Research Center. The facility consists of a reverberation chamber and an anechoic chamber connected by a 54 inch by 54 inch TL window. A schematic of the SALT facility is shown in Figure 1a. The acoustical properties of the SALT rooms are documented by Grosveld [1]. To measure the spatial acoustic response of a panel mounted in SALT, a traverse mechanism has been installed on the anechoic side of the TL window (Figure 1b-d). The positioning of the traverse can be controlled in the vertical, and either horizontal or azimuthal directions. Two primary rails above and below the TL window control the horizontal positioning of the traverse (Figure 1b). There is a smaller secondary rail, mounted to the primary rails, that controls the vertical positioning of the traverse (Figure 1c). The measurement transducers are mounted on a vertical rod that is attached to the rails (Figures 1c and d). If a curved panel is installed, the rotation of this rod can be controlled by a drive that is mounted to the secondary vertical rail. Control of the traverse is performed using in-house Visual Basic computer software that is run on a PC. Measurement automation of the traverse is obtained by linking Visual Basic software that controls the traverse to Visual Basic software that controls the data acquisition system. Commercially available software and a VXI data acquisition front end are used to acquire response data. Measurements were made using 3 two-microphone acoustic intensity probes mounted to the traverse mechanism (Figures 1d). With each probe, half-inch phase matched condenser microphones were used.

Measurement of sound intensity radiated from a noise source using two closely spaced, phase matched microphones is documented by Fahy [2]. The relation between the cross spectrum of the two microphones and the intensity parallel to the axis of the two microphones is also documented [2]. Radiated sound power is determined by integrating the normal intensity over a surface that encloses the source [2]. An intensity probe is used to measure the intensity normal to a surface by positioning the probe axis perpendicular to the surface at discrete measurement points. The energy flow through the surface for a grid of discrete measurement points, i, at a particular cyclic frequency, f, can be approximated by

$$\Pi(f) \cong \sum_{i=1}^{N} I_{n,i}(f) A_i \qquad (1)$$

where $I_{n,i}$ is the normal intensity measured at a grid point i, A_i is the area represented by the measurement at grid point i, and N is the total number of measurement points. A panel mounted in the TL window cannot be fully enclosed by a surface. Thus, a grid of scan locations is selected such that most of the energy radiated from the panel is captured by the scan. This is accomplished by extending the scan beyond the edges of the panel and ensuring that the intensity response at the perimeter of the scan is nearly zero. The time histories of the intensity probes mounted to the traverse mechanism are recorded using the data acquisition system.

Point force and reverberant excitations were studied. To measure radiated sound power for a point force excitation, a shaker is attached to the panel. The traverse mechanism was used to measure the spatial intensity radiated from the panel and equation 1 is used to compute the radiated power. To measure the TL of a panel, the reverberation room was driven with speakers to produce a reverberant excitation of the panel (Figure 1e). The speakers were driven by white noise. Both radiated and incident sound power were measured. The transmitted acoustic power is measured as described above. To compute the incident sound power, six quarter-inch condenser microphones were randomly distributed throughout the reverberation chamber (Figures 1e). The pressure response of these microphones was measured and the power spectrum was averaged. The energy density of the room was calculated from the average response of these microphones according to the standards ASTM E90-83 and ISO 3741-1988 [3,4]. The incident sound power was computed from the energy density of the room. The TL was computed as the ratio of the incident sound power to the radiated sound power [3].

3. Results and Discussion

Transmission loss measurements using the facility were investigated. The mass law behavior of the TL measurement was demonstrated using two limp masses of differing thicknesses. The limp masses are 1/4 inch and 1/16 inch thick rubber sheets that were 54 inches long on each side. The mass of the thicker sheet is four times the mass of the thinner sheet. The limp masses were mounted in the TL window, and the transmission loss was measured using the procedure outlined above. The TL measurements for the two limp masses are shown in Figure 2. An increase of between 11 and 12 dB was observed when comparing the TL of the 1/4 inch sheet to the 1/16 inch sheet. Also, a 6 dB per octave increase in the measured TL is observed for each limp mass. Thus, the method does yield results consistent with expected mass law behavior.

The TL characteristics were studied for a 0.216 inch thick Plexiglas panel mounted in SALT as shown in Figures 1b and 1d. The coincidence frequency was predicted to occur at 8000 Hz. From vibration measurements, it was found that the first mode occurs at 80 Hz. To capture these features, two different probe and spatial grid setups were used to measure the intensity over a range of frequencies from 50 Hz to 10000 Hz. For frequencies below 800 Hz, a 2 inch by 2 inch spatial sampling rate was used and the 1.96 inch intensity probe spacer was used. For frequencies above 800 Hz, a 1 inch by 1 inch spatial sampling rate was used and the 0.334 inch intensity probe spacer was used. The TL of the panel was found using the procedures outlined above. The TL measurement of the Plexiglas panel is shown in Figure 3. The dips at both the first resonance and the coincident frequency occur at the expected frequencies and mass law behavior is observed between these two features.

The Plexiglas panel was held in the TL window by a fixture as shown in Figures 1b and 1d. The Plexiglas window was bolted in an aluminum frame to simulate a clamped edge boundary condition. The aluminum frame was bolted into a 4 inch thick fiberboard fixture that was bolted into the TL window. To quantify flanking energy through the fiberboard, the Plexiglas window and aluminum frame were replaced by a 4 inch thick fiberboard plug. The TL of the fiberboard plug and fiberboard fixture was measured. The TL of the 4 inch thick fiberboard fixture is compared to the Plexiglas panel in Figure 4. The TL of the fiberboard plug is 5 to 10 dB higher than the TL of the window. Thus, the flanking energy transmitted through the fiberboard does not significantly affect the TL measurement of a typical Plexiglas panel.

To evaluate noise control treatments applied to a panel, the variation in the measured transmission loss must be smaller than the change caused by a treatment. The variability of the TL measurement of a panel was studied to ensure the quality of the measurements. Both the back-to-back measurement variation and the variation due to repeat installations were investigated. The back-to-back measurement variation was determined by repeating a TL measurement five times during a 4 hour period. The TL measurement of the five back-to-back tests is illustrated from 63 to 800 Hz in Figure 5a. The standard deviation of the TL measurements is illustrated in Figure 5b. The frequency average standard deviation of the transmission loss for back-to-back measurements during a single day is 0.03 dB. This is much smaller than expected, and does not contribute to variations in the measured TL that would limit the evaluation of the performance of noise control treatments applied to a panel.

The variation due to repeat installations was determined by measuring the TL of the same Plexiglas panel four times over a period of six weeks. The fixture that held the Plexiglas panel in the TL window was completely disassembled and reassembled before each test. The ambient temperature and pressure varied significantly between tests. The intensity probes and the reverberation room microphones were calibrated before each test with the same pistonphone. The measured TL for the 4 tests from 63 to 800 Hz is shown in Figure 5c. The standard deviation of the measured TL for the repeat installations is shown in Figure 5d. The frequency average standard deviation of the measured TL for the repeat installations is 0.5 dB. The variation due to repeat installations over a six week span is significantly higher than the variation due to repeat measurements (Figures 5b and d). However, the frequency averaged standard deviation of 0.5 dB is dominated by the high variation in the 63 Hz one-third octave band (Figure 5d). The standard deviation decreases as frequency increases (Figure 5d) and at higher frequencies is typically between 0.25 and 0.3 dB. At frequencies above 125 Hz the standard deviation of the TL measurement due to repeat installations is acceptable for evaluation of the performance of noise control treatments applied to a panel with a 95% confidence band of ±0.6 dB.

4. Conclusions

The experimental setup documented in this paper can be used to measure radiated sound power and transmission loss of panels mounted in the SALT facility at NASA Langley Research Center. Typical results have been presented and agree with expectations. The variation of the measured transmission loss due to back-to-back measurements is extremely small and does not limit the ability to measure changes in transmission loss due to added acoustic treatment. The variation of the measured transmission loss due to repeat installations of a typical panel is small enough to enable evaluation of noise control treatments applied to panels where the change in the transmission loss is greater than 0.6 dB. Thus, the technique can be used to evaluate the performance of noise control treatments applied to panels that simulate an aircraft fuselage and its components.

References

1. Grosveld, F., 1999, "Calibration of the Structural Acoustic Loads and Transmission (SALT) facility at NASA Langley Research Center," *Proceedings of Inter-noise 99*, Fort Lauderdale, Florida, USA.
2. Fahy, F., 1995, *Sound Intensity*. London: E & F N Spon.

3. ASTM, 1984, “ASTM standard method for laboratory measurement of airborne sound transmission loss of building partitions,” ASTM E90-83.
4. ISO, 1988, “ISO Acoustics international standard – determination of sound power levels of noise sources – precision method for broad band sources in reverberation rooms,” ISO 3741-1988.

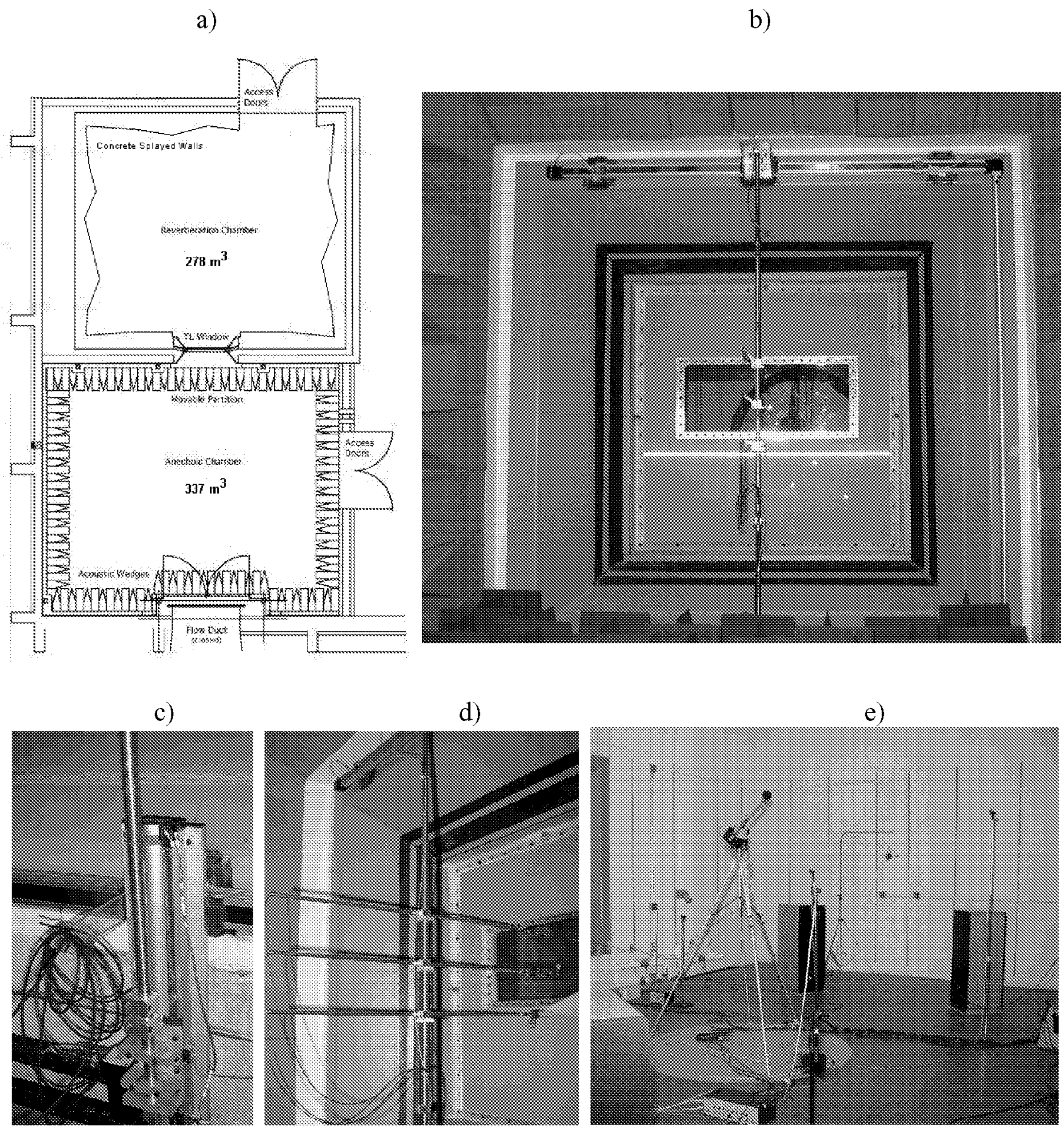

Figure 1: Picture of the automated intensity scanning of SALT, schematic of SALT, b) the scanning rig, c) the x-y traverse mechanism, d) the probe setup, and e) the excitation of the reverberation chamber.

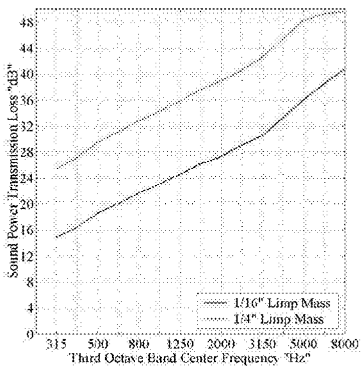

Figure 2: Comparison of the transmission loss of 2 limp masses.

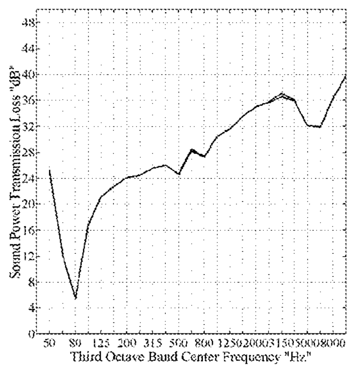

Figure 3: Typical transmission loss curve from 80 to 10000 Hz for a 0.216" thick Plexiglas panel.

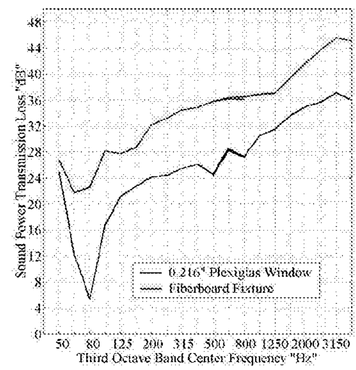

Figure 4: Measurement of the flanking energy.

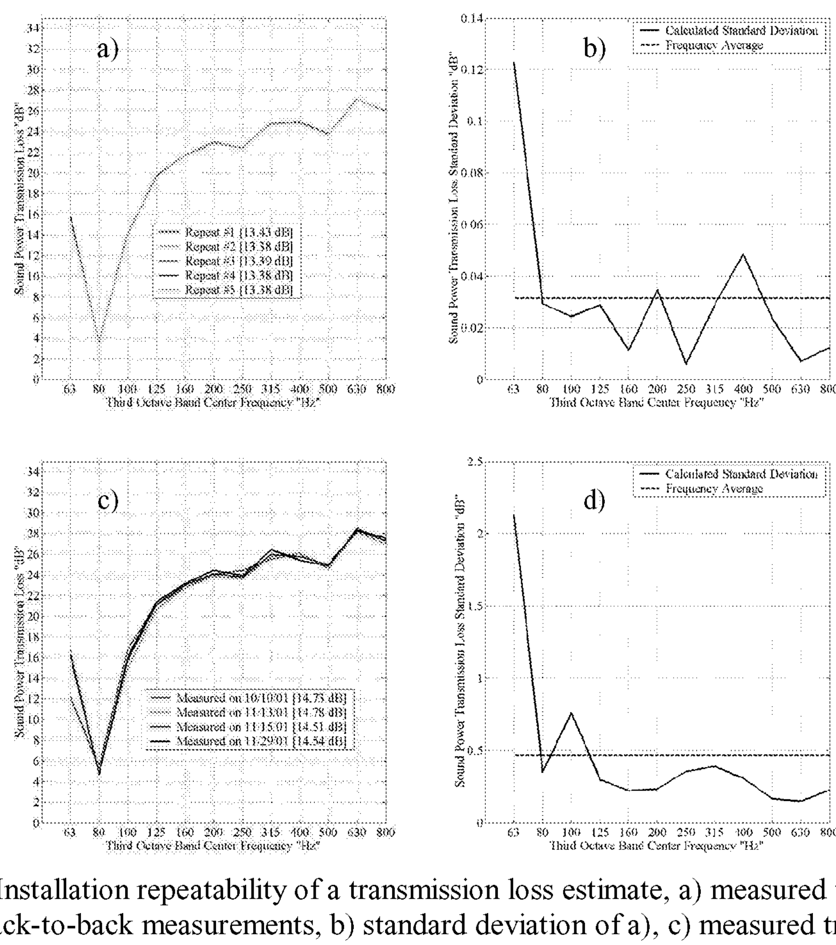

Figure 5: Installation repeatability of a transmission loss estimate, a) measured transmission loss for back-to-back measurements, b) standard deviation of a), c) measured transmission loss for repeat installations, and d) standard deviation of c). Total transmission loss integrated over the frequency range is indicated in the legend.