A Sound-Insulated Enclosure to Shield Acoustical Insect Detectors from Grain Elevator Background Noise

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ABSTRACT

Acoustical devices used to detect hidden insect infestations must be shielded from noise in most practical applications. One device developed specifically for a noisy environment, the Acoustical Location "Fingerprinting" Insect Detector (ALFID), quantitates the numbers of insects present in samples of grain such as are graded by the Federal Grain Inspection Service (FGIS) in shipments for export. The grading typically is done at offices inside commercial grain elevators that have broadband noise at Sound Pressure Levels (SPLs) of about 50-85 dB//ref:20 μPa. By contrast, small adult insects or larvae feeding inside kernels of grain produce low-intensity sounds of only about 15-35 dB//ref:20 μPa SPL from a distance of 3 cm inside a grain sample, primarily at frequencies between 2-6 kHz. This report describes a portable sound-insulated enclosure designed to shield background noise and provide for rapid loading and unloading of grain samples. The enclosure is a 70-kg, 68.5-cm-diameter by 81-cm-long cylinder, constructed from shells of steel, acoustical foam, vinyl, and lead. A pedestal with wheels, bearings, and a lock mechanism provides for mobility, safety, and rotation between horizontal and vertical, fixed positions. The noise reduction of the enclosure increases 6.5 ± 0.76 dB for each doubling of frequency, approximately the 6 dB per frequency doubling predicted from the mass law of transmission loss. Sound Pressure Levels of external noises are reduced 60-80 dB at frequencies between 1-10 kHz. This level of noise reduction is sufficient to permit operation of ALFID in a commercial grain elevator environment.

INTRODUCTION

Recent improvements in acoustical and digital signal processing technology have fostered development of practical devices for detecting hidden insect infestations. An example is the Acoustical Location Fixing Insect Detector (ALFID) (Shuman et al. 1993, Hagstrum and Shuman 1995, and these Proceedings), developed for use by the Federal Grain Inspection Service (FGIS) to grade grain destined for export. The ALFID contains an array of microphones embedded in the wall of an empty cylindrical chamber. A lid at the top of the chamber can be removed to load or unload 1-kg samples of grain for testing. The number of insects in the sample is estimated by counting the number of separate sound sources. Sampling is done by pointing ALFID up to load and down to unload. Holding ALFID horizontal during testing equalizes the pressure on the sixteen microphones in the sampling chamber.

The ALFID device must be acoustically shielded because insect feeding and movement sounds are of low intensity compared with background noise in FGIS offices at commercial grain elevators. The minimum amount of shielding needed was estimated in a study that Mankin, Shuman, and Coffelt have submitted for publication in the Journal of Economic Entomology. They compared sound pressure levels (SPLs) and power spectra of sounds made by insects feeding inside grain kernels with SPLs and spectra of the noise background in several FGIS offices. The sound pressure level 3 cm from a kernel of grain infested with a *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) larva is about 23 dB//ref:20 μPa (range: 15-35 dB), primarily between 2-6 kHz. The grain elevator noise background is a broadband signal with sound pressure levels of 50-85 dB//ref:20 μPa.

To provide sufficient shielding and simplify the grain sampling process, a sound attenuation enclosure was constructed to the following specifications: 1) 50-60 dB noise reduction between frequencies of 1-10 kHz, 2) portability and easy access to interior chamber, and 3) rapid pivoting between up, down, and horizontal, fixed positions. This report describes the construction and acoustical characteristics of the enclosure.

METHODS AND MATERIALS

Enclosure. The enclosure was fabricated from cylindrical shells of steel, acoustical foam, lead, and vinyl. The outer shell is a 68.5-cm-diameter by 81-cm-long, 1-mm-thick steel cylinder. Removable steel lids are latched at the top and bottom of the shell (Fig. 1). The only other opening is a passage for the 1.9-cm-diameter cable between ALFID and the data acquisition system. ALFID is placed into the enclosure by first wrapping it in two layers of 5.1-cm-thick polyurethane foam wedges (Illbruck Sonex, Minneapolis, MN) (Table 1). The assembly is pushed through the bottom opening into a 30-cm-diameter by 43-cm-long, 1-mm thick, steel cylinder, centered in the outer shell (Figure 2). The shells between the outer and inner steel cylinders are shown in Fig. 2.

A funnel below the top lid permits rapid loading and unloading of grain. The 23-cm-long, 0.4-cm-thick, aluminum funnel is 38 cm in diameter at the opening. The diameter decreases to 10-cm at the base, where the funnel exits into ALFID's sampling chamber. To reduce the transmission of vibrations, the funnel is not attached to the enclosure or to ALFID. It is held in place by pressure from a series of rings (Fig. 2) made of Illbruck Sonex, Prospec, vinyl barrier, Prospec (two rings), lead, and Prospec (three rings). A cone made from concentric layers of Sonex, Prospec, vinyl barrier, and lead fits between the funnel and the top lid to provide further acoustical insulation.

Pedestal. The frame of a movable pedestal for the enclosure was constructed from eight 94-cm, two 46-cm, and two cross-bracing, 109-cm bars of L-angle iron (Fig. 1). A 9.8-cm-diameter rubber caster is attached to each corner at the foot of the base. The attachment is cushioned with felt to reduce transmission of ground vibration.

Two 1.1-cm-diameter pillow-block bearings are mounted on top of the frame (Fig. 2) to enable the acoustical enclosure to pivot on the pedestal. The bearings house a shaft welded to a 7.62-cm- wide by 61-cm-long U-beam. The U-beams are welded to two 2.54-cm by 0.32-cm-thick steel bands, which are welded to the top and bottom of the enclosure.

A locking mechanism on the pedestal (Fig. 3) enables the enclosure to pivot among loading, testing, and unloading, fixed positions. A 1-cm-diameter, 25.4-cm-long pin at the side of the bearings locks the enclosure in a horizontal position. An identical pin below the bearings locks the enclosure vertically.

Noise Reduction Measurements. The attenuation of sound by the enclosure was measured in an anechoic chamber for sine-wave signals produced by a sweep generator (Wavetek model 185, San Diego, CA) between 0.2-10 kHz. The signals passed to a 200-W power amplifier (Audiosource model AMP One, Burlingame, CA) connected to a 120-W speaker (JBL model 2441, Northridge, CA) set near the center of the chamber. The tones were detected simultaneously by identical microphones (Brüel and Kjær (B&K) model 4145, Nærum, Denmark) inside and outside the enclosure, about 60 cm from each other and the speaker. The signals were band-pass filtered between 0.2 and 15 kHz

(Krohn-Hite model 3100, Avon, MA). Sound Pressure Level (SPL) was measured with a B&K model 2610 amplifier in dB//ref: 20 $\log_{10}$(pressure / 20 μPa), where 1 μPa = 10^{-6} Pascal.

RESULTS AND DISCUSSION

The relation between attenuation inside the enclosure and the frequency of external sound is shown in Fig. 4. The results conform to the mass law of transmission loss (e.g., Vér and Holmer 1971),

$$R \approx \mathrm{Log}(\rho_s f), \qquad (1)$$

where R is the transmission loss in dB//ref: 20 μPa, ρ_s is the surface density (mass density per unit thickness) in kg/m^2, and f is the frequency in Hz. According to Eq. 1, the transmission loss increases by 6 dB when the density of the enclosure (see Table 1 for densities and thicknesses of the enclosure shells), the frequency, or their combination is doubled. The line in Fig. 4 plots the regression equation of best fit, calculated by SAS Proc GLM (SAS Institute, 1985):

$$R = -2.4 + 21.8\ \mathrm{Log}_{10}(f), \qquad (2)$$

where R and f are defined in Eq. 1. Eq. 2 has a coefficient of determination, $r^2 = 0.75$, and the standard errors of intercept and slope are 8.68 and 2.54, respectively. A doubling of frequency increases the transmission loss by $21.8 \cdot \mathrm{Log}_{10}(2) = 6.55$ dB, within one standard error of 6, the expected value. The deviations from the mass-law equation in Fig. 4 are not necessarily measurement errors, but are due partly to resonances that occur in the different layers of the enclosure. The resonances occur at different critical frequencies and sound coincidence angles (e.g., Vér and Holmer 1971) that depend on the density and compressibility of each layer.

Overall, the sound-insulated enclosure provides 60-90 dB of noise reduction between 1-10 kHz. Given that the ALFID sensors must detect insect-generated sounds at 15-35 dB SPL, noise reduction in the insulated enclosure is sufficient to enable operation of ALFID at backgrounds up to 80 dB SPL.

To consider the likelihood of encountering backgrounds higher than 80 dB SPL, we compared grain elevator noise backgrounds measured under several different conditions in Fig. 5. The backgrounds were measured inside FGIS offices at two different grain elevators near New Orleans. Unless noisy equipment like a siever was operating, the noise backgrounds were usually below 75 dB SPL. The sievers usually operated for short durations once or twice per hour. The noise of grain dropping through a chute into the building was about 73 dB, primarily below 1 kHz. Consequently, the enclosure is expected to provide adequate sound insulation except during brief periods of the noisiest conditions we encountered.

Additional noise reduction above that provided by the sound-insulated enclosure can be provided by electronic filtering. Much of the background noise intensity is at frequencies below 2 kHz, but insect-generated sounds have the greatest intensity between 2-6 kHz. Consequently, ALFID may be operable at background levels > 80 dB, depending on the spectrum.

In environments where the position of ALFID is fixed relative to the locations of major noise sources, attenuation can be increased by fixing patches of acoustical materials to the inside of the enclosure at points of resonance (e.g., Yang et al. 1995). An example is the acoustical insulation of automobile bodies. The selective use of patching would permit a reduction in the total thickness, weight, and cost of insulation.

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Table 1. Components of acoustical enclosure.

Material	Thickness (cm)	Density (kg/m^3)
Illbruck acoustical plastics:		
Sonex foam (open-cell polyurethane wedges)	5.08	32
Prospec foam (open-cell polyurethane sheet)	2.54	32
Prospec barrier (loaded vinyl sheet)	0.318	128
Prospec composite (urethane/vinyl/urethane)	3.49	41
aluminum	0.04	2700
steel	0.095	7800
lead	0.318	11300

Figure 1. Three-dimensional view of enclosure with top and bottom lids attached, held in vertical position for loading.

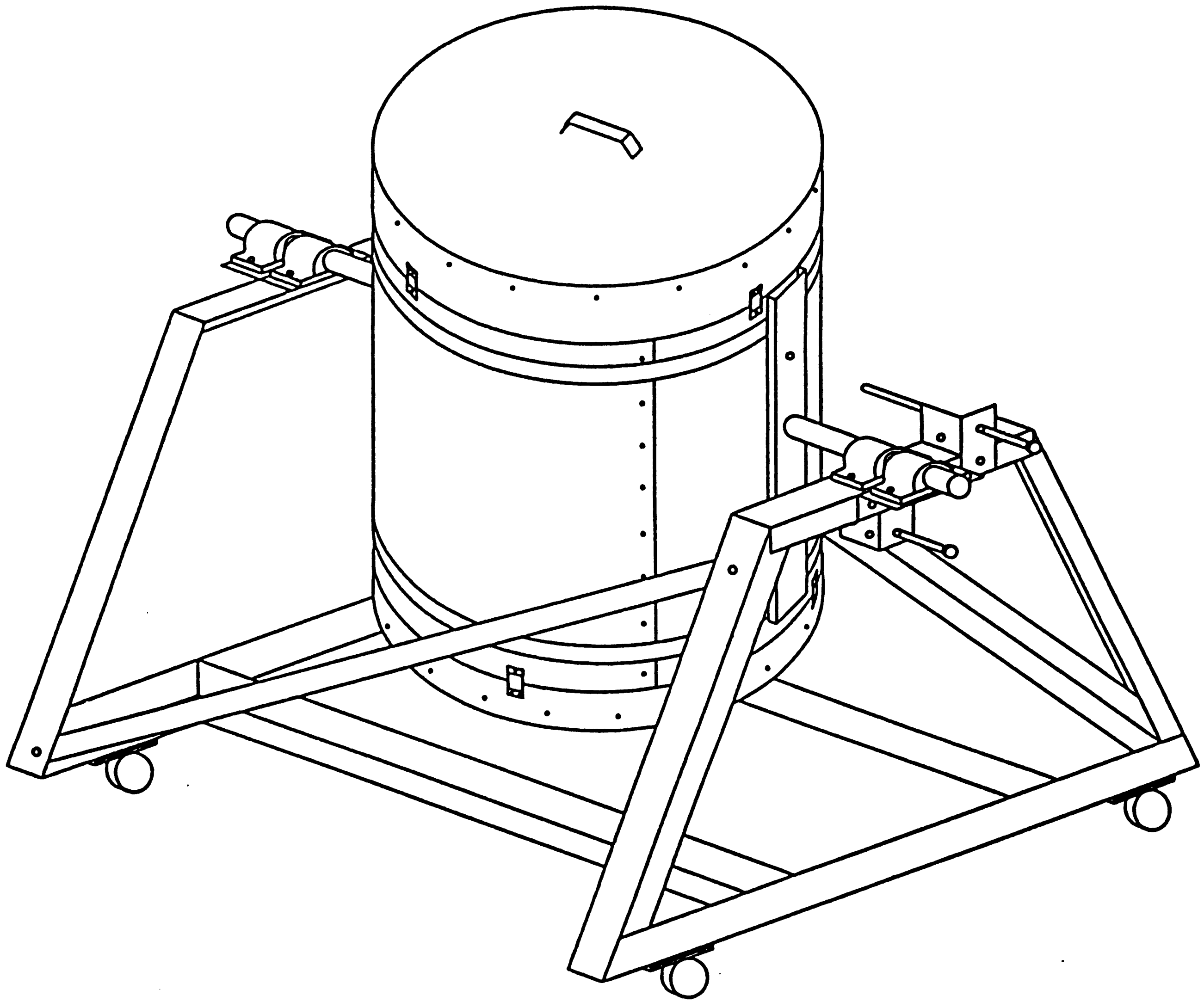
Figure 2. Cross-section of enclosure, showing the position of ALFID and the layers of steel, foam, lead, and vinyl barrier.

Figure 3. Position-locking mechanism on pedestal. The pin at the side of the bearing holds the enclosure in a horizontal position. The pin below the bearing holds the enclosure in a vertical position.

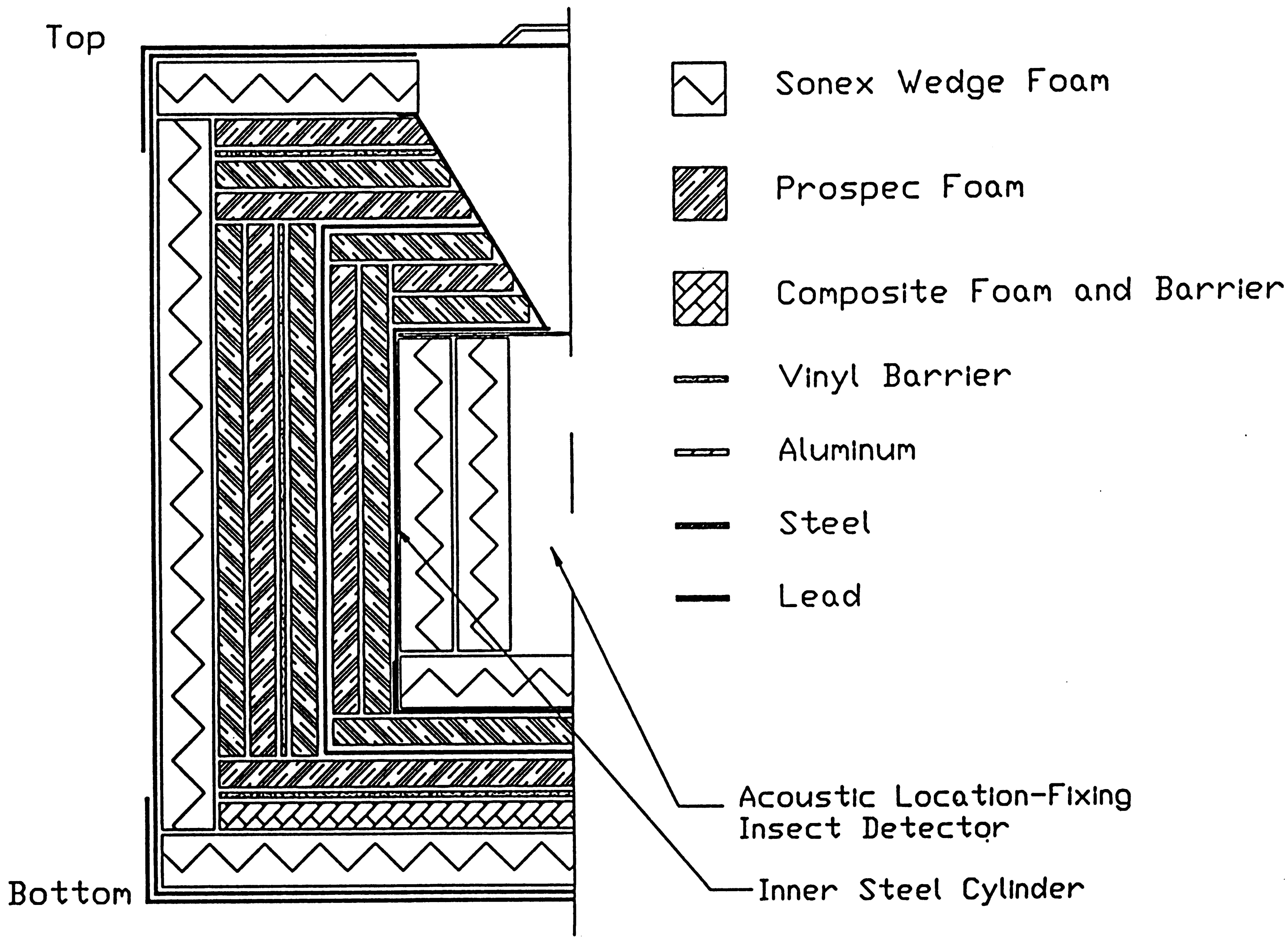
Figure 4. Noise reduction inside enclosure at different frequencies.

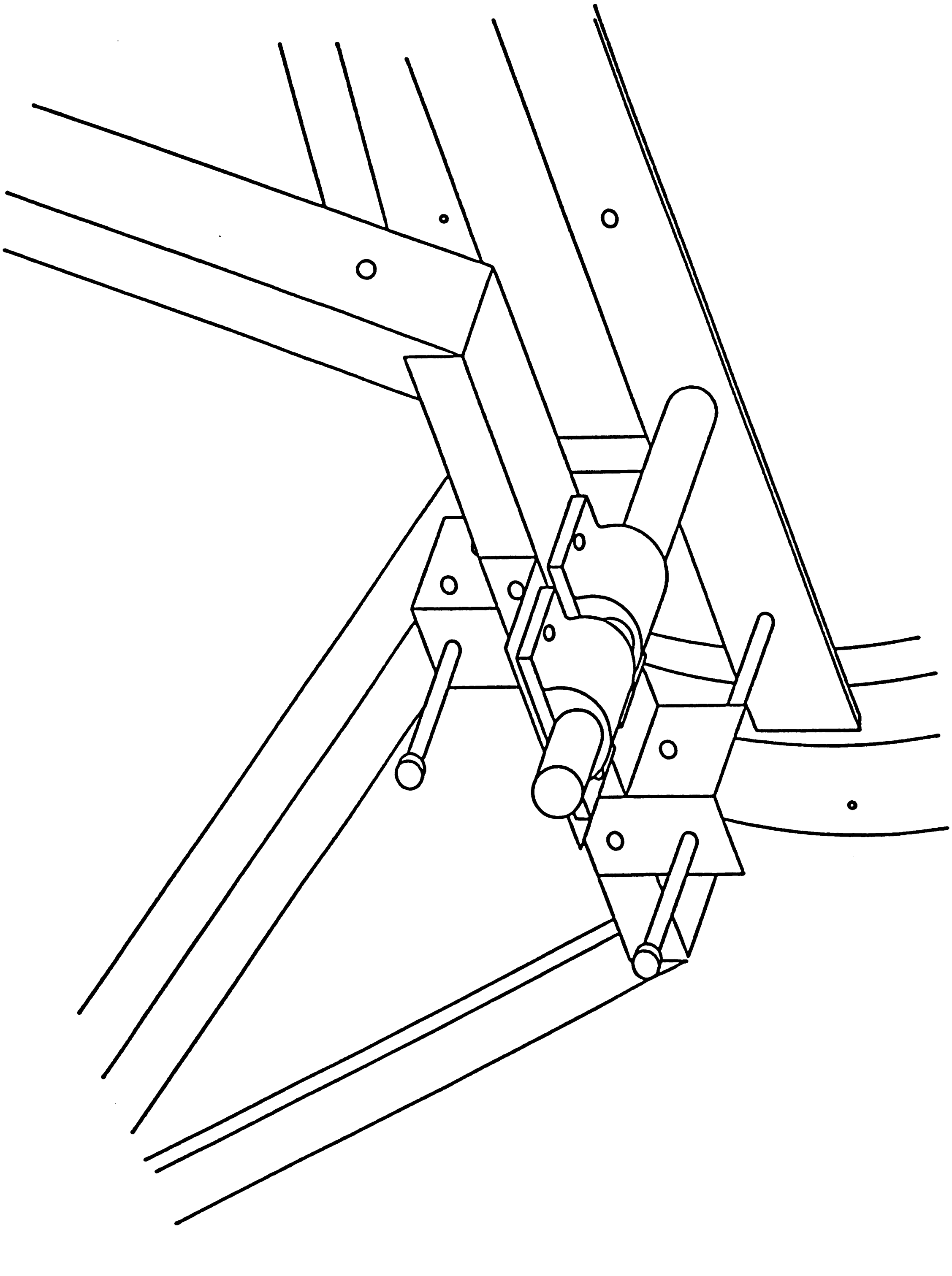
Figure 5. Examples of noise levels typically present inside a FGIS office at a grain elevator, including noises of grain dropping through chute entering building and noises of grain siever in operation.

Enclosure in Loading Position



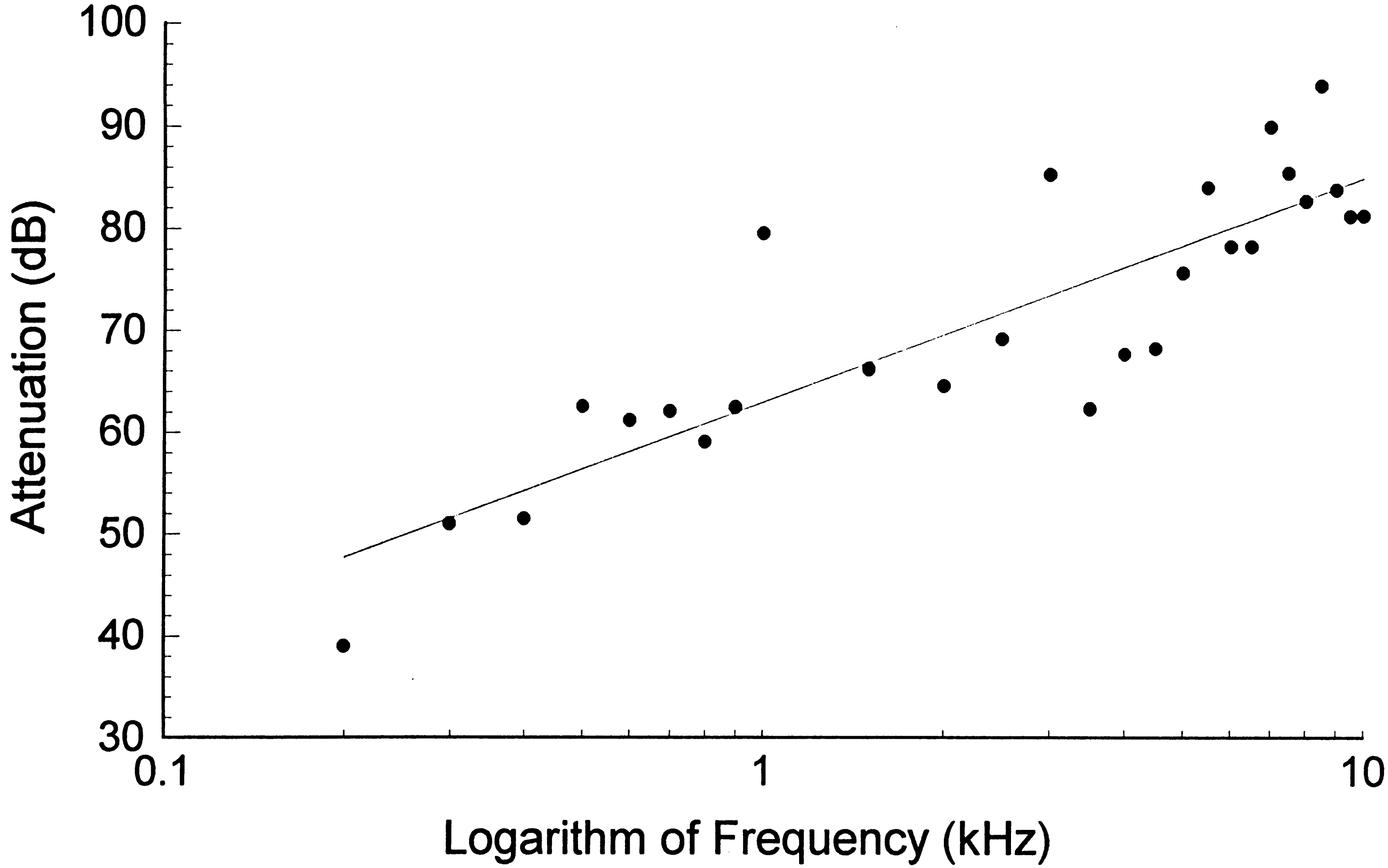
Enclosure Cross-Section





Locking Mechanism

Noise Reduction Inside Insulated Enclosure



Background Noise Levels Inside FGIS Office at Grain Elevator