Acoustical Insulation Design for Existing Schools and Residences Near San Francisco International Airport

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The environs of the San Francisco International Airport include a large number of residences and other examples of sensitive land use that are acoustically incompatible with California state requirements for the noise levels found near the airport. In this study, a sample of 12 residences and 2 schools in the area was examined. Retrofit designs were developed for each structure to reduce interior sound levels, using simultaneous indoor-outdoor sound level measurements and architectural acoustical analysis of the structures. Follow-up sound level measurements were conducted to confirm the original acoustical predictions for interior sound levels.

South San Francisco (population ~50,000) is one of the suburban communities that has grown up in San Mateo County, California, around San Francisco International Airport. When commercial aviation began, the city of San Francisco lacked suitable land within its own boundaries for airport development, so the city government purchased land in San Mateo County to build what eventually became San Francisco International Airport. Thus the acoustical impact of the airport primarily affects areas other than the city of San Francisco. The airport is now among the most important and most active in the world. More than 24 million passengers use the airport every year. If general aviation and military flights are both included, there are ~380,000 takeoffs and landings per year.

To characterize community responses to noise, the government of the state of California has devised the community noise equivalent level (CNEL), which is a measurement in decibels of the total daily noise dosage, adjusted to account for the frequency response of the human ear, the number of individual noise events, and the heightened sensitivity of human communities to noise during evening and nighttime. For this study, the boundaries of the noise compatibility planning area approximately followed the 65-CNEL contour. The structures in the project area are in the 65–70 exterior CNEL exposure zones. These CNEL levels are generally considered to be a significant noise impact.

A substantial body of scientific evidence documents the effects of very high levels of noise on human health and well being, both physical and psychological. There is also documentation on the effects of noise on the level of annoyance in subjects and interference with their daily living. The problem is particularly serious in urban areas surrounding major metropolitan airports, such as the San Francisco International Airport, where the arrivals and departures of jet aircraft create a great deal of noise in the areas surrounding the airport.

The response to the problem of airport-related noise in general can be twofold: (a) reducing noise at its source and (b) resolving or preventing land use incompatibilities around the airport. It is the latter approach that is addressed in the study described in this paper.

The choice of 65 CNEL as the boundary for the study area was based primarily on the provisions of the California Airport Noise Standard. This noise standard required that by January 1, 1986, all land uses around airports that are subject to noise levels of 65 CNEL or above should be compatible with the noise environment generated by airport operations. Schools and residences are land uses that are usually defined as incompatible with airport noise above 65 CNEL. However, these uses are compatible under the following circumstances:

- There is an avigation easement for noise,
- The structures are high-rise apartments with acoustical treatment to achieve maximum interior noise level of 45 CNEL, and
- Any existing residential unit subject to noise levels of 65 to 80 CNEL has acoustical treatment of the structure to provide an interior noise level that does not exceed 45 CNEL.

Commercial, industrial, agricultural, and other open space uses are deemed compatible with airport noise under this California law.

DEFINITION OF RESIDENCES AND SCHOOLS ANALYZED

The selections of residences for the study were based on the following factors:

- The need for a reasonable sampling of residential types,
- The ability to produce successful insulation results,
- The desire for a strong numerical representation of dwelling units near and within the 70-CNEL zone, and
- Input from the city of South San Francisco and from interested volunteers.

The project created strong community interest, and there were far more interested volunteers than could be accommodated in the first phase. Home owners who expressed interest were placed on a list of prospective volunteers, and 12 residences were selected from the targeted structures for study by the authors.

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The residences selected were typically of wood frame construction, with stucco or wood siding and peaked roofs. The roofing was of reasonably airtight materials, such as tar and gravel, bitumen, or composition shingles. The attics were not utilized as living space. Ceilings consisted of gypsum board or similar relatively high-density material, and there were no exposed beams. The attics were not insulated in some cases. The windows were single paned.

Two schools were also included in the first-phase insulation study. Saint Veronica's School is a single-story wood frame structure with exterior stucco and relatively large windows that face the playground and parking lot. A flat roof with numerous skylights created special insulation problems. The Ponderosa Elementary School is a flat-roofed single-story wood frame structure with a stucco exterior and large windows facing north.

SOUND REDUCTION MEASUREMENTS

Sound level readings were conducted simultaneously inside and outside each of the 12 residences and 2 schools. The results were reported in CNEL units and were based on a minimum reading of 1 hr at each structure. Readings in each dwelling unit were taken in the geometric center of the main bedroom at the same height (4 ft) above floor level. Readings were also taken outside of the same bedroom at a distance of 10–20 ft from the exterior wall, as far as feasible from other walls or obstructions, at a height of 4 ft. At each school, four different interior measurement locations were selected in representative classrooms. The exterior measurement site was selected so that it was exposed to the predominant aircraft flight pattern nearest the subject school.

The results of the premodification monitoring are presented in Table 1, along with the results of the postmodification monitoring (discussed later). As can be observed, the premodification monitoring in the residences yielded outdoor-to-indoor sound level differences that ranged from 18 to 24 dBA. The outdoor CNELs were determined to be 46–50 dBA. In the schoolrooms, the outdoor-to-indoor differences before retrofitting were measured at 18 dBA, and the CNEL was determined to be 47 dBA in each case.

RECOMMENDATION OF SOUNDPROOFING MEASURES

Each structure was inventoried for physical characteristics, and a spectral analysis was conducted to determine the exterior and interior insertion losses by $^{1}/_{3}$-octave frequency. A mathematical analysis was carried out to simulate the acoustical response of each structure to a variety of retrofit strategies. The simulation methodology was one that was used previously at San Jose International Airport (*1*). In essence, the computer model that is used is responsive to hypothetical structure modifications and permits an accurate forecast of interior sound levels for a known exterior noise environment. Use of the model allows exploration and costing for a wide variety of retrofitting strategies.

Residential Soundproofing

The customized solution for one of the residences, 125 Rockwood Drive, that resulted from the computer model is typical. It was decided to install weatherstripping around the front and kitchen-garage doors. The kitchen-garage door was replaced with a solid core door. The windows in the living room, dining room, and bedrooms and the sliding glass door were replaced with tight-fitting, thoroughly caulked, double-glazed window assemblies with total glass thicknesses of $^{3}/_{8}$ in. The greenhouse window in the kitchen was replaced with a double-glazed, tight-fitting greenhouse window with total glass thickness of $^{3}/_{8}$ in. The bathroom window was also replaced with a tight-fitting, thoroughly caulked, double-glazed assembly with total glass thickness $^{3}/_{8}$ in., frosted. Insulation was installed in the attic, which had no existing insulation, and the attic trap door was replaced with a perimeter-sealed heavy door (a minimum of 2-in.-thick solid core) to reduce sound transmis-

TABLE 1 RESULTS OF PREMODIFICATION AND POSTMODIFICATION SOUND MONITORING AT RESIDENCES

Residence Address	Exterior CNEL	Premodification Monitoring Sound Level: Outdoor/Indoor Attenuation (dB)	Postmodification Monitoring Sound Level: Outdoor/Indoor Attenuation (dB)	Premodification Monitoring: Interior Level (CNEL)	Postmodification Monitoring: Interior Level (CNEL)
101 Manor	70	20	26	50	44
102 Manor	70	21	25	49	45
111 Manor	70	24	31	46	39
125 Rockwood	70	24	28	46	42
127 Rockwood	70	24	30	46	40
129 Rockwood	70	20	26	50	44
203 Rockwood	65	19	29	46	36
223 Rockwood	65	18	23	47	42
315 Rockwood	65	19	29	46	36
343 Rockwood	65	19	22	46	43
112 Sherwood	65	19	28	46	37
107 Rosewood	65	18	25	47	40

NOTE: There is actually a range of values within a given residence because the acoustical response varies from room to room and may even vary within a given room. The lowest or most conservative value is used here and for ensuing calculations.

TABLE 2 RESULTS OF PREMODIFICATION AND POSTMODIFICATION SOUND MONITORING AT PONDEROSA AND SAINT VERONICA'S SCHOOLS

Exterior CNEL	Room	Premodification Monitoring: Outdoor/Indoor dB Reduction	Postmodification Monitoring: Outdoor/Indoor dB Reduction	Premodification Monitoring: Interior Level (CNEL)	Postmodification Monitoring: Interior Level (CNEL)
Ponderosa School					
65	1	18	23	47	42
65	11	18	23	47	42
Saint Veronica's School					
65	3	—[a]	37	—[a]	28
65	8	18	36	47	29

[a] Room 3 was unavailable for premodification monitoring.

sion from the attic to the main residence. The new living room windows were supposed to have wood frames, in keeping with the existing decor. The cracks at the top and bottom of the existing wood paneling were sealed to reduce potential noise transmission pathways.

Ponderosa School

The existing windows were replaced with double-glazed windows, and the existing exit doors were replaced with solid core doors. The existing ceiling was removed, a new ceiling was installed, and the existing light fixtures were readjusted. Baffles were installed around the gravity roof vents and around the furnace flue at the roof. Trim was installed at the ceiling along the windows.

Saint Veronica's School

Double-glazed windows were installed at all existing classroom skylights and at all existing clerestory windows in the library. All existing metal doors were replaced with new solid core doors with double-glazed openings. All existing acoustical tile was removed to allow installation of new gypsum board in all classrooms. The existing metal grid systems in the ceilings were removed and the existing acoustical tiles were replaced with new supporting systems in all classrooms. The existing light fixtures were then relocated. New exterior vent enclosures were installed at all existing furnaces and painted. A new roof ventilation fan for the library and classrooms was installed. New gypsum board was placed over existing plywood at the clerestory ceiling. Insulation was installed around the existing furnace flue at the roof, and the existing caps were replaced with new caps at all classrooms.

SOUND LEVEL MEASUREMENTS AFTER RETROFITTING

Monitoring was performed again after insulation was installed. Tables 1 and 2 present the results obtained and the conversion to indoor CNEL. The goal of 45 CNEL was met in all structures and exceeded in many. The data validate the computer model's ability to predict the changes in sound levels for a given retrofit strategy. Saint Veronica's School showed the greatest improvement as well as the lowest postmodification interior CNEL measurement. The test data for the school were subjectively confirmed by the favorable opinions expressed by the principal, teachers, and students.

CONCLUSION

The results provide additional evidence that soundproofing of existing structures in sensitive areas affected by airport noise is a viable method for noise reduction. The most important technical finding of the present study is that use of a detailed mathematical model to evaluate proposed retrofitting strategies is a must. For example, a variety of the insulation strategies analyzed for a given building turned out to be virtually without effect, even though these same strategies had been applied effectively in apparently similar situations elsewhere. In other words, each structure is unique and must be treated as an individual case in soundproofing design. The costs for retrofitting each residence were $7,000–$9,000 per single-family dwelling.

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REFERENCE

1. C. M. Hogan and J. Ravnkilde. Design of Acoustical Insulation for Existing Residences in the Vicinity of San Jose Municipal Airport. In *Transportation Research Record 1033,* TRB, National Research Council, Washington, D.C., 1985, pp. 54–59.

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