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Design of Acoustical Insulation for Existing Residences in the Vicinity of San Jose Municipal Airport

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ABSTRACT

The vicinity of the San Jose Municipal Airport includes a large number of residences that lie in land-use zones that are acoustically incompatible with California state requirements. Analyzed in the current study was a sample of 10 residences of various ages, locations, and structure types within this incompatible residential class. Retrofit designs were developed for each structure to reduce interior sound levels, based on simultaneous indoor-outdoor sound level measurements and on architectural acoustical analysis of the structure. Follow-up sound level measurements were conducted to establish the success of original acoustical predictions for interior sound levels.

The location of the San Jose Airport has many advantages for providing commercial and general aviation services to the San Jose metropolitan area. In the midst of the urban area, the airport is convenient to major economic and employment centers in Santa Clara County and industrial areas in San Jose, Santa Clara, and Sunnyvale as well as the San Jose downtown core area, and is a significant attraction to private investment and development in these centers. The airport is also centrally located for the population in the south San Francisco Bay area, the area that provides the bulk of the airport's users.

However, the central location of the airport, surrounded by urban development, also involves impacts that extend beyond its boundaries. The noise produced by aircraft affects the living environment close to the airport.

STATEMENT OF PURPOSE OF THE AIRPORT VICINITY PLAN

The purpose of the Airport Vicinity Plan of July 15, 1980, is the achievement and maintenance of compatibility between the airport and its environs through 1997, the planning horizon of the Airport Development Plan. Specifically, the objective of the plan is to establish a realistic program that

- Permits persons who live, work, and own property near the airport to enjoy a maximum amount of freedom from noise and other impacts generated by the operation of the airport
- Recognizes the vital service provided by the airport and the need to maintain the level of operations necessary to satisfy existing and future aviation requirements of the community
- Protects the public investment in the airport, a facility for which there is no feasible replacement
- Complies with airport noise standards mandated by the state of California
- Complies with the operational and safety requirements of the Federal Aviation Administration (FAA), U.S. Department of Transportation regulations

BACKGROUND

Study Area

The boundaries of the study area for the purposes of noise compatibility planning are an approximation of the projected 65 community noise equivalent level (CNEL) contour for the year 1997, developed as part of the Airport Master Plan Study. The projected contours are based on the following:

- A projected aircraft mix, and levels and hours of operations for air carrier aircraft
- Typical flight paths and aircraft departure profiles (i.e., gross takeoff weight) in current operations and assumed arrival profiles, each of which varies by type of aircraft
- The assumption that all air carrier aircraft will be new models or will be retrofitted to comply with the noise emission requirements of Federal Aviation Regulations (FAR) Part 36: Noise Certification

The study area is characterized by a diversity of land uses. Commercial uses include neighborhood retail outlets and major regional centers, including downtown San Jose and the Great America Theme Park. Industrial land uses include small, older establishments such as machine and welding shops as well as large, modern facilities devoted to electronics manufacture and research and development. Public and quasi-public uses include neighborhood schools and churches as well as regional facilities such as Agnews State Hospital and the City of San Jose, County of Santa Clara Civic Center. Residential land uses include single family, duplex, townhouse, and multifamily dwellings, ranging in age from recently constructed to over 50 years old.

Noise

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 of the effects of noise on level of annoyance and interference with daily living. The problem is particularly serious in urban areas surrounding major metropolitan airports, such as San Jose Airport, where the arrival and departure of jet aircraft cause noise impacts in the airport environs.

The response to the problem of airport-related noise is twofold: (a) reduction of 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 Santa Clara County Airport Land Use Commission's Land Use Plan for Area Surrounding Santa Clara County Airports (1).

California State Noise Law

The choice of 65 CNEL as the boundary for the vicinity is based primarily on the provisions of the California Airport Noise Standards. These noise standards require that by January 1, 1986, all land uses around airports that are subject to noise levels of 65 CNEL or above be compatible with the noise environment generated by airport operations. Schools and residential land uses are defined as usually incompatible with airport noise above 65 CNEL. However, these uses are compatible under the following circumstances:

- Subject to an avigation easement for noise
- Highrise apartments with acoustical treatment to achieve maximum interior noise level of 45 CNEL
- Any existing residential unit subject to noise levels of 65 to 80 CNEL as long as acoustical treatment of the structure provides an interior noise level that does not exceed 45 CNEL

Commercial, industrial, agricultural, and other open-space uses are deemed compatible with airport noise.

Federal and California Sound Level Standards

The California Airport Noise Standards form the basis of the noise standards in this Vicinity Plan, in which the primary focus is on schools and residences. In the vicinity of San Jose Airport, the following noise compatibility standards will apply.

- Exterior noise levels below 65 CNEL are acceptable for any land use.
- Existing and new schools and residences are compatible with exterior noise levels of 65 to 76 CNEL if a maximum interior noise level of 45 CNEL is achieved through acoustical treatment.
- Schools and residences are not compatible with exterior noise levels in excess of 76 CNEL, regardless of interior noise levels.
- Existing commercial, industrial, and open space uses are compatible with noise levels in excess of 65 CNEL.

• New industrial and commercial uses are compatible with exterior noise levels in excess of 65 CNEL if a maximum interior noise level of 55 CNEL is achieved through acoustical treatment. A higher interior noise level is acceptable if it is demonstrated that the inherent noise characteristics of the particular use being proposed would exceed 55 CNEL irrespective of exterior noise levels.

The maximum exterior noise level for schools and residences is 76 CNEL because General Plan noise standards in both San Jose and Santa Clara identify this level as the maximum noise level in conformance with the U.S. Environmental Protection Agency hearing loss criteria. The allowance in the California Airport Noise Standards for exclusive reliance on avigation easements was not incorporated in the noise standards of this plan. While they may eliminate an airport's legal liability for noise resulting from aircraft overflight and may also serve as a consumer protection device for prospective purchasers of noise-impacted properties, avigation easements clearly do not provide actual relief from noise.

The noise criteria for interior spaces are based solely on a CNEL measurement rather than on a single-event criteria as has been adopted by the Land Use Commission of the Santa Clara County Airport. There are several reasons why single-event criteria were not used in this plan. First, the most restrictive single-event criteria are to protect the sleeping environment; yet current and projected aircraft operations during the time period from 11 p.m. to 7 a.m., the hours typically devoted to sleep, constitute a negligible portion of the total operations in a 24-hour day at San Jose Municipal Airport. Second, achieving compliance with single-event criteria is not at all practical. For remedial sound attenuation of existing school and residential structures, single-event criteria are virtually impossible to meet. For sound attenuation in new construction, single-event criteria can be achieved, but only with considerable additional expense. The intent of this plan was that standardized construction methods and materials could be identified to meet noise criteria rather than having to rely on sound meter testing in each project. Third, the air carrier aircraft of the future will be quieter than those presently in operation at San Jose Airport. With the likelihood that aircraft noise emissions will be reduced even below the requirements of FAR Part 36, it makes little practical sense to rely on the noise characteristics of aircraft from the period before FAR Part 36 to develop land-use compatibility criteria.

Finally, it should be noted that the noise standards in the Airport Vicinity Plan have been developed with practicality and other goals in mind rather than in an abstract, theoretical way. The choice of interior noise standards using CNEL rather than single-event ratings is one example of keeping noise in context, balancing protection from noise against other considerations. A second such example is using the 65-CNEL contour as the boundary of the vicinity. Aircraft noise does not cease to be a concern outside the 65-CNEL contour; rather, this noise contour defines the extent of the most critical impact area. The noise standards do not appear to take into account impacts on outdoor activities, often an integral component of the residential environment. Although the effects of noise on outdoor activities were not ignored, it was judged that the disadvantages in the vicinity for outdoor activities typically associated with residences are outweighed by the advantages of housing in the vicinity, including proximity to employment centers and the housing price advantage of some older neighborhoods.

NOISE INSULATION STUDY

Ten residences were selected so that diverse situations in the airport vicinity could be sampled. The final selection of the 10 residences for the pilot Noise Insulation Study reported in this paper was evaluated by using the following criteria:

• Spatial distribution around the San Jose Airport
• Location within the 1997 noise contours
• Location according to the main aircraft approach and take-off pattern
• Variety of building structures

The 10 residences selected, including a brief description of the structures, are presented in Table 1.

Five of the 10 homes are located northwest of the airport, 3 of the homes are located east of the airport, and 2 of the homes are located southwest of the airport. Five of the 10 homes are exposed to

TABLE 1 Final Selection of Residences in the Pilot Program

Residence No.	Subarea	City	Brief Description of Structure Before Soundproofing
1	2C	Santa Clara	Bitumen shingle roof; shingle-stucco exterior walls; double-hung and side-hung wood windows; single glass; wood paneled doors; no weather stripping; sheetrock ceilings; no insulation
2	2C	Santa Clara	Wood shake roof; stucco exterior walls; double-hung wood and aluminum slide windows; single glass; wood doors; no weather stripping; plasterboard ceilings; no insulation
3	3A	Santa Clara	Wood shake roof; stucco exterior walls; aluminum sliding windows and doors; single glass; main door—solid wood; weather stripping; sheetrock ceilings; 6 in. of insulation in attic
4	3B	Santa Clara	Asbestos shingle roof; stucco exterior walls, one wall wood siding; aluminum sliding windows; single glazing; entrance door—1.25-in. wood with ornament glass; no weather stripping; plasterboard ceiling; 1-in. insulation in attic
5	3B	Santa Clara	Wood shingle roof; stucco exterior walls; aluminum sliding windows and doors; single glazing; wood entrance door with glass; weather stripping; plasterboard ceiling; insulation in attic
6	4D	San Jose	Tarpaper roof; wood siding exterior walls; aluminum sliding windows and doors; single glass; wood door; no weather stripping; exposed beams on ceiling
7	4D	San Jose	Bitumen shingle roof; stucco exterior walls; aluminum double-hung windows; aluminum sliding door with single glazing; paneled wood doors; no weather stripping; plasterboard ceiling; 9-in. insulation in attic
8	4B	San Jose	Bitumen shingle roof; stucco exterior walls; double-hung wood windows; aluminum sliding door; wood exterior doors; minor weather stripping; plasterboard ceiling; no insulation
9	6B	San Jose	Wood shingle roof; stucco exterior walls; side-hung wood windows; single glass; paneled wood door; no weather stripping; plastered ceilings; 2- to 3-in. insulation in attic
10	6B	San Jose	Wood shingle roof; stucco exterior walls; double-hung wood, wood-framed-fixed and aluminum-framed-sliding windows; single glazing; paneled wood door; no weather stripping; plastered sheetrock ceilings; 6-in. insulation in attic

operational aircraft noise levels from 65 to 70 CNEL, and the remaining 5 homes are exposed to noise levels from 70 to 75 CNEL. The 10 homes represent a variety of common building structures, which are typical of residential structures in the vicinity of San Jose Airport.

Sound Reduction Measurements

The initial sound measuring program was performed during the week of January 19-23, 1982. The measurements were performed simultaneously indoors and outdoors for each residence, during a minimum time of 1 hr. The outdoor microphone was placed in front of that side of the residence facing the airport or the typical flight path. The microphone was located 6 ft above the ground and 6 ft from any object. The indoor microphone was located in a room (preferably a bedroom) with an exterior wall and a window facing the airport or the typical flight path. In two cases, the kitchen was selected as the interior microphone position because the bedrooms were located on the opposite side of the house.

Care was taken to ensure that all doors and windows were closed during the period of measurement, and that household appliances, ventilation, and heating systems were inoperable and would not affect the interior sound level. During the sound measurements, the dimensions of the house, doors, windows, and so forth were measured, and a description related to existing weather stripping, caulking, and insulation in exterior walls and attic was prepared. The sound insulation performances for each of the 10 structures were calculated and compared with the actual measured sound insulation. Table 2 presents the results of the measured and calculated sound insulation of the residences.

TABLE 2 Summary of Sound Measurements and Calculations

Residence No.	Measured Difference of Outdoor-to-Indoor dBA a (L10)	b (Leq)	Existing (calculated) STC c	d
1	17.2	17.5	11.7	17.7
2	16.5	17.0	15.0	17.0
3	17.5	17.3	18.2	20.3
4	18.0	14.7	17.0	19.5
5	16.8	16.2	17.0	19.5
6	14.0	14.1	11.7	15.4
7	19.0	19.2	16.5	19.0
8	13.2	13.2	13.0	12.6
9	19.0	23.3	14.0	20.0
10	16.7	13.8	15.0	17.0

Note: In Column a, L10 is the A-weighted sound level, which is exceeded 10 percent over the duration of the monitoring. In Column b, Leq is the A-weighted average sound level, which represents the average energy content of the sound rather than the average sound pressure level. In Column c, STC, sound transmission class, is the calculated average sound reduction of the house, including roof-ceiling, exterior walls, windows, and doors. In Column d, STC is the calculated sound reduction of the wall facing the airport or the flight pattern.

Two sets of calculations were performed for each residence. The first calculation considered the sound insulation of the total building envelope, (Table 2, Column c), and the second calculation took only the exterior wall facing the airport or the flight path, into consideration (Table 2, Column d). A relatively low calculated value of the building envelope indicates low insulation of the roof-ceiling assembly.

Recommendations of Proposed Improvements

As discussed previously, the purpose of the Noise Insulation Study was to demonstrate a cost-effective solution for reducing the interior noise level in residences. Therefore, the candidate improvements included accessible components, materials, and methods normally available on the market. Improvements that were acceptable to the homeowners and the building authorities and at the same time represented a reduction in energy consumption for house heating were installed.

Each residence was evaluated in a nondestructive way. Information about the design of exterior walls and the amount of thermal insulation was, in many cases, estimated based on information from the homeowner and possible visual inspection because detailed building plans did not exist. The current homeowner was often not the first owner of the residence, and thus the information was approximate. The attic space was not always accessible; therefore, the amount of insulation in the attic, in many cases, was estimated based on homeowner information. The quality of the residence, the maintenance condition, and possible air leaks around window and door frames were evaluated carefully.

Based on the above information and estimates, the sound insulation performance of each building component was adjusted according to the actual conditions in the residence. This adjustment required experience and knowledge of the sound insulation performance of the wide range of building materials and components, as well as of the changes in the characteristics of the sound reduction frequency range due to varying amounts of insulation in exterior walls and attics, air leaks around windows and doors, and the possibilities of other sound transmission paths.

The basic data for a wide range of building components are generated as laboratory measurements, which are available in reference literature. Many of these measurements are rated according to the sound transmission class (STC) reference contour, which yields a single number rating for the building component. There are, however, significant differences in the results of the sound insulation measurements between the laboratory measurements, which are performed under carefully controlled conditions, and the field measurements, which include all possible sound transmission paths. Differences of 3 to 5 dB for building components from the laboratory measurement to the field measurement are not uncommon, and additional differences due to other (multiple) transmission paths in the actual building structure are almost always present and must also be considered.

The adjusted STC values for the various building components were used for computing the existing sound insulation of each residence. The computations were performed as the composite transmission loss of the building structure or the partial building structure. Based on the sound reduction measurements of each residence, a correction factor for the calculation program was derived for each individual residence. This correction factor would take the following into consideration:

- Varying angles of incidence of the sound from the noise source (aircraft)
- The whole building envelope not being exposed to an equal level of sound energy because of directional characteristics of the sound
- Sound transmission paths that can not be corrected without major reconstruction of the residence

The correction factor for each individual residence was applied during the computations of the proposed improvements.

In most cases, it will be found that the windows in older residential structures often represent the highest transmission loss in the building structure. The exterior doors will often be the second-ranking components, closely followed by uninsulated attics. When energy-conserving aspects are included, the improvements of the insulation of the attic should initially be considered in the computations.

In one case, the residence featured a peaked open-beam ceiling and no insulation. An additional and insulated roof (constructed over the existing roof) was recommended. In the remaining cases, additional insulation to a minimum thickness of 5 in. was recommended. Standard, solid core doors with a perimeter seal and without a mail slot would provide a reduction in sound equivalent to 20 STC. All door and window frames should be sealed between the frame and exterior wall to prevent air leaks. The modifications for each home are described in Appendix B of Architectural Specifications for the Representative Residences (2). A summary of the proposed improvements is given in Table 3.

At this point it should be stressed that the Noise Insulation Study intends to include accessible standard components, materials, and methods, and to avoid recommendations of sophisticated and expensive measures. Acceptable recommendations include thermal insulation of a minimum thickness that can satisfy energy conservation requirements, and a maximum thickness limited by the space in the building component. Replacement of existing exterior windows, doors, and glazed areas with new doors, windows, and glazing each with a standard STC rating are also acceptable recommendations.

Sound Reduction Measurements After Improvements

The sound reduction measuring program of the 10 homes was performed during the week of July 11-15, 1983. The microphone positions used were exactly the same as initially installed in each residence. The results of the sound reduction measurements are presented in Table 4.

As stated previously, the goal of the Noise Insulation Study was to demonstrate that interior noise in residential structures can be reduced to or below 45 CNEL as required by the state of California by using cost-effective and energy-effective methods. In addition, the technical objective was to demonstrate that predictions of the interior sound level after improvements could be achieved by meeting a desired goal.

CONSTRUCTION PROBLEMS

The improvements of the residences were carried out by a contractor and craftsmen without previous special acoustical training and with commercially available materials and components. The improvements, however, demanded good craftsmanship and attention to details so that the improvements would be acoustically effective. The improvements were carried out in inhabitated residences.

The improvements of the homes were considered almost as remodeling of homes. Two major areas of concern were found during this project. First, planning of the work by one contractor in a small number of distinctively different homes distributed over a

TABLE 3 Summary of Proposed Improvements

Residence No.	Exterior CNEL in 1997	Roof Alterations	Windows Replaced	Doors Replaced (STC)	Predicted Sound Reduction (STC)	Predicted Indoor CNEL (dB)
1	71	More than 5-in. insulation	26	20	27	44
2	72	More than 6-in. insulation	26	20	27	45
3	67	None	26	20	25	42
4	73	More than 5-in. insulation	26	20	28	45
5	74	More than 5-in. insulation	26	20	28	46
6	69	Additional roof (insulated)	26	20	23	46
7	71	None	26	20	26	45
8	68	More than 4-in. insulation	26	20	23	45
9	67	More than 4-in. insulation	26	20	26	41
10	68	None	26	20	25	43

Note: Data are from Earth Metrics (1983).

TABLE 4 Results of Sound Reduction Measurements Related to 1997 CNEL

Residence No.	Exterior CNEL in 1997	Sound Calculated (dB)	Reduction Measured (dB)	Deviation from Calculated CNEL[a]	Interior CNEL in 1997
1	71	27	25	-2	46
2	72	27	29	+2	43
3	67	25	26	+1	41
4	73	28	29	+1	44
5	74	28	28	0	46
6	69	23	25	+2	44
7	71	26	27	+1	44
8	68	23	19	-4	49[b]
9	67	26	26	0	41
10	68	25	22	-3	46[c]

Note: Data are from Earth Metrics (1983).

[a]+ = more attenuation than designed; - = less attenuation than designed.

[b]Estimated 45 CNEL in bedroom.

[c]Estimated 43 CNEL in bedroom.

relatively large area appears to be very difficult. In inhabited residences, it is necessary to minimize the inconvenience to the homeowner by compressing the time of construction in each home. The work ideally should be executed continuously or should be executed by appointment to minimize disruptions to the family's routine. The second area of concern was that acoustical modifications involve unusual craftsmanship requirements and attention to details. Several of the homeowners had complained about planning procedures, failure to set up work appointments with homeowners, and failure to keep work appointments. For the continuation of the Noise Insulation Study, the following two measures are recommended.

• Each neighborhood should be subdivided into groups of residences of similar design and structures to aid in planning work and ordering materials.
• The acoustical modifications of residences should be performed on a large enough scale to utilize the services of a large contracting organization.

EVALUATION OF RESULTS

From a technical point of view, the Noise Insulation Study was very successful. A deviation of plus or minus 2 dB from the design goal is acceptable, given state-of-the-art data for acoustical performance of building components, realistic craftsmanship standards, and round-off effects. From this point of view, eight of the ten residences met the technical objective prediction range but two residences did not meet the design goal. From the standpoint of sound level standards, six of the residences achieved 45 CNEL or below, three residences achieved 46 CNEL, and one residence achieved 49 CNEL. The four residences that did not meet the 45 CNEL are discussed next.

In Residence No. 1, the interior sound level resulted in 46 CNEL. An examination of the windows revealed that the recommended weather stripping had not been installed, leaving airgaps around window sashes. The installation of the recommended weather stripping would have increased the sound insulation by 2 to 3 dB, thereby reducing CNEL to below 45.

In Residence No. 5, the interior sound level resulted in 46 CNEL, 1 dB above the design goal, but meeting the designed CNEL. A comparison was performed between Residence No. 5 and Residence No. 4. The two residences are almost identical acoustically, and the STC recommendations for the two residences are identical. Two different window types were installed. In Residence No. 4, the existing windows remained in place and additional interior storm windows, which according to Earth Metrics recommendations should provide 26 STC, were installed. In Residence No. 5, the existing windows were replaced by new aluminum sliding windows, which according to Earth Metrics recommendations should also provide 26 STC. The results of the sound measurements indicated that the installation of additional interior storm windows was a better solution than the replacement of the windows. Therefore, it appears that the windows installed in residence No. 5 did not provide the required 26 STC. Based on the comparison of these two residences, it is emphasized that only window and glass sliding-door components with documented sound reduction data should be used.

Moreover, the installation of additional storm windows in Residence No. 4 resulted in less expense than replacement of existing windows in Residence No. 5. This indicates that in the continuation of the Noise Simulation Study, actions to be considered are (a) selecting groups of residences of similar house type, (b) developing a noise remedy package that will meet the desired goal, and (c) offering this package to the homeowner.

In Residence No. 8, the interior sound level resulted in 49 CNEL, 4 dB above the design goal and 4 dB above the designed CNEL; the major cause was as follows. The outdoor patio is located along the exterior wall facing the airport. The roof over this patio is supported by posts along the outside edge and attached to a 2 x 4-in. wood plate, which is mounted to the exterior wall; this roof contains approximately 100 ft^2 of fiberglass material. Aircraft-generated vibrations of the patio roof are transmitted to the interior through the building structure, representing the major sound transmission path and limiting the installed sound insulation features. (The sound transmission path from the patio roof to the interior of the residence could be eliminated by detaching the patio roof from the building structure and supporting the roof on separate posts along the exterior wall.) Furthermore, the interior microphone was located in the kitchen, where the reverberation time normally is somewhat longer; this results in a slightly lower sound reduction because calculations of the interior sound level generated by exterior noise sources indicate variations in the interior sound level, depending on the reverberation time in the receiving room. Within a range from 0.8 sec (typical for kitchens) to 0.3 sec (typical for bedrooms), the sound level will vary 4 dB.

The location and orientation of Residence No. 10 did not leave many options for the positions of the exterior and interior microphones. To avoid the shielding effect of the adjacent residence, the exterior microphone was located outside the kitchen (Windows 6 and 7). Because all bedrooms were located on the opposite side of the residence (away from the flight path), only the kitchen could be used for the location of the interior microphone. As noted previously, reverberation time in kitchens is normally somewhat higher than in living rooms and bedrooms, which contain more absorbent materials such as carpeting and upholstered furniture. As a result, the interior sound level generated by exterior noise sources is 2 to 4 dB higher in kitchens than in living rooms and bedrooms. This matter has been discussed for Residence No. 8.

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