A Typical Case Study of School Sound Insulation

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In order to mitigate noise due to aircraft operations associated with Manchester Airport, the Federal Aviation Administration (FAA) and the City of Manchester sponsored a sound-insulation program at Green Acres Elementary School. The sound insulation modifications included replacing windows and aluminum wall panels with acoustically-rated units, installing acoustical doors, installing upgraded ventilation, and installing new acoustical ceiling tiles. The Noise Level Reduction after sound insulation was 29 to 31 dB. This article summarizes the designs, construction process, ventilation system design and acoustical test results.

The Manchester Airport Authority has been sound insulating schools and residences around Manchester Airport since the early 1990s, through the Airport Improvement Program (AIP) sponsored by the Federal Aviation Administration (FAA). Existing and future noise environments at Green Acres Elementary School were determined in terms of the Sound Exposure Level (SEL) of a single aircraft overflight, as well as in terms of the Day-Night Average Sound Level (DNL) and the hourly average sound levels L_{eq1h}. SEL and DNL values for various aircraft operating out of Manchester Airport were calculated using the FAA's Integrated Noise Model (INM), Version 6.0b. In addition, DNL and L_{eq1h} values were measured at 20 locations in the community near Manchester Airport for one week in 1998.[1]

Sound Exposure Levels. The year 2003 exterior SEL values for aircraft departing on Runway 06 of Manchester Airport were calculated to determine the most adverse noise impacts at the school. Table 1 summarizes the aircraft types and exterior SEL values.

The 'worst-case' exterior SEL of 100 dB was produced by a Boeing 727 aircraft equipped with hushkitted engines. Of the nonhushkitted Stage 3 (FAR Part 36 Classification) aircraft modeled, the loudest was a McDonnell Douglas MD81 with an SEL of 92 dB. For design purposes, an SEL of 93 dB was used to define the exterior noise environment at Green Acres School. The louder aircraft equipped with hushkitted engines constitute only a small fraction of flights at the airport (anticipated to be 6 to 12 flights, or 4 to 7 percent of daily operations). It was expected that most of those, especially the cargo flights, would occur outside school business hours and would not necessarily depart from Runway 06. The exterior SEL of 93 dB was considered representative of the range of noise levels of most typical aircraft departures from Runway 06.

DNL and L_{eq1h}. The DNL output from INM at the school is 65 dB. Outdoor noise levels were not measured at the school. However, noise levels were measured at various other locations near the airport. There were two measurement locations for which the average weekday DNL over five weekdays averaged 65 dB. For these two locations the average sound level during school hours (assumed to be weekdays from 7 a.m. to 3 p.m.) was 62 dB at one location and 64 dB at the other. The loudest hourly average sound level L_{eq1h} during school hours ranged from 61 to 71 dB for these two locations over the five weekdays.

Pre-Modification Conditions

School Description. The 50,000 ft^2 school is located in Manchester, NH, north of Manchester Airport, about 0.6 miles north of the straight-line departure flight track from Runway 06. The school is comprised of three one-story wings and a multipurpose room (auditorium/cafeteria/gymnasium). The building wings are oriented differently relative to the aircraft flight track. Two wings (A and B) and the multipurpose room have brick and concrete block walls, but the third, newer wing (C) has pre-cast concrete panel walls. The exterior walls in the two original wings were comprised of aluminum wall panels with two casement windows per classroom. Glazing occupied approximately 15 percent of the exterior wall area in a typical classroom. In the third newer wing, each classroom only has one awning window that occupies about 9 percent of the classroom exterior wall. The roof-ceiling assembly consists of a flat metal deck roof with a suspended acoustical tile ceiling. The school had a heating system but not central air-conditioning. Figure 1 shows a typical curtain wall system at A- and B-wing classrooms. Figure 2 shows a typical exterior wall of a C-wing classroom.

Noise Level Reduction Testing. Initial noise reduction measurements were conducted at the school in June 2001 to assess the pre-modification acoustical characteristics. These tests were performed before an asbestos abatement project began for which the existing ceiling tiles were removed. Three representative classrooms (one in each wing), an interior conference room, and the multipurpose room were tested using an interior sound source technique. The test procedure consisted of activating amplified loudspeakers inside each room and producing a high-amplitude pink noise signal. The signal was filtered using an equalizer to produce a typical aircraft departure noise spectrum in the tested room. Each sound source consisted of a JBL Eon Power 15 powered loudspeaker, an Ashly GQ215 equalizer, and an Ivie Electronics IE-20B noise generator.

Average A-weighted sound levels inside and outside the tested rooms were measured using a Larson-Davis Laboratories Model 820 integrating sound level meter. The microphone was swept throughout the main volume of the room and outside the building near the exterior elements. The difference between the average interior sound level and average sound levels measured outside each exterior element was a measure of the existing Noise Level Reduction (NLR) provided by that element.

Upon completion of the measurements, the overall NLR was calculated for each tested room based on the individual NLR values measured for the different exterior elements and the respective areas of the elements. Table 2 summarizes the results of the measurements.

As can be seen from the table, classrooms in all three wings had overall NLR values of 24 to 25 dB. The highest pre-modification NLR value of 28 dB was for the conference room. This interior room has no exterior elements other than a roof, and was tested primarily to determine the noise reduction provided by the existing roof/ceiling assembly. The lowest pre-modification NLR of 20 dB was for the multipurpose room. This space is more exposed to aircraft noise since it has a large roof and a significant area of single-pane windows.

Table 1. Calculated aircraft exterior Sound Exposure Levels.

Aircraft Type	Noise Stage (FAR Pt. 36)	Stage Length (nm)	Flight Type	Runway	SEL (dB)
727	3	500-1000	Dep.	06	100
DC9	3	500-1000	Dep.	06	98
MD81	3	500-1000	Dep.	06	92
A310	3	500-1000	Dep.	06	87
737/300	3	500-1000	Dep.	06	84

Based on a paper presented at NOISE-CON 2003, the National Conference on Noise Conrol Engineering, Cleveland, OH, June 23-25, 2003.

Figure 1. Exterior curtain wall at A- and B-wings before modifications.

Analysis of the measurement results showed that for the rooms in A- and B-wings the curtain wall panels, and to a lesser extent the windows, were acoustically the weakest elements. In C-wing, however, the roof/ceiling assembly appeared to transmit most of the sound energy into the classroom. Due to the massive wall construction and small window area, these elements were less critical for the existing sound insulation in C-wing.

Existing Interior Noise Levels. Noise levels in classrooms were determined by subtracting the measured NLR of 24-25 dB from the estimated outdoor noise level. The indoor SEL was 68 to 69 dB, the time-average noise level L_{eq} on weekdays during school hours was 37 to 40 dB, and the loudest-hour average noise level on weekdays during school hours L_{eq1h} was 36 to 47 dB.

Modification Designs

Design Goals. Noise intrusion due to aircraft operations affects speech communication between the teacher and students in the classroom. The interior sound level and the level of reverberation are the two key factors that affect speech intelligibility in a room. The selected design goal for the classrooms was a maximum sound exposure level of 60 dB due to aircraft overflights. Using this criterion would ensure sentence intelligibility of 90 to 95 percent for students in the classroom when aircraft fly over the school.[2]

The predicted SELs of 68 to 69 dB in classrooms were significantly higher than the design goal SEL of 60 dB. Therefore, sound insulation modifications were warranted. Aircraft noise will still be audible in the classrooms with an SEL of 60 dB; however, there would be an appreciable reduction from the existing noise levels.

The desired noise level reduction was determined by subtracting the interior SEL design goal from the exterior aircraft overflight SEL. The resulting NLR goal is 33 dB (93 dB exterior SEL minus 60 dB interior SEL goal). Table 3 summarizes the existing and desired interior noise levels and NLR values based on the SEL criterion.

The FAA design goal for classrooms is that the time-average A-weighted sound level L_{eq} resulting from aircraft operations during normal school hours be reduced to 45 dB or lower after sound insulation modifications have been implemented (Order 5100.38B, Airport Improvement Program Handbook, Section 812.c.(1), May 2002). However, the FAA allows the use of alternative goals such as the SEL goal described above. As noted, the average sound level on weekdays during school hours at the school is estimated to be 62 to 64 dB. If the NLR had increased to 33 dB, as proposed, the resulting interior sound level would be 29 to 31 dB. This is well below the 45 dB FAA design goal. Thus, the design goal of an SEL of 60 dB (and an NLR of 33 dB) established for the school is more conservative than the FAA goal of an L_{eq} of 45 dB.

Table 2. Pre-modification Noise Level Reduction.

Room	Noise Level Reduction (dB)
Classroom 3A	24
Classroom 6B	25
Classroom 7C	25
Conference Room 1C	28
Multipurpose Room	20

Figure 2. Exterior wall of C-wing classroom.

American National Standard S12.60-2002 "Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools" provides additional guidance on appropriate noise levels in classrooms. This standard was not published during the design period for this sound insulation program; however, it is useful to compare existing noise levels in the classrooms to the ANSI standard criteria. The primary criterion in the ANSI standard is an average noise level of 40 dB for hours dominated by noncontinuous noise sources such as aircraft. The existing loudest L_{eq1h} (stated above) of 36 to 47 dB will exceed the ANSI criterion of 40 dB on many days. Therefore, sound insulation is warranted under the ANSI criteria.

Building Envelope. An iterative acoustical analysis was performed to evaluate the effectiveness of the existing school construction and alternative modifications. This analysis consisted of examining the exterior envelope of the school rooms and computing the areas and composite transmission losses for the walls, windows, and roof/ceiling system. A few modification options were analyzed for each of the elements. With the selected modifications, the calculated post-modification NLR values generally satisfied the design goal noise level reduction value of 33 dB established for the classrooms.

Most noise entered the classrooms and offices in A- and B-wings through the existing curtain wall-and-window assemblies. As the prime noise contributors, these elements had to be modified in order to provide significant noise reduction. In C-wing, due to the better wall construction, only the windows needed modification. The selected sound insulation modifications included the following:

- Replacement of existing curtain walls and windows in the classrooms and offices (A- and B-wings) with a new curtain wall system having a minimum Sound Transmission Class (STC) rating of 40.
- Replacement of windows in the C-wing classrooms, library, offices and multipurpose room with acoustical assemblies having a minimum STC rating of 40.
- Replacement of exterior hollow metal doors in the multipurpose room and library area with insulated doors having an

Table 3. Comparison of noise level reduction and interior sound exposure level values.

	Existing Conditions	Design Goal
Noise Level Reduction	20-28 dB	33 dB
Maxiumum Interior SEL due to Aircraft Operations	65-73 dB	60 dB

Figure 3. Front façade before sound insulation modifications.

Figure 4. Front façade after sound insulation modification.

STC rating of 40.

- Replacement of the ceiling in the classrooms, offices and library with a new suspended ceiling tile system with acoustical panels having a Ceiling Attenuation Class (CAC) rating of 40-45, and installation of 6 in. of additional fiberglass batt insulation above the new tiles. These modifications were implemented in 2001 as part of the separate asbestos abatement program completed prior to the sound insulation program.
- Installation of 6 in. of additional fiberglass batt insulation above the existing ceiling tiles in the multipurpose room. Since the existing ceiling in the multipurpose room had been installed recently, it was not replaced as part of the sound insulation program.
- Removal of existing skylights at C-wing, and installation of plywood and insulation at the openings

Figures 3 and 4 show the front façade before and after the sound insulation modifications.

HVAC System. Since sound insulation modifications make a building much more airtight and require windows to be closed all the time to achieve aircraft noise reduction objectives, additional fresh air must be provided to the building. A new ventilation system employing roof-top energy recovery ventilation (ERV) units was designed to provide the necessary fresh air supply for the classrooms and library. The new roof-top units were located above the corridors. Return air ducts were installed in the existing ventilation chases. Supply air ducts traveled outdoors along the roof before turning down into the classrooms in new duct enclosures. Each room received one supply air diffuser and one return air register. The administration areas are served by indoor ERV units. Figure 5 shows a typical new supply air diffuser and duct enclosure in a classroom.

Table 4. Noise Level Reduction comparison.

Room	Pre-mod. NLR (dB)	Post-mod. NLR (dB)	NLR Improvement (dB)
Classroom 3A	24	30	6
Classroom 6B	25	29	4
Classroom 7C	25	30	5
Avg. of 3 Classrooms	25	30	5
Conference Room 1C	28	31	3

Figure 5. New supply air diffuser and duct enclosure.

When the design effort began, it was intended that noise levels from new mechanical equipment not exceed a room criterion rating of RC(N) 35 inside the classrooms. The new ventilation system design incorporated noise control measures such as inline duct silencers, internally sound-lined plenums and ducts, and long duct runs above the roof. The potential for cross-talk (noise traveling between adjacent rooms through ducts) was examined and addressed through proper diffuser and register locations and the use of internal sound lining.

Toward the end of the design process, the design goal for background noise from the new ventilation system in classrooms was changed to 35 dBA. This is the criterion for continuous noise sources such as ventilation systems contained in the recently published ANSI standard discussed above. The revised design goal of 35 dBA is more strict, in most cases, than the original design goal of RC(N) 35. With the preliminary design, the predicted noise levels due to the ventilation system generally met the RC(N) 35 goal but not the 35 dBA goal. As a result, the design needed to be changed through the use of longer and additional silencers among other measures. Due to cost and space limitations it was not feasible to achieve the 35 dBA goal.

Post-Modification Conditions

Noise Level Reduction. A second series of noise reduction measurements was conducted at the school in September 2002 to assess the effectiveness of the implemented sound insulation modifications. The measurements were performed in the same rooms that had previously been tested, with the exception of the multipurpose room. No testing was performed in the multipurpose room since the existing hollow metal doors in the room had not been replaced with the proposed acoustical doors by the time of testing. The results of the pre- and post-modification measurements are summarized in Table 4.

The post-modification NLR measured in the school is 29 to 31 dB, which is slightly below the original design goal of 33 dB. However, these NLR values satisfy the FAA design objective of an interior time-average A-weighted sound level of 45 dB resulting from aircraft operations (62 to 64 dB outdoors minus 29 to 30 dB NLR equals 32 to 35 dB indoors). Two factors contributed to this result. First, the noise spectrum produced by the loudspeakers during the measurements overemphasized the low-frequency components of aircraft departure noise in an effort to simulate the worst-case spectrum instead of a more typical aircraft overflight spectrum. It is estimated

Table 5. Measured ventilation system noise levels.

Room	dBA	Room Criteria
Classroom 6A	35-38	RC(N) 30 - RC(N) 33
Classroom 5B	32	RC(H) 25
Classroom 6B	29	RC(R) 18 - RC(R) 20
Classroom 6C	35-38	RC(RVB) 28 - RC(RV) 30
Classroom 9C	41-42	RC(NVB) 35 - RC(NVB) 36

that the NLR values using a typical aircraft overflight spectrum would have been higher.

Secondly, the exterior sound levels measured during the post-modification testing in some cases did not sufficiently exceed the ambient background noise levels at the site. Although appropriate corrections for the high background noise levels were applied to the measured sound levels, some degree of uncertainty in those results remains. Thus, the measured post-modification NLR values should be considered as the minimal values that the rooms might achieve.

As can be seen from Table 4, an improvement of 4 to 6 dB was achieved in the three tested classrooms. The average NLR improvement for the three classrooms is 5 dB, with a variation of ±1 dB. This variance is within the accuracy of the measurements. This NLR improvement is considered significant and in compliance with the FAA requirement that noise levels be reduced by at least 5 dB. As discussed above, the actual improvement is estimated to be slightly higher than these results indicate.

In the interior conference room, which was tested primarily for design purposes and where the initial pre-modification NLR was already the highest due to the absence of exterior walls, an improvement of 3 dB has been achieved as a result of only modifications to the ceiling. This demonstrates that the replacement of the ceiling tiles and the installation of additional insulation did improve the acoustical performance of the roof-ceiling assembly.

As noted above, the estimated loudest L_{eq1h} due to aircraft were 61 to 71 dB. The resulting indoor loudest Leq1h is estimated to be 31 to 42 dB in the three tested classrooms (61 to 71 minus 29 to 30). Therefore, at most times, the loudest L_{eq1h} would comply with the ANSI criterion of 40 dB. In fact, the range of 61 to 71 dB is based on five weekdays at two locations; the loudest Leq1h was only over 69 dB on one day at one of the two locations. Therefore, the ANSI criterion would be met on approximately 90% of the days based on the available data. It must be noted that this analysis does not consider shielding provided by the school; sides of the school facing away from the typical aircraft departure flight path will be exposed to lower noise levels.

HVAC System Noise Levels. Noise levels due to the new ventilation system were measured in early 2003 in five classrooms in the following locations: the location nearest the supply air diffuser and the location farthest from it. The selected classrooms were those expected to have the highest noise levels (i.e., those nearest the roof-top units). The results are presented in Table 5.

The measured noise levels due to the ventilation system comply with the ANSI limit of 35 dBA in some classrooms but not all. The combined noise levels due to aircraft and the ventilation system can be determined by combining the noise levels presented above.

Conclusion

Overall, the modifications implemented at Green Acres Elementary School were successful at significantly reducing noise levels from aircraft operations and meeting the FAA criteria. Noise levels due to the ventilation system generally met the original design goal of RC(N) 35 (with one slight exception), and slightly exceeded the ANSI criterion of 35 dB in the most impacted classrooms.

References

1. "Noise Study for Manchester, NH Airport," Wyle Research Report WR 98-36, May 1999.
2. "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Report No. 550/9-74-004, Washington, D.C., March 1974.

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