Project No. 02-31 **COPY NO. 1**

ASSESSMENT OF SOUND INSULATION TREATMENTS

FINAL REPORT

Prepared for
ACRP
Transportation Research Board
of
The National Academies

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September 2013

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EXECUTIVE SUMMARY

This research funded by the Airport Cooperative Research Program of the National Academy of Science is in response to a concern as to whether the acoustic performance achieved in early airport sound insulation programs has met the test of time and still provides the same protection as when it was first introduced. Although no exhaustive studies have been performed, there have been reports that the acoustical performance of treatments applied in early programs might have deteriorated over time. Accordingly, the objectives of the research were as follows:

The objectives of Airport Cooperative Research Program (ACRP) Project 02-31 are as follows:

1. Identify and evaluate the degree and causes of deterioration, and what changes have been made in current programs that reduce the likelihood of deterioration, and
2. Predict the performance of current procedures and provide guidance to help airports determine the expectation of the durability and performance of current sound insulation techniques, treatment and materials.

The project consisted of ten tasks conducted in two phases. In Phase I, a literature search was conducted to develop the chronology of airport sound insulation programs and provide leads to the identification of sources of data. The plan was to use the chronology to identify changes in methods and procedures from early to current programs, and relate these changes to possible degradation in acoustic performance. This effort followed with actual acoustical testing and architectural evaluations of representative sample of dwelling units that were insulated in the early years.

The results from the tests conducted at two sound insulation program sites showed that there has been less deterioration in performance over the years than expected. This is consistent with the lack of reported deterioration in performance obtained from the survey of US programs. In most cases, any deterioration in performance is more likely to be the result of homeowner modifications, poor maintenance, extreme weathering, and in some cases poor installation, and generally not due to deterioration in the products themselves.

This does not imply that there have been no problems with products or installation procedures. Many programs have reported such issues, but to a large extent, these have been identified by the program sponsors (or their consultants) and corrected by the product manufacturers or contractors. The lessons learned along the way have led to changes in products, installation, and quality control procedures that have reduced the frequency of such problems.

In Phase II, the longevity of acoustic treatments was assessed, and guidance material prepared to assist program sponsors in ensuring long-term noise reduction effectiveness. This guidance material is published as a separate, stand-alone document.

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CHAPTER 1. INTRODUCTION

It is now 40 years since the first residential sound insulation project was successfully demonstrated in the U.S. as a means of reducing noise impact in communities near airports. At the time, sound insulation was not considered a cost-effective mitigation measure due to the very high aircraft noise levels and hence the requirement for high values of noise reduction. The subsequent phase-out of the early, noisy jets in the 1970s, and the corresponding reduction in aircraft noise levels, improved the cost-effectiveness of the measure, and, coupled with the availability of federal funding in the early 1980s, has led to the implementation of sound insulation programs at most major, and many medium and small, airports.

In the early days of airport sound insulation programs, acoustical products were hard to find, and those that were available were designed primarily for commercial applications. Furthermore, even with the best products specified and purchased, the results were only as good, efficient, and effective as the method of installation. Over the intervening years, as sound insulation programs progressed and became more numerous, the manufacturers responded to market needs, and together with increased contractor experience, many of these initial problems were resolved. The question that remains though is whether the acoustic performance achieved in the early programs has met the test of time and still provides the same protection as when it was first introduced.

There have been reports from homeowners that the acoustical performance of treatments applied in early programs might have deteriorated over time. Although no exhaustive studies have been performed to validate these claims, it is documented (Massaro 2007), that defects have been discovered in some homes treated in the early years of the program. Clearly, each of these defects could reduce the noise attenuation provided by the building envelope, but, to date, no acoustic tests have been performed to determine the magnitude of any reduction, if one exists. Reports of deterioration have also been reported elsewhere, but again, there has been no proof of any degradation in acoustic performance.

In order to assess the performance of the early programs, the objectives of Airport Cooperative Research Program (ACRP) Project 02-31 are as follows:

3. Identify and evaluate the degree and causes of deterioration, and what changes have been made in current programs that reduce the likelihood of deterioration, and
4. Predict the performance of current procedures and provide guidance to help airports determine the expectation of the durability and performance of current sound insulation techniques, treatment and materials.

The project consisted of ten tasks conducted in two phases. In Phase I, a literature search was conducted to develop the chronology of airport sound insulation programs and provide leads to the identification of sources of data. Program data was collected from representative airport programs. A testing methodology was then developed and implemented to assess the current acoustic performance of the early programs. In Phase II, the longevity of acoustic treatments was assessed, and guidance material prepared to assist program sponsors in ensuring long-term noise reduction effectiveness. This guidance material has been published as a separate, stand-alone document.

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CHAPTER 2. LITERATURE REVIEW

2.1. Scope of the Review

This literature review summarises the research, technology, regulation, and implementation of airport sound insulation programs in the United States as they have progressed over the past half century.

It is now 40 years since the first residential sound insulation project was successfully demonstrated in the U.S. as a means of reducing noise impact in communities near airports. The advent of these programs has generated an increased interest in the prediction and measurement of the noise reduction of exterior noise in single- and multi-family residences. For the first time, the acoustics of small, absorbent spaces exposed to noise from exterior sources has assumed an importance in the acoustic community that hitherto had been assigned to the interior acoustics of office spaces and multi-family dwellings. The availability of federal funding in the early 1980s has led to the implementation of sound insulation programs at most major, and many medium and small, airports by application of this technology.

The following sections of this literature review chart the advances in acoustical technology related to sound insulation programs, provide the chronology of federal policies and regulations, briefly describe the history of airport sound insulation programs as they have been implemented in the U.S., and assess the effectiveness of these programs. In keeping with the theme of this project, wherever possible the review of the literature is presented in chronological order so that changes in technology, measurement procedures, federal policies, and other factors that may have influenced acoustic performance can be understood.

2.2. Sound Insulation Studies and Research

In the decades from the 1950s through the mid-1970s the subject of architectural acoustics was a hot topic for research, spurred on by the widespread development of multi-family housing in large cities and the associated need for acoustic privacy between dwelling units and office spaces. Significant advances were made in prediction and design principles, as well as in the development of standard acoustic test methods for measuring the sound insulation properties of structures, all in the interest of providing appropriate intra-dwelling isolation. Most of the research and development in those days was directed towards control of interior noise with little attention given to the protection of residents from exterior noise, other than in the design of office buildings (Bishop 1975). A comprehensive description of the state-of-the-art in prediction, design, and measurement as it was in 1980 is described in a report prepared for the National Bureau of Standards (Sharp 1980).

The basic principles of sound transmission are, of course, the same for all structures whether they are intended for interior or exterior (facade) applications, but there are a number of factors that distinguish sound insulation for exterior structures exposed to aircraft noise from that for interior walls between offices, namely (Quirt 1980, Sharp 1994, Bradley 1998):

- The noise spectrum from aircraft noise sources contains more low-frequency energy;
- The exterior sound is incident at different angles of incidence as opposed to a more or less diffuse sound field in a room; and
- An exterior structure usually consists of many elements - walls, roof, windows, doors, etc. - and the overall noise reduction is determined by the combination of these elements.

These differences are not as trivial as they might seem at first sight, as they lead to a reconsideration of design and measurement procedures. Moreover, whereas a large database has been developed for noise reduction (transmission loss) of interior structures, relatively little of such data was available for exterior structures. And in contrast to the interior structure database, that for exterior structures has been gathered from small consulting studies of field situations. This is positive, in that the

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data represents real in-situ conditions, but did not provide information on the performance of individual elements.

Early European Studies

Some of the earliest published studies of sound insulation for aircraft noise were for measurements of overall noise reduction of dwellings adjacent to London's Heathrow Airport and associated research of methods to provide a satisfactory interior noise environment (Scholes 1967). The dwellings were all of double brick wall construction. Noise reduction modifications consisted of the addition of secondary windows, attic insulation, sound attenuating ventilators, and the closing of chimney openings. The improvement in overall sound insulation varied depending on the orientation of the dwelling to the aircraft noise, but noise reductions achieved were on the order of 35 to 40 dB without a loss of ventilation.

U.S. Department of Housing and Urban Development

In the 1960s, the Department of Housing and Urban Development (HUD) was responsible for funding a number of noise studies related to exterior transportation noise transmission into buildings. Operation BREAKTHROUGH was this country's first large-scale systematic housing demonstration program, featuring the public demonstration of innovative house designs and site plans. HUD initiated BREAKTHROUGH to encourage more use of industrialized methods. It put these advanced ideas on trial, in prototype form, at nine locations across the U.S.

As part of the HUD program, basic information was gathered on the acoustic performance of existing housing, including noise reduction measurements in several types of single family houses (Bishop 1966a). Bishop compared the data from field measurements with the results of a number of laboratory sound transmission loss measurements of residential type windows and doors, selected since they generally constitute the "weakest links" in achieving effective noise insulation. This and other field noise measurement data for houses in different geographical regions was summarized in a SAE Aerospace Information Report (SAE 1971).

Bishop also selected five houses in three localities and modified them in different ways to achieve more effective reduction of aircraft noise (Bishop 1970). The noise reductions achieved in the rooms most extensively modified were compared with the noise reduction reported for 15 rooms in England. The average noise reduction achieved in both the United States and English houses was quite similar, even though the walls in the English houses were more massive, supporting his previous conclusion that windows and doors were the weakest link. There was little or no benefit from specifying heavier construction for walls or the roof unless sound-transmission paths through windows, floors, or other openings were carefully controlled. A further study demonstrated that the noise-reduction values measured in the field were usually well below those that are calculated on the basis of basic wall or roof structures (Bishop 1966b).

As part of Operation BREAKTHROUGH, HUD sponsored research on the design and development of innovative building elements that provided increased noise reduction at lower weight and thickness than existing structures (Sharp 1973). As in many previous studies, the primary focus of this study was on intra-dwelling insulation, but some innovative exterior building element designs were developed. In 1971, HUD issued their Noise Assessment Guidelines that provided guidelines for assessing exterior transportation noise (HUD 1971), following which they sponsored an additional study to assess appropriate noise attenuation measures specifically for external noise (Sharp 1976). The study included a comprehensive listing of modifications for increasing the noise reduction of exterior structures together with a procedure for estimating energy savings from the various combined treatments.

Operation BREAKTHROUGH ended in 1978 and was generally regarded as a failure as it did not prove the marketability of most of its sponsored housing construction methods. With this cancellation, HUD ended its immediate funding of noise programs.

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Los Angeles International Airport

At about the same time, as part of the first phase in a pilot sound insulation program, the Los Angeles Department of Airports sponsored a study to determine the costs and benefits of different modifications to increase the noise reduction provided by typical residential dwellings (Wyle 1968). At this time, there was little data on the transmission loss characteristics of exterior building structures and for individual elements. All that existed were laboratory measurements for a few commercially available window and door assemblies. In order to develop a data base, the first phase of the Los Angeles project was conducted on three test houses in which over 80 combinations of treatment were tested using aircraft as the noise source. The results of these tests provided the first large database of field measured treatments for sound insulation.

U.S. Department of Agriculture

In the early 1970s, the U.S. Department of Agriculture sponsored studies to gain a better understanding of the in-situ performance of building elements. Field measurements in wood-framed buildings showed that the sound insulation was closely correlated (within 3 dB) with predictions based on laboratory test results, provided that close attention was given to controlling sound leaks and flanking transmission (Heebink 1971). Laboratory tests were also conducted in an evaluation of the effect of windows on the noise reduction of a residence (Heebink 1975). Heebink tested operable windows with storm windows added, and studied the effect of sealing. The improvements demonstrated an increase in the combined wall/window STC of between 7 and 10 points. He concluded that, for wood-framed buildings, ordinary windows and well-sealed storm windows were adequate for reducing the indoor reception of exterior noise to levels that are satisfactory.

U.S. Department of Commerce, National Bureau of Standards

In the mid-1970s, the National Bureau of Standards conducted laboratory tests of sound transmission loss, thermal transmittance and air leakage on over 100 typical residential exterior wall constructions with and without window and door assemblies (Sabine 1975). The walls were wood-frame construction with exterior surfaces of wood siding, stucco, and brick veneer. This was a significant database of the laboratory performance of residential structures which provides information on their relative performance.

In a study conducted for EPA, the National Bureau of Standards developed a methodology to measure the cost impacts of acoustical performance requirements for new buildings (NBS 1981). The methodology provides the ability to estimate the change in construction costs resulting from modifications to doors, windows, and exterior walls, and includes a cost minimization model for selecting the least-cost design for a particular level acoustical performance. Although designed for application to new buildings, the principles of the methodology are generally transferable to modification of existing structures. However, it does not appear as though the methodology has been used to any great extent.

National Research Council of Canada

The early 1970s was notable for the start of decade-long research activities at the National Research Council (NRC) of Canada to address aircraft noise and sound insulation design. A number of studies were conducted to develop a database of noise reduction treatments and to develop design procedures for their implementation,

NRC developed a method whereby a dwelling unit may be designed to reduce the noise produced by aircraft to an acceptable level. The individual components contributing to the transmission of sound were chosen so that their effects on the total sound produced were equal (Donato 1973). The total internal sound field may then be calculated by the application of simple weighting factors. The method, although somewhat restricting, had the great advantage that the choice of elements in the design may be made by unskilled personnel. Tables were given showing the insulation factors of various elements and the effect

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of their relative surface area on the total sound field. This study was based on estimates of performance of particular components, obtained from laboratory tests and data for exterior walls with some extrapolation of the results for internal partitions.

An experimental study was then undertaken to determine the performance of exterior walls and roofs, and to compare insulation against an isolated source such as an aircraft with that obtained for the reverberant sound fields used in conventional laboratory measurements (Quirt 1978). A composite structure that embodied the main features of typical Canadian housing units was constructed in the NEF 40 zone on an approach path to Ottawa Airport, where it was exposed to noise from a wide variety of aircraft during routine operations. In addition, a Jetstar aircraft was made available for special flights on the four sides of the house to permit a study of the effect of aircraft position on the noise reduction. Several varieties of windows, doors, exterior walls, and roofs were tested, together with tests of special components such as ventilator fans and fireplace flues. First results of the outdoor studies are in agreement with estimates in the guideline document (Quirt 1978).

Design procedures to reduce the interior noise produced by aircraft to an acceptable level were then developed for the Central Housing Corporation (Canada 1981) applying the Acoustic Insulation Factor (AIF) as a measure of the reduction of outdoor noise provided by the elements of the outer surface of a building (Quirt 1980).

In the late 1990s, the Canadian Department of National Defense were concerned over civilian complaints of military aircraft noise and the impact of the noise on on-base housing. In addition, Transport Canada was concerned over the increased noise resulting from expansion of Toronto and Vancouver Airports. These agencies funded NRC to conduct the IBANA project (Insulating Buildings Against Noise from Aircraft). The complete IBANA project included both laboratory and field measurements of building façade sound insulation as well as the creation of computer software to permit the convenient use of this data to design the exterior sound insulation of buildings against aircraft noise.

The project produced a database of over 100 laboratory measurements of the sound transmission loss of building façade components. These included various wall and roof constructions along with some windows and a number of tests to evaluate the effects of vents on sound insulation (Bradley 2000). On the basis of this data, NRC developed IBANA-Calc software to calculate the effect of sound insulation against aircraft noise and to provide the user with indoor noise levels for different outdoor aircraft noises and building constructions (Birta 2001).

Additional work under the IBANA project included measurements on wood stud exterior walls to better understand the acoustic performance (Bradley 2001), and a comparison of laboratory and field measurements of noise reduction where it was demonstrated that the noise reduction of wall/window combinations can be accurately predicted using laboratory measured data (Bradley 2002a).

U.S. Department of Transportation, Federal Aviation Administration

In response to the Airport and Airways Development Act Amendments of 1976, FAA sponsored a study to assess the feasibility and practicality of soundproofing public buildings (Wyle 1977a). The procedures for soundproofing were developed, and the total costs for implementation on a national scale were estimated. The study identified that the threshold of disruption in classrooms is approximately 45 dB, and 40 dB for hospitals. Architectural surveys and acoustic measurements were conducted on 44 school buildings, and modifications were designed and costed. It was determined that noise reduction increases of up to 10 dB could be achieved with the addition of double-glazed windows and by sealing leaks.

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U.S., Federal Highway Administration

The feasibility of sound insulating houses from highway noise was studied for the Federal Highway Administration in the mid-1970s, (Davy 1977). A detailed set of guidelines was developed for designing improvements, but no significant implementation has occurred.

U.S. Environmental Protection Agency

As part of an overall systems program conducted by the EPA to examine options for the reduction of aircraft noise impact, a study was conducted to estimate the costs of soundproofing dwellings within the DNL 65 contour at major U.S. commercial airports (Sharp 1981). Housing types were identified for 11 different regions of the US and field surveys were conducted to establish the local characteristics that determine the noise reduction of dwellings. A computer optimization technique was employed to identify the most cost-effective modifications needed to meet the interior criteria of DNL 45.

2.3. Testing Standards

2.3.1. Acoustic Test Procedures

The description of the history of research in architectural acoustics presented in the previous section applies equally well to the development of test procedures for measuring the acoustic performance of building elements and building envelopes. Prior to the early 1980s significant research had been conducted in the development of testing methods for measuring the acoustic performance of individual building elements, but these efforts were concentrated almost entirely on interior building elements, such as wall partitions, leaving methods suitable for building facades to the discretion of the acoustical consultant.

For application to airport sound insulation programs there are three types of required acoustic measurements, namely:

1. To measure the acoustic properties of individual building elements (walls, windows, doors, etc.) to provide basic information for the design of sound insulation treatments;
2. To measure the noise reduction of a building envelope and to determine its eligibility for participation in a sound insulation program; and
3. To determine the increase in noise reduction resulting from the application of building modifications.

The first two of these requires the measurement of an absolute value of noise attenuation; the third requires a measurement of the difference in noise reduction before and after the modifications.

2.3.2. Laboratory Test Procedures

The standard method used in the U.S. for measuring the acoustic properties of a structure in laboratory conditions is the ASTM E90 procedure, first issued in 1955 as E90-55. Periodically updated over the years, with gradually stricter requirements for room design and measurement accuracy, the latest version was issued in 2009 as E90-09 (ASTM 2009). In Europe, the procedure used is defined in the ISO Recommendation 140-3 (ISO 1995). The basic elements of both these procedures are essentially the same.

The sound transmission loss properties of a structure are measured by placing it in the dividing wall between two reverberant rooms, one of which - the source room - is equipped with a source of sound, and measuring the sound level in each room using bandwidths of one-third octaves in the frequency range from 100 or 125 Hz to 4000 Hz. The difference in sound levels, when suitably adjusted for the area of the structure and the absorption in the receiving room, is then equal to the transmission loss of the structure. The adjustment, or normalization, is designed to provide values of transmission loss that are independent of the test facility, so that the transmission loss is purely a function of the structural parameters. The sound transmission loss is a basic acoustic property of the structure alone.

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A review of the available data on laboratory measurements of transmission loss shows that, despite efforts to the contrary, there is considerable variation in the values measured in different test facilities (Ferrara 1997, Sharp 1980). The factors responsible for these variations are:

- The spatial characteristics of the sound field in the source and receiving rooms;
- The test structure mounting in the dividing wall; and,
- The size and location of the test structure in the dividing wall.

The ASTM procedure recommends room volumes of at least 80 m^3 for measurements in the one-third octave band centred on 125 Hz, and 125 m^3 for measurements down to 100 Hz. In deference to existing smaller facilities, a room size of 80 m^3 is acceptable but not recommended for new installations. The ISO R140 procedure states that the room volumes should be greater than 50 m^3, with a desirable volume greater than 100 m^3 Thus the ASTM procedure is the stricter of the two and should give more repeatable results at low frequencies.

To increase the diffusion of the sound field, the ASTM procedure suggests the use of randomly spaced diffusing elements or rotating reflectors. A minimum dimension of 2.4 m. is required for the test structure, except for doors and windows, which should be of normal size. Both procedures state that the structure should be installed so that the edge conditions are as similar as possible to normal field installation.

The number of measurements required in the ASTM procedure to sample the sound field in each room is calculated to ensure 95 percent confidence limits of ±3 dB in transmission loss at 125 Hz and 160 Hz, ±2 dB at 200 Hz and 250 Hz, and ±1 dB at higher frequencies. From round robin testing on copies of a reference specimen, it has been determined that the reproducibility standard deviation is about 2 dB or less at all frequencies from 125 to 4000 Hz (ASTM 2009).

2.3.3. Field Test Procedures

Aircraft Overflight Procedure

For airport sound insulation measurements, it would seem that, since aircraft are the source of the noise, and there are usually plenty of these near airports, outside and inside noise measurements should be made with aircraft overflights. This method has the definite advantage of precisely simulating the noise problem experienced by the residents, provided that the measured overflights are representative of the airport's normal operation. If they are, then clearly this may the most suitable method, and in the early years of airport residential sound insulation programs, this was a commonly used technique utilized for the measurement of sound insulation provided by the building envelope (Sharp 1980). The preferred method is to use departing aircraft as the source, as the noise levels are generally higher and the frequency spectrum broader. Exterior and interior noise levels are measured with sound level meters installed outside and inside the building, and the difference between the two sound levels recorded for a number of aircraft flyovers indicates the outdoor-indoor noise reduction.

There are situations, however, that do not lend themselves to this simple approach. If the building to be measured lies directly under the nominal flight path, the normal lateral dispersion of aircraft tracks may result in some rooms being shielded from the direct sound for some of the overflights but not others. The average noise reduction for any given room must then be determined only from overflights that directly impact the room. Another situation is where there are only occasional flights, such as may occur near seldom used runways, or in the vicinity of small airports, although this may be more of an inconvenience than a technical problem.

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In-Situ Noise Reduction Measurements

The first standard test procedure for measuring sound insulation in field (in-situ) conditions is contained in ASTM E336, first issued as E336-71T in 1971. The primary application of E336 is to measure sound isolation between rooms, but general guidelines for measurements of exterior structures with an external noise source are briefly discussed in an appendix. The procedure requires measuring the sound insulation with the exterior noise source at varying angles of incidence, but no guidance is presented as to how this data is to be combined to provide a composite value.

The E336 procedure for field measurement was subsequently revised as E336-77T in 1977 (ASTM 1977) specifying certain conditions that must be met for the results to be as independent as possible of the sound fields in the two rooms and the building in which the structure is installed. For example, the procedure is valid only at frequencies equal to or greater than a lower limiting frequency that is a function of the room volume. For any given lower limiting frequency, the minimum room volume is about one-half that recommended for laboratory facilities in the ASTM E90 procedure. Judging by the results presented by Higginson, whose test rooms would be suitable at frequencies equal to and greater than 250 Hz, this criterion may lead to poor repeatability at the lower and even medium frequencies (Higginson 1972). It is difficult to increase the sound diffusion in small rooms because the size of the diffusing elements necessary to modify the low-frequency modes would be comparable to the room dimensions, leaving very little space for suitable microphone locations. Thus poor diffusion must be accepted in the measurement of field transmission loss (Higginson 1972). As a consequence, the accuracy and repeatability of field measurements conducted in typical dwelling rooms is generally poor unless considerable care and time are taken to sample adequately the sound field in each room. The problem is particularly acute at low and medium frequencies where sound diffusion is low.

The uncertainty of the measurements increases with increasing absorption and with reducing the number of sampling positions. Increasing the amount of absorption actually increases the uncertainty because the sound diffusion is lowered. Test results in rooms of volume 35 to 50 m3 (8’ x 10’ x 15’) indicate that measurements in rooms having absorption typical of furnished dwellings are recommended only if the room volumes are adequately sampled with at least 9 measurement positions. (Nightingale 2001).

If significant flanking transmission exists between the source and receiving rooms, steps must be taken for its reduction before the noise reduction can be measured. The E336-77 procedure provides guidance in determining whether flanking transmission exists by specifying a number of qualitative and quantitative tests. A mandatory test involves adding a temporary shield to the partition and repeating the measurements.

Facade Noise Reduction Measurements

The increasing interest in providing protection for buildings against the external noise produced by highway traffic and aircraft, and in soundproofing existing buildings, led to the requirement for a much more closely controlled test procedure. As a result, the International Organization for Standardization established a standard test procedure, ISO 140-5 (ISO 1978). In 1984, ASTM issued their first standard for measuring the sound insulation of building facades in the form of E966-84 (ASTM 1984). Subsequent versions have since been issued in 1990, 1999, 2002, 2004, with the latest version issued in 2010 (ASTM 2010).

Unlike the measurement procedures for interior building areas, the noise reduction and field transmission loss of building facades depends on the noise source characteristics. The exterior sound field often consists of progressive waves radiated from the source with few reflections from nearby obstacles. For a point source, such as a single vehicle, the sound will be incident on the building facade at a single angle of incidence. For a line source, such as a highway, or for aircraft overflights, sound will be incident

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at many angles. Both the ISO and ASTM procedures allow for measurements to be performed using either highway noise or loudspeakers as the sound source.

The E966-84 Standard was developed for the measurement of sound insulation of building facades from highway noise sources; in fact there is no mention of aircraft noise as a possible source (ASTM 1984). Alternatively, measurements can be conducted with an artificial noise source, such as a loudspeaker. The procedure is designed to measure the outdoor-indoor noise reduction (OINR) of an entire building envelope, but can be adapted for measuring individual elements (such as a window) by incorporating measured corrections for flanking transmission of the noise. Such corrections are time-consuming to measure and inaccurate if the element has a high noise reduction itself (as it may after sound insulation modifications are introduced).

If a loudspeaker is used as the source, it is recommended that it be placed to provide incident sound at 45 degrees to the building facade. The volume of the interior room must be at least 40 m^3 to provide sufficient sound diffusion for measurements at the lowest frequency (125 Hz). Furthermore, it is recommended that the room contain hard furniture to increase the sound diffusion. These requirements can only be met in an interior room of size 12 ft. by 15 ft. with little absorption from furnishings, e.g. a dining room, but not a bedroom.

E966-90 issued in 1990 contains a short section on using aircraft noise as the source, and describes what is termed "The FAA Method" (ASTM 1990) in reference to the procedure using aircraft over-flights. However, as the range of vertical angles of incidence from aircraft over-flights can be large, and vary for each noise event, it was recommended that measurements with aircraft noise sources be restricted to components such as roofs, ventilators, and complete structures that cannot be readily tested by other means. If a loudspeaker noise source is utilized, it should be positioned a 45 degree angle to the facade. Measurements of outdoor-indoor level reduction (OILR – a change from OINR in nomenclature only) can also be made at other angles and the values reported at each angle. The recommendation for minimum interior room size was increased to 50 m^3 (1770 ft3).

A subsequent version of E966, issued in 1999, recommended that the integrated average sound level (that is, the sound exposure level, or SEL) of the outdoor and indoor sound pressures be measured simultaneously for aircraft flyover noise, or where natural traffic is sparse.

The next version of E966 was released in 2002 as E966-02 (ASTM 2002) with the only significant change being a procedure for combining the outdoor-indoor level reduction (OILR) measured at different angles into a single angle-averaged value.

The latest published version of E966 was issued in 2010 (an intermediate version E966-04 was issued in 2004 with only minor changes) that contains more information on measuring aircraft noise using individual SEL measurements, but the emphasis is still on traffic noise (ASTM 2010). It is noted that loudspeakers have been used as the outdoor sound source, measuring the level reduction in third octaves and calculating the A-weighted level difference based on a typical aircraft spectrum. As no body of experience in the use of this guide exists at present, it is estimated that the repeatability standard deviation of these test procedure is of the order of 2 to 3 dB, depending on frequency.

Appendix X1 of E966-10 contains information on other measurement methods, including methods used by the Federal Highway Administration and the Federal Aviation Administration. The latter refers to methods using aircraft over-flight measurements, an external loudspeaker, and an indoor-outdoor procedure (Gurovich 2004).

There have been criticisms of the measurement procedure using a loudspeaker as the noise source. The incident sound wave from an aircraft flyover varies in level, spectrum, and angle of incidence as the aircraft moves along its flight track. Since the noise reduction is dependent on both the spectrum and the angle of incidence, it follows that measurement at one single loudspeaker position does not necessarily represent the complete event (Karfalk 1976). It has been demonstrated that variations of up to

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4 dB can be observed in measured noise reduction with different angles of incidence, and that an angle of 60 degrees is more appropriate than the 45 degrees as recommended in ASTM E966 (Jonasson 1986). It is therefore difficult to define a single representative location for an artificial source that exposes a building to the same sound field as does an aircraft overflight. The loudspeaker method may be suitable for measuring differences in noise reduction, but even this may not be representative of the real noise situation.

The ASTM E966 procedure allows exterior noise to be measured a) in the free field away from the building, b) at a distance of 2 m from the facade, or c) close to (17 mm) the surface of the facade. Quirt has demonstrated that neither Methods b) or c) give consistent results, and that Method a) is the procedure that should be implemented (Bradley 2002b).

Summary of Field Test Procedures for Aircraft Noise Sources

Currently, there is no standard measurement procedure specified by the FAA or by any of the standards institutions for the measurement of noise reduction for aircraft sources. Measurements using aircraft overflights are representative of the real situation, but results can vary as the noise source is uncontrolled. Loudspeaker measurements would seem to be the answer, but, a review of the data (Sharp 1994, Mulholland 1971) shows that caution is necessary if this approach is to be adopted.

2.3.4. Single Number Sound Transmission Loss Metrics.

The methods described above for measuring transmission loss in the laboratory and level reduction in the field are designed to give detailed data on the acoustical performance of structures as a function of frequency. It is common to present the results in each of 16 or 17 one-third octave bands. This information is valuable to the acoustic specialist so that he can fully understand the change in performance with frequency and can perform detailed calculations on the expected sound isolation in finished buildings, but the data in this form are often confusing to the non-acoustical specialist, such as the architect who has the task of designing the building. To overcome this problem, several methods have been proposed to characterize the sound attenuating properties of a structure in terms of a single number. Such methods can be applied to:

- Rank-order structures in terms of acoustic performance.
- Allow for simplified calculations of noise reduction – such as in a design guide.
- Develop a design optimization procedure that selects the combination of components that achieves a given noise reduction at minimum cost.

One such method involves the use of a grading curve, specifying the transmission loss required in each one-third octave band, against which the measured values for a given structure are compared. The grading curve concept can be used in two ways - it can represent a strict requirement for all structures to be used in a given building type, or it can be adjusted to give a ranking of one structure against another. Since it would be unreasonable to discriminate between two structures whose transmission loss characteristics differed by only one or two decibels in a frequency band, current grading procedures allow for a certain number of deviations below the grading curve.

Several alternative grading curves have been developed or suggested for use in building design. Basically, the curves have been determined by taking the difference between typical source levels in buildings and suitable criteria for acoustical privacy in neighbouring rooms. A comprehensive description of the basis for the different grading curves has been prepared by Yaniv and Flynn (1978). In their review, they conclude that the subjective response data used to establish the requirements for sound levels in dwellings is extremely variable and has led to the development of a number of grading curves that differ by up to 10 dB at some frequencies. The lack of a comprehensive data base on subjective response does not allow an assessment to be made of the importance of these differences. Also, the shape of the grading

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curve for partitions is dependent on the typical source spectrum selected for the calculations. As a result, there is considerable uncertainty as to the validity of current grading procedures.

In the United States, the standard grading procedure for the transmission loss of building structures was originally given in ASTM E413-70, Standard Classification for Determination of Sound Transmission Class (STC). Initially, this procedure was intended for application to data measured in the laboratory, and thus provided a single number for ranking the potential performance of structures. The same grading curve is also used to describe the field transmission loss of structures (FSTC) and the noise reduction between rooms (NIC - Noise Isolation Class).

Single-figure rating schemes are intended to rate the acoustical performance of a partition element under typical conditions involving office or dwelling separation. The higher the value of either rating, the better the sound insulation. Thus, the rating is intended to correlate with subjective impressions of the sound insulation provided against the sound of speech, radio, television, music, office machines and similar sources of noise characteristic of offices and dwellings. In applications involving noise spectra that differ markedly from those referred to above (for example, aircraft noise), the STC values are of limited use. Generally, in such applications it is desirable to consider explicitly the noise spectra and the insulation requirements.

Rettinger established that for jet aircraft noises, the necessary insulation of such exterior room boundaries is not well represented by an STC rating as the typical STC curve is lacking in low frequency insulation when it is applied to exterior boundaries (Rettinger 1974). There is actually no simple relationship between the A-weighted sound level and the required STC noise reduction characteristic to achieve a desired interior noise spectrum or a desired A-weighted sound level.

In this respect it should be noted that ASTM Standard E413-70T states distinctly that excluded from the scope of the STC classification system are applications involving noise spectra that differ markedly from the sounds of speech, music, ands similar sources in offices and dwellings. Single-number ratings, such as STC, are often inadequate for the purpose of calculating the required insulation against various types of external noises, although they may be satisfactory for a single type of external noise valuated in a specific way (Rettinger 1974).

A single-number index, called the Exterior Wall Rating, or EWR, has been developed for rating the sound transmission loss of exterior facades (Mange 1978). This index was closely patterned after, but different from, the Sound Transmission Class, or STC, single-number index. The latter provides a fairly reliable single-number rating for the sound transmission loss of interior partitions for typical indoor sounds, but is not suitable for assessing the sound transmission loss of exterior walls to transportation noise sources with high low-frequency content. However, by applying principles similar to those upon which the STC rating was developed, a practical index was constructed which can reliably rate exterior building elements in terms of their ability to attenuate A-weighted sound levels from transportation sources, i.e., aircraft, highway, and railroads. As a method for ranking the performance of exterior facades in terms of subjective response, this method suffers from the same criticisms given to other grading procedures. An advantage of the EWR rating is that the numerical rating value can be used to calculate the interior noise level from knowledge of the exterior level.

Concurrent with the development of the EWR, the National Bureau of Standards developed the Shell Isolation Rating, also intended to predict the A-weighted level reduction (Pallett 1978). The SIR uses a rating curve method similar to E413, but the grading curve is a straight line with a slope of 3 dB per octave from 125 to 4000 Hz.

The EWR index was specifically designed to be used for all transportation sources, so that each structure would have a single rating number. In 1990, the ASTM published Standard Classification for determining the outdoor-indoor transmission class (OITC) for a structure that is applicable for a given

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outdoor noise spectrum (ASTM 1990). As with the EWR, the OITC can be used directly to calculate interior noise levels.

According to the ASTM Classification, the rating value only represents the OITC for the given outdoor noise spectrum, so it is a useful method to apply for this or a similar spectrum. However, for practical design purposes, the method can be used for any given spectrum.

2.3.5. AAMA Test Standards for Building Elements

The focus of ACRP project 02-31 is on assessing potential deterioration in the acoustic performance of treatments in the early airport sound insulation programs. The previous two subsections have presented a review of test standards specifically designed to measure and evaluate acoustic performance. However, there are other test standards that, while not directly addressing acoustic performance, do test products for characteristics that can affect the acoustic performance – characteristics such as air leakage, water penetration, hardware cycling, etc. The evolution of these test standards is presented in this subsection.

The first version of ANSI/AAMA 101 voluntary specification was produced by the American Architectural Manufacturers Association (AAMA) in 1985. It replaced the ANSI/AAMA 302.9 "Voluntary Specifications for Aluminum Prime Windows" and the ANSI/AAMA 402.9 "Voluntary Specifications for Aluminum Sliding Glass Doors" standards. The new 101 standard covered 14 different types of aluminum products. This initial standard required operating force, air leakage, water penetration and uniform load structural tests which are the foundation for the standards that superseded it. It also included some forced entry resistance (optional), safety drop, hardware cycling, concentrated load, deglazing and torsion tests for particular product types or components. The three product "Grades" for this standard were Residential (R), Commercial (C) and Heavy Commercial (HC). The Performance Classes covered design pressures ranging from 15 to 50 psf. It also provided basic information and requirements for product components such as the aluminum alloy materials, finishes, reinforcements, fasteners, weather-stripping, glass, insulating glass, glazing materials, mullions and hardware. This document did include dual window (DW) systems and addressed the summer/winter configurations for certain tests.

The next version of ANSI/AAMA 101 was released in 1993. In this revision, Poly Vinyl Chloride (PVC) prime windows and glass doors were included with the aluminum products. Swing (hinged) glass doors, dual action swing doors, dual action windows and side hinged windows were added to the list of products. Architectural (AW) grade windows and doors were added to the existing R, C and HC product grades. Higher water resistance and air infiltration performance requirements were set for AW products than those required for HC products. Architectural products also were required to meet the deflection limit of L/175 for the uniform load test and the Life Cycle specifications of AAMA 910. Thermal Transmittance and Condensation Resistance tests, in accordance with AAMA 1503, were added as an option for product manufacturers. The Welded Corner test was also added since this revision now included PVC windows and doors.

The AAMA/WDMA 101/I.S.2-97 voluntary specification introduced the new "Gateway" term for the first time. Each product type has a set of primary requirements before entry into the product performance class is permitted. A minimum test size is one of the gateway requirements. The product designation now includes the Product Type, Performance Class, Performance Grade and the Maximum Size Tested. For example a 48" wide by 76" high, light commercial, horizontal sliding with design pressure of 25 would designated HS-LC25 48x76. Wood window and door products were also included in this version of the 101 document. Basement (BW), Hinged Egress (HE) and Tropical Awning (TA) windows were added to the list of product types. The Forced-Entry Resistance test was made mandatory for all windows and doors. The maximum air leakage criteria was reduced from 0.37 and 0.15 cfm/ft3 to 0.30 and 0.10 cfm/ft3 respectively, which should help to improve the acoustical performance of some

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products. The list of optional tests now included Acoustical Performance which would be performed in accordance with ASTM E1425 or AAMA 1801. These acoustical methods reference the ASTM E90 test method for the sound transmission loss test procedure.

The AAMA 101 voluntary specification, up to this point, was primarily a standard to be utilized by manufacturers, code bodies and specifiers in the United States. The 101/I.S. 2/NAFS-02 document was composed by a task group of representative members from AAMA, Canadian Standards Association (CSA), Canadian Window and Door Manufacturers Association (CWDMA), National Fenestration Rating Council (NFRC), National Research Council Canada (NRC/IRC) and Window and Door Manufacturers Association (WDMA). The goal was to have a single performance standard that could be used by the United States and Canada. However, this goal was not achieved and the standard was only approved by AAMA and WDMA.

The 101/I.S. 2/NAFS-02 document preserved the products designations contained in the previous 101 standard but used SI (Metric) units as the primary designator and IP (Inch/Pound) units as the secondary unit. Skylights (Glass & Plastic), Sidelites, Transom and Specialty Products were added to the list of products. Other materials to be used in the manufacture of fenestration products were added such as Cellular PVC, Fiberglass, Steel, Cellulosic Composite Materials, and Acrylonitrile Butadiene Styrene (ABS). The ASTM E2068 test was now specified for evaluating the operating force of all operable sash or panels. Criteria for the maximum force required to initiate motion of the operable sash or panels from both the fully closed and fully open positions, as well as the force required to maintain motion to the opposite limits of travel were specified. This new NAFS document contained 55 illustrating figures and 80 tables to clarify the requirements of the standard. A Laboratory Test Report section was added to the NAFS-02 document that required a more thorough description of product components and a statement that "horizontal and vertical cross–section drawings of the test specimen were reviewed by the testing agency, and that those drawings matched the tested specimen". Cross–section and component drawings were now required to be stamped and retained by the testing agency.

The AAMA/WDMA/CSA 101/I.S.2/A440-05, Standard/Specification for windows, doors, and unit skylights, was jointly published by AAMA, WDMA, and CSA. This revision retained the five performance classifications (R, LC, C, HC and AW) and the product designations. Four new product types were added to the product list. Test requirements and criteria for side hinged exterior doors were added to this standard specification. The door tests included latching force, limited water, cycle/operation, hardware water, vertical load, forced entry resistance. The air leakage test pressures and criteria are primarily used in the United States; three levels of air infiltration/exfiltration performance criteria are required in Canada for different product types. Impact performance for windows, doors and skylights was added as an optional requirement, and a section included more details to be included in test reports. The acoustical test sizes for windows referenced the gateway performance test sizes of this standard which would require different test sizes for the five performance classes. The test sizes for doors were taken from the ASTM E1408 document, which was withdrawn by ASTM.

The second edition of the AAMA/WDMA/CSA 101/I.S.2/A440 specification was published in 2008 with the following title, "North American Standard/Specification for windows, doors, and skylights". In this revision, the number of window and door performance classes were reduced from five to four by eliminating the C and HC Classes and adding a new class identified as CW. Tubular Daylighting Devices (TDDs) were added to the list of products. There were several revisions and clarifications of the design pressure (DP) and performance grade (PG) terms and some changes to the test sizes. The maximum required force to latch a side hinged door of 65 N (15 lbf) was removed and the required force needed to be measured and reported. This document still did not specify a singular test size for windows, doors and skylights for acoustical performance. Glass and insulating glass units (IGU) descriptions were improved and weatherability, light transmittance, impact strength, smoke density, self-ignition and combustibility test requirements were added for plastic glazing material. The

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Framing/cladding materials section was expanded to cover many types of wood, vinyl, aluminum, steel, fiberglass and other types of product components.

The third edition of the AAMA/WDMA/CSA 101/I.S.2/A440 was approved by AAMA, WDMA and CSA in 2012. The standard/specification was restructured so there are separate sections for products, materials and components. The addition of criteria for secondary storm products (SSPs) was added throughout the entire document. This is an important change since many of the sound insulation products have secondary storms. The summer/winter mode test conditions were removed due the addition of SSPs. This standard/specification defines requirements for four Performance Classes. The Performance Classes are designated R, LC, CW, and AW for windows, doors, and secondary storm products (SSPs), skylights, and roof windows. TDDs are not identified with a Performance Class, but are treated in a way similar to specialty products. Both positive and negative design pressures can be noted in the product designations for skylights, roof windows and TDDs. The total number of products has now been increased to 37. This standard now specifies the test sizes listed in ASTM E1425 for products being tested for acoustical performance. These test sizes are nearly identical to the NFRC thermal transmittance test sizes.

2.3.6. Summary

The AAMA 101 document has been significantly improved over the past 25 years. The latest document covers virtually every type of fenestration product that is used in residential and commercial buildings except for curtain wall and storefront systems. Many of the test procedures that are included in this standard require manufacturers to improve the performance of their products. There are optional performance requirements and test procedures that can now be included in product specifications to improve the longevity of products used in residential sound insulation programs.

2.4. Federal Policies and Regulations

In this section we present a brief overview of the development of federal policies and regulations related to airport sound insulation programs, followed by a more in-depth review of the noise criteria established for these programs.

2.4.1. An Historical Overview

Federal policies regarding airport sound insulation programs have been the result of many years of research and experience by a number of federal agencies in the understanding of the effects of aircraft noise on people, and the needs of communities adjacent to sources of transportation noise, such as airports. Federal funding for airport sound insulation programs only became available in the early 1980s, but the history of the legislation that provided this funding goes back to the 1970s.

Federal aviation noise policies are based on the tenet that airport proprietors are normally held responsible for any consequences that aircraft noise may cause as a result of the operation of their airports. Commensurate with that liability is the authority to control those consequences through local use restrictions and other actions that do not violate Constitutional safeguards or federally pre-empted areas. Because airport noise impacts are essentially local in nature, and actions to alleviate those impacts depend greatly on local political and geographical factors that differ from airport to airport, it is axiomatic that noise abatement planning is best accomplished locally by the airport proprietor. The federal government first recognized this concept formally as part of the Aviation Noise Abatement Policy, which was issued in November 1976 by the Secretary of Transportation and the Administrator of the FAA (DOT 1976).

The basic theme of the 1976 policy statement was that aviation noise abatement is a shared responsibility among all elements of the airport community - the federal government, the airport proprietor, aircraft operators, air transportation users, airport neighbours, and local governments. The statement outlined the general responsibilities of each of these elements; and, as one of the federal actions to carry out its responsibilities. FAA established a pilot program of local airport noise compatibility planning known as the Airport Noise Control and Land-Use Compatibility (ANCLUC) Program through

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which FAA funded voluntary planning projects at 56 airports across the United States (FAA 1977). These projects were generally well accepted and beneficial.

Based on the experience gained from this pilot program, the Congress, in the Aviation Safety and Noise Abatement Act (ASNA) of 1979, directed the FAA to establish a permanent airport noise compatibility program, to be voluntary at the initiative of each airport proprietor Accordingly, in January 1981, FAA published interim regulations as Part 150 of the Federal Aviation Regulations (FAA 1981) that established a single system for the measurement of airport noise, a single system for determining the exposure of individuals to airport noise, and a standardized airport noise compatibility planning program.

In mandating the establishment of the airport noise compatibility program, which resulted in the issuance by FAA of 14 C.F.R. Part 150, the Congress directed that FAA "identify" land uses which are "normally compatible" with various levels of community noise exposure. The resultant guidelines for land-use compatibility are contained in Table 1 of Part 150 (FAA 1981). Basically, these guidelines identify a DNL less than 65 dB as normally compatible with residential land uses. Values of DNL between 65 and 75 dB may be considered compatible if a community determines such use must be allowed and appropriate sound insulation measures are taken. Above a DNL of 75 dB, residential use should be discouraged.

In developing Table 1 of Part 150, FAA considered earlier compatibility guidelines to assure consistency and validity of its information. In particular, FAA considered the material of the EPA Levels Document (EPA 1974), the Federal Interagency Committee on Urban Noise (FICUN 1980), and the ANSI standard on descriptors for compatible land use (ANSI 1980). FAA also considered basic guidance previously used for earlier noise exposure metrics to assure continuity. These various sources were mutually consistent and compare well.

The Airport and Airway Improvement Act of 1982 established a grant program, the Airport Improvement Program (AIP), with a ‘‘set-aside’’ of funds specifically for noise compatibility planning and projects approved under Part 150[1] including projects that reduce airport-related noise or mitigate its effects. Airports were required to provide a “matching share” ranging from 10 percent to 25 percent of a project’s total cost, depending on the type of project and the size of the airport. For noise-related projects funded under the noise “set aside,” the percentages were established at 20 percent for large airports and 10 percent for small airports. This was an important turning point because partial funding was now available for sound insulation programs. To qualify for AIP funds that are set aside for noise-related projects, an airport must have an FAA-approved noise compatibility program that includes the projects the airport wants funded, except that projects to insulate public buildings used primarily for educational or medical purposes can be funded even though an airport does not have such an approved program.

In 1983, FAA issued an Advisory Circular 150/5020-1 (FAA 1983) providing general guidance for noise control and compatibility planning for airports as well as specific guidance for preparation of airport noise exposure maps and airport noise compatibility programs by airport operators for submission under Part 150. This document remains valid and in effect today. It is understood that FAA is planning to update the document in 2013.

14 C.F.R. Part 150 was revised and made final in January 1985[2]. The program continued to be entirely voluntary on the part of the airport proprietor, but provided the incentive of subsequent eligibility for federal funding, under the Federal Airport Improvement Program, to carry out the approved plan. Funded projects include soundproofing homes and public buildings (schools, hospitals, churches, etc.), acquiring noise-sensitive properties and relocating their uses, implementing noise abatement procedures, and encouraging compatible zoning.

[1] P. L. 97-248.

[2] 14 CFR Part 150 “Airport Noise Compatibility Planning.

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In 1985 FAA issued the first version of the Airport Improvement Program (AIP) Handbook that inter alia specified the requirements and technical criteria for noise insulation projects (FAA 1985). The Handbook has subsequently been updated, first in 1989 (FAA 1989), then in 2002 (FAA 2002), and finally in 2005 (FAA 2005).

Since 1991, airport operators have had an additional funding mechanism to reduce noise impacts. The Aviation Safety and Capacity Act of 1990[3] grants commercial service airports the authority to levy a passenger facility charge (PFC) to assist in financing capital improvement programs[4]. For example, PFCs may be used for airport noise compatibility measures, such as sound insulation, that are eligible for federal assistance, even if the measures have not been approved as part of a Part 150 Program. However, the measures implemented must be consistent with the requirements of Part 150.

The chronological sequence of federal legislation and policies is summarized in the following table.

[3] P. L. 101-508 (title IX, subtitle B).
[4] 14 CFR Part 158, "Passenger Facility Charges".

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Year	Month	Event	Reference
1976		Airport and Airway Development Act Amendments of 1976 authorize for the first time the use of federal airport development funds on projects designed to achieve noise relief.	P.L. 94-353
1976	November	FAA Aviation Noise Abatement Policy initiated a pilot project through (up to 25 grants per year) to encourage the preparation of comprehensive noise abatement plans by airport proprietors including acquire noise suppressing equipment, construction of physical barriers, and landscaping for the purpose of reducing the impact of aircraft noise with FAA financial assistance.	FAA ANAP 1976
1979		Aviation Safety and Noise Abatement Act of 1979 (ASNA) directed the FAA to receive voluntary submissions of noise exposure maps and noise compatibility programs from airport proprietors.	P. L. 96-193
1981	January	Part 150 – interim regulation -- implements ASNA	46 FR 8316
1982		The Airport and Airway Improvement Act of 1982 established a ‘‘set-aside,’’ of Airport Improvement Program (AIP) funds specifically for noise compatibility planning and projects under Part 150.	P. L. 97-248
1983	August	Noise Control and Compatibility Planning for Airports – Soundproofing, Para. 345, Section 4	AC150-5020-1
1985	January	FAA Part 150 – final rule	14 CFR part 150
1985	February	Airport Improvement Program (AIP) Handbook – *Cancelled in 1989*	AC 5100.38
1987		Airport and Airway Safety and Capacity Expansion Act of 1987 provided continued funding of noise compatibility planning under AIP.	P. L. 100-223
1989	October	Airport Improvement Program (AIP) Handbook – *Cancelled in 2002*	AC 5100.38A
1990		Aviation Safety and Capacity Expansion Act of 1990 established PFC program.	P. L. 101-508 (title IX, subtitle B)
1993	July	Announcement of Availability Report No. DOT/FAA/PP/92-5, Guidelines for the Sound Insulation of Residences Exposed to Aircraft Operations	AC150-500-9A
1994	July	Announcement of Availability: Passenger Facility Charge (PFC) Application	AC150-5000-12
2002	May	Airport Improvement Program (AIP) Handbook – Sec. 812 Noise Insulation Projects – *Cancelled in 2005*	AC 5100.38B
2005	June	Airport Improvement Program (AIP) Handbook – Sec. 812 Noise Insulation Projects	AC 5100.38C

2.4.2. Criteria for Sound Insulation Programs

Airport Improvement Handbook Guidelines

Following the issuance of the interim Part 150 rule in 1981, FAA issued Advisory Circular AC 150/5020-1 in 1983 (FAA 1983) providing, amongst other things, qualitative guidance for soundproofing projects, including a listing of possible treatments, for buildings in non-compatible land areas, e.g. DNL

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65 and above for residences. The Order does not specify criteria for the degree of additional noise reduction to be achieved. According to AC 150/5020-1:

"*The airport cumulative noise metric (Ldn) is useful as an indicator that soundproofing may be required in a particular area. However, when considering any specific building site within a cumulative noise exposure contour (representing significant noise impact) it is recommended that additional analysis via single event maximum sound level and/or sound pressure level versus frequency data be used to determine the necessity (and/or eligibility) for soundproofing.....The A-weighted sound level is more utilitarian than other single event metrics in establishing the need for soundproofing as many of the sleep, speech and activity interference criteria have been developed using LAS levels*."

The quantitative criteria for federally funded sound airport insulation projects were listed in the 1985 Airport Improvement Program (AIP) Handbook, designated as FAA Order 5100.38 (FAA 1985). In defining the standards to be used in designing modifications to increase the sound insulation of residences, the FAA stated that (FAA 1985):

> *"A 45 dB(A)-48 dB(A) interior noise level is considered a reasonable objective. Federal assistance will not be provided to achieve interior noise levels below 45 dB(A)".*
>
> *"A total noise reduction of 25-35 dB from exterior noise levels to interior levels usually can be achieved with some combination of storm windows, solid-core exterior doors.....and central air conditioning".*

In 1986, FAA issued some additions and changes to the noise criteria of 5100.38 in a version identified as 511.38 CHG3 (FAA 1986), namely that:

> *"The structure must be located within a 65 yearly day-night average sound level (L_{dn}) contour. Normally, unless extenuating circumstances dictate, noise attenuation should not be considered for structures within a 75 L_{dn} or greater noise contour since acquisition is preferred".*
>
> *"A 45 Ldn within the major habitable rooms of a dwelling is considered the reasonable design objective for selecting noise attenuation measures".*

However, the revised 1986 FAA Order added the following provision:

> *"Since it takes at least a 5 dB improvement in Noise Level Reduction (NLR) to be perceptible to an average person, the existing interior noise level of the dwelling must be 50 Ldn or greater to be considered a candidate for noise attenuation".*

With this unusual interpretation and incorporation of the minimum perceptibility concept, FAA took the position that a dwelling exposed to an exterior noise level of DNL 65 could only be a participant if its noise reduction was 15 dB or less – a low value that most dwellings will only exhibit with open windows.

The statement that it takes at least a 5 dB improvement to be perceptible is in keeping with a 'rule of thumb' long held by acoustical engineers that a 5 dB difference in noise level is necessary to differentiate the noise of two separate events, such as aircraft flyovers, from each other when presented sequentially. Surveys of homeowners who participated in airport sound insulation programs at three major airports have shown that a 3 dB increase in noise reduction is considered a 'slight improvement'. A 7 dB increase in noise reduction was rated as 'improved', and a 9 dB increase as 'much improved' (Brown 1990). Further analysis of the survey data indicated that an interior DNL of 43 dB corresponded to a 'slightly improved' response, and 38 dB to an 'improved' or 'much improved' response.

As might be expected, the initial lack of specificity in Order 5100.38, followed by a series of changing requirements, caused a certain amount of confusion in the industry, and led to several different interpretations that were not resolved until the 1989 version of the AIP Handbook was issued.

Documents
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Full document details: Assessment of Sound Insulation Treatments