



AEROSPACE RECOMMENDED PRACTICE

ARP6973™

REV. A

Issued 2021-04
Revised 2025-05

Superseding ARP6973

(R) Aircraft Noise Level Reduction Measurement of Building Façades

RATIONALE

Standard methods for measuring the noise reduction of façades have been published by the International Organization for Standardization (ISO) and ASTM International, but these methods do not provide the technical details necessary to obtain reproducible results when applied to realistic field situations, particularly when the façades are exposed to aircraft noise sources. This SAE Aerospace Recommended Practice generally follows the methods of previous standards but was developed to provide these additional details.

This revision to ARP6973 provides an alternative method for measuring the noise reduction of a building façade using a loudspeaker as the noise source. Experience has shown that there are many situations in the field where it is difficult to position an outdoor loudspeaker according to the guidelines in ARP6973. To overcome this limitation, an alternative methodology has been added that uses an indoor loudspeaker to conduct the measurements. This method provides a measure of the noise reduction that is consistent with measurements conducted using the outdoor loudspeaker method.

This revision to ARP6973 also incorporates some improvements to the outdoor loudspeaker method based on experience from field implementation. Most of the changes are minor and relate to wording of various sections to clarify details. More substantive revisions include additional procedures for specific building features, such as porches or balconies, and for measurements in confined spaces.

FOREWORD

Historically, there have been two methods used to measure the noise reduction of structures. The flyover measurement procedure employs aircraft as the exterior noise source. Since aircraft are the source of the noise, outside and inside noise measurements are made simultaneously with aircraft overflights. This method has the advantage of simulating the noise problem experienced by the residents, provided that the measured overflights are representative of the airport's annual average daily operations for the year of interest. However, aircraft as noise sources are uncontrollable and the measurement results can sometimes be difficult to replicate if aircraft fly different tracks on different days or arrive some days and depart others on a specific runway. The result is that the data obtained are often representative only for the day of measurement. Furthermore, the testing procedure requires multiple sound level meters to conduct noise measurements simultaneously in multiple rooms and can be time-consuming if airport runway usage does not always match the need for measurements. The aircraft flyover measurement method is presented in Section 3 of this ARP.

The second method for measuring noise reduction employs an outdoor loudspeaker as the noise source and adapts the ASTM E966-18a test procedure with noise level measurements outdoors and indoors. The loudspeaker is a controlled source, so the measured data are more accurate and repeatable than that using aircraft as the source and are not subject to the day-to-day variations in aircraft operations. However, the data obtained using the ASTM method are not necessarily reproducible by consultants as it lacks procedural details for applying the method to realistic field situations. The outdoor loudspeaker measurement method presented in Section 4 of this ARP is based on research designed to provide the necessary test details to obtain reproducible results in realistic situations.

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Experience has shown that there are many situations in the field where it is difficult to implement the outdoor loudspeaker method according to the guidelines in Section 4. To overcome this limitation, an alternative test methodology is presented in Section 5 that employs a loudspeaker inside the building, together with noise level measurements inside and outside to determine noise reduction. This indoor loudspeaker method provides the consultant with a tool that expands the number of situations suitable for testing.

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1. SCOPE

This ARP provides two methods for measuring the aircraft noise level reduction of building façades. Airports and their consultants can use either of the methods presented in this ARP to determine the eligibility of structures exposed to aircraft noise to participate in an FAA-funded Airport Noise Mitigation Project, to determine the treatments required to meet project objectives, and to verify that such objectives are satisfied.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 ANSI Accredited Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ANSI S1.43 Specifications for Integrating Averaging Sound Level Meters

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E966-18a Standard Guide for Field Measurements of Airborne Sound Attenuation of Building Façades and Façade Elements

ASTM E2235-04 Standard Test Method for Determination of Decay Rates for Use in Sound Insulation Test Methods.

2.1.3 ISO Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ISO 6926:2016 Acoustics - Requirements for the performance and calibration of reference sound sources used for the determination of sound power levels

2.1.4 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 61672-1 Electroacoustics - Sound level meters

2.1.5 Other Publications

Beranek, L.L. (1986). *Acoustics*. Copyright by the Acoustical Society of America (from the original 1954 version).

Sharp, B.H., Cox, J.E., and Zheng, Z.C. (2019). *Noise level reduction measurement method equalization and normalization* (Report no. DOT/FAA/TC-19/34). U.S. Federal Aviation Administration.
<https://www.airporttech.tc.faa.gov/Products/Airport-Safety-Papers-Publications/Airport-Safety-Detail/ArtMID/3682/ArticleID/2678/Noise-Level-Reduction-Measurement-Method-Equalization-and-Normalization>.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

ACRP (2016). *Evaluating methods for determining interior noise levels used in airport sound insulation programs* (Report no. 152). Airport Cooperative Research Program, U.S. Federal Aviation Administration. <https://doi.org/10.17226/23473>.

Bajdek, C.J., Cox, J.E., Mentzer, R.C., Nicholas, B.L., and Reindel, E.M. (2016). *Review and evaluation of aircraft noise spectra used to estimate noise level reduction for airport sound insulation programs based on the loudspeaker test method*. U.S. Federal Aviation Administration. https://www.faa.gov/sites/faa.gov/files/about/office_org/headquarters_offices/apl/pears_to43.pdf.

Landrum & Brown, Inc. (2013). *Study of noise level reduction (NLR) variation*. U.S. Federal Aviation Administration. Available at https://www.faa.gov/sites/faa.gov/files/about/office_org/headquarters_offices/apl/BTV_NLR_report_0.pdf.

Sharp, B.H., Cox, J.E., and Zheng, Z.C. (2018). *Investigation of ASTM E966 adjustment factors* (Report no. DOT/FAA/TC-18/15). U.S. Federal Aviation Administration. <https://www.airporttech.tc.faa.gov/Products/Airport-Safety-Papers-Publications/Airport-Safety-Detail/ArtMID/3682/ArticleID/160/Investigation-of-ASTM-E966-Adjustment-Factors>.

Sharp, B.H. and Cox, J.E. *Indoor-Outdoor Method for Measurement of Noise Reduction*, (Report no. DOT/FAA/TC-23/42). U.S. Federal Aviation Administration. <https://www.airporttech.tc.faa.gov/Products/Airport-Safety-Papers-Publications/Airport-Safety-Detail/indoor-outdoor-method-for-measurement-of-noise-reduction>

Sharp, B.H. and Cox, J.E. *Final Report on Field Validation of the Indoor-Outdoor Noise Reduction Measurement Method* (Report no. DOT/FAA/TC-24/43). U.S. Federal Aviation Administration.

2.3 Definitions

COMMUNITY NOISE EQUIVALENT LEVEL (CNEL): The community noise equivalent level (CNEL) is the energy average sound level over a period of 24 hours with a 5-dB adjustment to levels occurring between the hours of 1900 to 2200 and a 10-dB adjustment to levels occurring between the hours of 2200 and 0700.

DAY-NIGHT AVERAGE SOUND LEVEL (DNL): The day-night average sound level (DNL) is the energy average sound level over a period of 24 hours with a 10-dB adjustment to levels occurring between the hours of 2200 and 0700.

FAÇADE: A façade is one exterior side of a room in a building.

INDOOR-OUTDOOR NOISE REDUCTION (NR_{IO}): The noise reduction of a building façade as measured using an indoor loudspeaker together with sound level measurements inside and outside the building.

NOISE LEVEL REDUCTION (NLR): The noise level reduction (NLR) of a building façade is a single-number metric representing the difference between an A-weighted exterior aircraft noise spectrum and the corresponding A-weighted interior noise level in the room behind the façade.

OUTDOOR-INDOOR NOISE REDUCTION (NR_{OI}): The outdoor-indoor noise reduction (NR_{OI}) of a building façade is defined as the difference between the free-field sound pressure level, generated by an exterior noise source, that would exist at the exterior of the façade if the building and façade were not present and the sound pressure level in the room behind the façade. Noise reduction is measured and reported as a function of frequency in one-third octave or octave bands.

SOUND EXPOSURE LEVEL (SEL): The level, in decibels, of the time-integral of the square of the instantaneous A-weighted sound pressure for a specific period of time, such as the duration of an aircraft sound measurement, and relative to the reference sound exposure of $(20 \mu\text{Pa})^2(1\text{s})$.

2.4 Abbreviations

CNEL	Community Noise Equivalent Level, dB
DNL	Day-Night Average Sound Level, dB
NLR	Noise Level Reduction, dB
NR _{IO}	Indoor-Outdoor Noise Reduction, dB
NR _{OI}	Outdoor-Indoor Noise Reduction, dB
SEL	Sound Exposure Level, dB
SLM	Sound Level Meter

3. PART 1: AIRCRAFT FLYOVER MEASUREMENT METHOD

3.1 Overview of the Aircraft Flyover Measurement Method

The noise level reduction (NLR) of a building façade is determined by measuring the difference between the exterior and interior sound exposure levels (SELs) from an aircraft flyover.

Because the noise exposure differs for each aircraft flyover, it is necessary to conduct the measurements for a sufficiently large number of aircraft events in order to obtain a reliable average value of NLR. Statistical analysis is applied to establish an acceptable sample size to achieve a 95% confidence that the reported value of noise reduction is within ± 0.5 dB of the correct value (this usually requires at least 10 to 15 overflights).

Note that the data obtained are often representative only for the time of measurement as aircraft flight tracks and fleet mix may vary from hour to hour and day to day.

3.2 Equipment and Measurement Conditions

3.2.1 Measurement Equipment Specifications

Measurements of exterior and interior SELs require an integrated, time averaging sound level meter (SLM) instrumentation system meeting the Type 1 requirements of ANSI S1.43, which includes a 1/2-inch microphone and protective windscreen, or the Class 1 requirements of IEC 61672-1. The sampling interval for such a system shall preferably be 0.5 second but not greater than 1 second.

Calibration checks of the measurement equipment must be performed before the start and at the end of each set of measurements. The clocks on all SLMs must be synchronized daily with no more than a 2-second difference.

3.2.2 Windscreen

The measurement microphone shall be covered by an open cell foam windscreen to reduce the direct effect of moving air on the microphone and to protect the microphone from the environment, such as from dust or possible mechanical contact with hard objects.

3.2.3 Background Noise

Sound level measurements shall not be conducted in the presence of intermittent background noise sources, such as truck pass-bys, public address system announcements, lawn mowers, construction equipment, etc. Intermittent noise sources should be disabled where possible or measurements limited to time periods between background noise events.

3.2.4 Weather Conditions

Noise measurements should not be conducted when the wind speed exceeds 23 ft/s (15 mph).

3.3 Measurement of Exterior Sound Level

The exterior microphone should be positioned adjacent to the structure so that it is exposed to the entire aircraft flyover with no obstructions to interfere with the sound propagated from the aircraft. The microphone shall be placed at a height of 5 feet above the ground and located away from the structure and other structures as well as away from reflections from large objects or buildings to achieve as much as possible a free-field measurement. Alternatively, the microphone can be placed 5 feet above the roof of the test structure. Microphones should not be placed close to a busy roadway or other source of noise.

During the noise measurements, the operator should monitor the site from the outside to identify any contamination of the measured data due to non-aircraft events occurring at the same time as an aircraft event.

If noise event triggering is used, the trigger threshold should be chosen so that maximum sound levels during aircraft noise events are at least 10 dB above the threshold value. If this condition is not satisfied, the measurement is considered invalid.

3.4 Measurement of Interior Sound Level

The interior noise level in a room is determined by arithmetically averaging the individual sound level measurements made simultaneously at two locations within the room. The microphones should be mounted on tripods at different heights and positioned at least 2 feet from any major reflective surface, such as a wall, ceiling, or floor, and 2 feet from the center of the room. If open floor space is not available, the microphones may be mounted above soft furnishings, such as sofas, beds, soft chairs, etc., but not immediately above hard furniture, such as tables.

For the duration of the interior noise measurement, all exterior and interior doors shall be closed, all prime and storm windows in the test room shall be closed and latched with shutters opened, and all household noise sources must be temporarily deactivated during the measurements. This includes televisions, stereos, radios, ceiling fans, aquarium pumps, and ventilation systems in all rooms of the house. Pets and children should not be present in the test room. No speech should occur during the measurements. The microphones must not be placed close to household noise sources, such as ticking clocks or refrigerators, that cannot be deactivated. These noise sources will be quieter than the aircraft flyover but may be loud enough to accidentally trigger the measuring threshold of the sound level meter.

The setup of all microphones/tripods must be documented with photos of each location, together with a simple sketch. Photos of all rooms where microphones have been placed must document the room conditions for absorption and the condition of the elements in the rooms (windows, walls, exterior doors, roof/ceiling, or in-wall air conditioning units).

3.5 Determination of Noise Level Reduction (NLR)

The interior and exterior sound level data for each recorded aircraft event shall be examined to ensure that the maximum sound level for each event is at least 10 dB greater than the background sound level before and after the event. Events that do not meet this requirement should be removed from subsequent analysis.

The noise level reduction for the test room, NLR_i , for the i th aircraft flyover event is given by the following expression:

$$NLR_i = SEL_{ext,i} - SEL_{int,i} \text{ dB} \quad (\text{Eq. 1})$$

where:

$SEL_{ext,i}$ = SEL measured by the exterior microphone

$SEL_{int,i}$ = arithmetic average of the measured interior SELs for the same event

The average NLR for the test room, NLR_{av} , taken over N aircraft events, is then calculated by the expression:

$$NLR_{av} = \frac{1}{N} \sum_{i=1}^N NLR_i \quad (\text{Eq. 2})$$

In almost all situations, a minimum sample size, N , of 10 to 15 overflights is required to achieve a 95% confidence that the reported value of NLR is within ± 0.5 dB of the real value.

In performing the analysis, the measured data should be studied to identify any outliers, namely values of noise level reduction that appear to be inconsistent with the remainder of the data. If the reason for the outlier value can be determined, and it is a once-only occurrence, or the data belongs to a different population, then the outlier value should be deleted from the calculation of NLR_{av} . Examples would be a single turboprop aircraft event in a dataset of jet aircraft events or contamination of the interior sound level. If the cause cannot be identified, the analysis should be conducted with and without the outlier. If the conclusions are significantly different, then the outlier is influential and this should be noted in the report.

If there are multiple values that appear inconsistent, or if the standard deviation of the sample set is large, then the analysis should be conducted using the median value of the noise reduction dataset.

An alternative approach is to calculate the 95% confidence level after each flyover using a spreadsheet as the aircraft noise is measured and events are downloaded from the sound level meters. The data from each event are entered into a spreadsheet and the 95% confidence interval updated after each event until it reaches ± 0.5 dB. The spreadsheets that calculate the NLR must be saved and included as part of the documentation for each property.

3.6 Documentation

The documentation of the measurements shall include the following:

- Property address, geographical coordinates (optional), and description
- Exterior and interior building photographs and floorplan sketches
- DNL/CNEL contour zone value
- Weather conditions during tests - temperature, wind conditions
- Instrumentation
- Documentation of exterior and interior microphone locations
- Documentation of aircraft events - time, aircraft type, arrival/departure, runway end (optional)
- Measured SEL for each event for each microphone (exterior and interior)
- Process for determining NLR

All spreadsheets that calculate the NLR measurement results must be saved and included as part of the documentation for each property.

4. PART 2: OUTDOOR LOUDSPEAKER MEASUREMENT METHOD

4.1 Overview of the Outdoor Loudspeaker Measurement Method

The outdoor loudspeaker measurement method is designed to measure the noise reduction of a building façade using an external loudspeaker as the noise source. This measurement method is preferred over the aircraft flyover method as the repeatability of the measurements is increased by utilizing a controlled noise source. Research conducted at several airports has shown that this method leads to lower measured values of noise reduction and higher estimates of interior noise levels than the aircraft flyover measurement method, which includes the effects of shielding of some rooms from direct exposure to the aircraft flight path. The difference can be as much as 2 dB.

Specialized equipment as described in 4.2 is used to perform the measurements. A loudspeaker is used to generate the exterior sound exposure on the test façade. The height, distance to the façade, and angle of incidence of the loudspeaker are selected to ensure a uniform exposure over the entire façade (see 4.3). The level of the sound incident to the façade can be measured at the façade surface (see 4.4.2) or close to the façade (see 4.4.3), with adjustments applied to account for reflections from the façade. The incident sound level can also be determined using a calibrated loudspeaker (see 4.4.4), which eliminates the need to apply such adjustments.

The selection of the most appropriate method for measuring the exterior incident sound level will depend on the layout of the room to be tested and the external building environs and may differ from room to room within the building. Section 4.7 provides guidance on the selection of the most appropriate method suitable for application in different field situations.

The average interior sound level in the room behind the façade is measured by means of a volume or spatial average scan over the central portion of the room (see 4.5). The outdoor-indoor noise reduction (NR_{OI}) is then defined as the difference between the exterior and interior sound levels in each of the one-third or octave frequency bands. The NLR is a single-number metric representing the difference between an A-weighted exterior aircraft noise spectrum and the corresponding A-weighted interior noise level in the room behind the façade (see 4.8).

4.2 Equipment and Test Conditions

4.2.1 Measurement Frequency Range

Measurements of exterior and interior sound pressure levels and calculation of noise reduction shall be recorded in one-third octave bands from 100 to 2500 Hz, inclusive, or in octave bands from 125 to 2000 Hz, inclusive.

The single-number NLR metric for most structures exposed to aircraft noise is determined largely by the values of noise reduction in frequency bands from 100 to 1000 Hz, which is termed the main frequency range of interest.

4.2.2 Loudspeaker Specifications

The loudspeaker used to generate the exterior sound field at the test façade should be a compact, single-unit system capable of generating an overall sound pressure level of at least 110 dB overall, and 105 dB A-weighted, measured in the free-field at 3 feet (0.91 m) on the main axis of the loudspeaker diaphragm over the frequency range 100 to 2500 Hz.

The frequency and directivity specifications of the loudspeaker shall be as follows:

- Output spectrum measured on axis should vary no more than ± 3 dB from 63 to 2500 Hz.
- Horizontal (azimuthal) directivity (-6 dB): ± 45 degrees at 1000 Hz.
- Vertical (elevation) directivity (-6 dB): ± 45 degrees at 1000 Hz.

For measurements of noise reduction using a ground-level loudspeaker mounted on its side, the width of the loudspeaker cabinet shall be such that the centers of the loudspeaker cone and high-frequency horn are no greater than 9 inches above the ground surface.

The electrical input signal to the loudspeaker shall be random noise with equal energy per frequency band (i.e., pink noise), and the operator shall ensure that the output remains constant throughout the test period.

4.2.3 Instrumentation Specifications

Measurements of exterior and interior sound pressure levels require an integrated, time averaging instrumentation system meeting the Type 1 requirements of ANSI S1.43, which includes a 1/2-inch microphone and protective windscreen, or IEC 61672-1.

Calibration checks of the measurement equipment must be performed before the start and at the end of each set of measurements.

4.2.4 Windscreen

The measurement microphone shall be covered by an open cell foam windscreen to reduce the direct effect of moving air on the microphone and to protect the microphone from the environment, such as from dust or possible mechanical contact with hard objects.

4.2.5 Background Noise

Sound level measurements shall not be conducted in the presence of intermittent background noise sources, such as aircraft flyovers, truck pass-bys, public address system announcements, lawn mowers, construction equipment, etc. Intermittent noise sources should be disabled where possible or measurements limited to time periods between background noise events. Corrections for steady levels of background noise should be applied in accordance with the procedures described in 4.6.

4.2.6 Weather Conditions

Measurements should not be conducted when the wind speed exceeds 23 ft/s (15 mph).

4.3 Loudspeaker Configuration

4.3.1 Background

The location of the loudspeaker noise source shall be selected to provide an external sound field that is as uniform as possible over the entire surface of the façade(s) of the room to be tested. The parameters that affect uniformity are the distance from the façade, the angle of incidence relative to the perpendicular to the surface of the façade, and the loudspeaker height above the ground.

4.3.2 Loudspeaker Distance and Angle of Incidence

The distance of the loudspeaker to the façade and the angle of incidence determine the variation of the sound level over the façade due to variation in the propagation distance to different points on the façade. The variation of sound level will depend on the ratio of the loudspeaker distance to the lateral dimension of the façade - the larger this ratio, the lower the variation.

Loudspeaker placement starts with selecting the distance from the center of the façade and the horizontal angle of incidence (the angle with the perpendicular to the façade) based on the width of the test façade using the design chart shown in Figure 1. Note that the distance derived from the chart in Figure 1 is the minimum distance of the loudspeaker from the center of the façade. Larger distances than the minimum may be used for situations where loudspeaker positioning is difficult, provided that the interior sound levels can be maintained as required in 4.6.

As an example, if the width of the test façade is 15 feet, then a maximum variation of 3 dB would be achieved with a loudspeaker distance of 30 feet at an angle of incidence of 45 degrees. If the available distance is limited to 22 feet, then the angle of incidence should be reduced to 35 degrees to maintain the same sound level variation over the test area.

Best practice is to select the maximum distance possible, consistent with achieving the required signal-to-noise ratio in the room interior, at an angle of incidence of 45 degrees. Measurements at distances less than 10 feet are not recommended as the uniformity of the sound level over a typical façade begins to decrease more rapidly at these distances as the result of changes in loudspeaker directivity. Exceptions to this rule are allowed when space is limited (see 4.7.1.1).

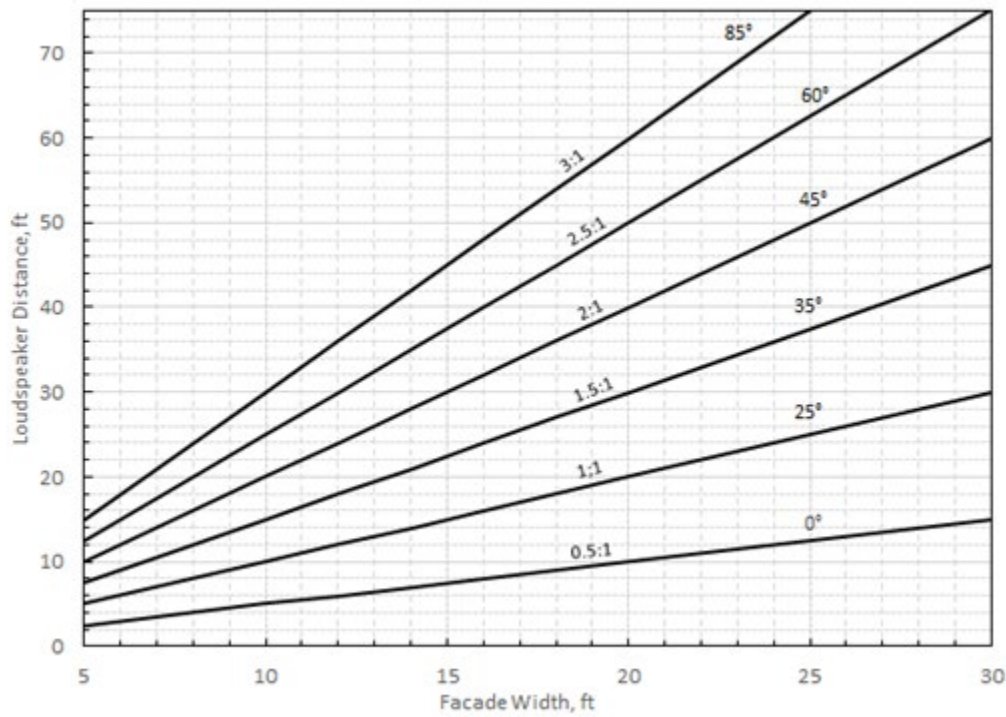


Figure 1 - Design chart for determining the minimum loudspeaker distance to façade center and angle of incidence to achieve a maximum variation of 3 dB over a façade surface

In situations where local conditions restrict the location of the loudspeaker, the alternative method using an indoor loudspeaker as described in Section 5 should be considered.

4.3.3 Loudspeaker Height

The loudspeaker height determines the frequency at which the ground reflection interference with the direct propagation path occurs. Sound level uniformity over the façade is accomplished by selecting the loudspeaker height such that the interference frequency is either below or above the main frequency range of interest, namely 100 to 1000 Hz.

Best practice is for measurements of noise reduction to be performed with a loudspeaker placed on the ground. If the ground slopes from the building, the loudspeaker may be lower than the test façade. In practice, it is necessary to lay the loudspeaker on its side to approximate a ground source such that the center of the diaphragm is no greater than 9 inches above the ground surface.

Alternatively, the loudspeaker can be mounted on a tripod at a height of not less than 10 feet. This may be necessary in situations where it is impractical to place the loudspeaker on the ground or when it is necessary to increase the signal level at the test façade. Measurements of noise reduction for structures where roof transmission may be important may also require a loudspeaker height of 10 feet (see 4.7.6).