



AEROSPACE RECOMMENDED PRACTICE

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(R) Acoustical Considerations for Engine Test Cells

RATIONALE

This SAE Aerospace Recommend Practice has been revised. This document has been updated to include changes and advancements in acoustic modeling and code requirements. In recent years, there has been increased emphasis on managing sound emissions and exposure that people have to audible and inaudible noise levels in the workplace and at home. This update also addresses mitigation of an unknown source of foreign object damage in the jet engine test cell.

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1. SCOPE

1.1 Purpose

This document discusses, in broad and general terms, the subject of acoustical considerations in engine test cells. One of the primary purposes of an engine test cell is to control the noise emanating from the operating engine in order to reduce noise in the surrounding facility and community to acceptable levels. This is done by the design and installation of specialized acoustic elements and features, which need to be fully integrated into the overall test cell design. It should be further noted that the requirements of acoustic control are critical to the proper operation of the engine, safety of plant equipment and personnel, and meeting local and legal noise requirements.

1.2 Beneficiaries

This document is a compilation of input from several test cell designers, operators, and users that summarizes the best practices and recommendations from these experts. This document is intended to benefit operators and owners of engine test cells who are contemplating new facilities, refurbishment of existing facilities, and addition of new engine models to existing facilities. It is intended to aid these owners in understanding the basic terms, regulations, and concerns with engine test cell acoustics. It is not intended that this document be an exhaustive design guide that any owner or contractor could independently accomplish the task of test cell acoustic design and installation. Rather, it is intended to provide a basic knowledge and understanding to operators and owners in the selection and evaluation of acoustic designs and contractors.

1.3 Considerations and Consequences of Improper Acoustic Design/Installation

When choosing a contractor for the design and installation of an acoustic solution for an engine test cell, potential risks and loss of productivity should be carefully considered. The consequences of an improperly selected, designed, or installed acoustic system can greatly vary in scope and impact to the customer. Schedule loss can impact and delay the facility ready for operation scheduling. Operational loss can directly create financial and reputation loss due to lost operation and test time for the backlog of engines ready for test. Physical loss can cause loss of life of personnel, engine equipment, and surrounding facilities. Financial loss ties in with all of the above where those causes create a financial loss effect.

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 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (U.S. and Canada only) or +1 724-776-4970 (outside U.S. and Canada), www.sae.org.

AIR4827	Physical Modeling Techniques for Jet Engine Test Cell Aerodynamics
AIR4869	Design Considerations for Enclosed Turbofan/Turbojet Engine Test Cells
AIR4989	Design Considerations for Enclosed Turboshift Engine Test Cells
AIR5303	Infrasound Phenomenon in Engine Test Cells

2.1.2 BSI Publications

Copies of these documents are available online at www.bsigroup.com.

BS 4142	Methods for rating and assessing industrial and commercial sound
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2.1.3 DIN Publications

Copies of these documents are available online at www.din.de/en.

DIN 45680 Measurement and Assessment of Low-Frequency Noise Emissions

2.1.4 ISO Publications

Copies of these documents are available online at www.iso.org/store.

ISO 7196 Acoustics - Frequency-Weighting Characteristic for Infrasound Measurement

2.2 Definitions

ACOUSTIC ELEMENT: Any major assembly, component, or subcomponent of the equipment in the test cell that is used for acoustic control of noise in a test cell.

AUDIBLE SPECTRUM: Acoustic energy in the frequency range normally heard by the human ear. In test cell acoustics, this is normally from 20 to 20000 Hz.

BAFFLE: An acoustic element, normally installed directly in the test cell airstream, intended to attenuate acoustic noise. Baffles are most usually metal structures filled with acoustic absorbing material.

DECIBEL: A unit of measure of the loudness or intensity of noise.

dB: Abbreviation for decibels.

dBA: Abbreviation for decibels adjusted. A measure of the absolute noise power weighted to the sensitivity of the human ear.

DBG: Unit of measure for infrasound.

FOD: Abbreviation for Foreign Object Damage. Loose materials, unsecured hardware, and debris that could be ingested by an engine.

HERTZ: Unit of measure of frequency equal to 1 cps.

Hz: Abbreviation for hertz.

INFRASOUND: Acoustic energy with a frequency below what the human ear can normally hear. Usually defined as between 0 and 20 Hz.

OSHA: Abbreviation for U.S. Occupational Safety and Health Administration.

SOUND POWER LEVEL (Abbreviation PWL): The sound power level of a source is expressed in decibels (dB) and is equal to 10 times the logarithm to the base 10 of the ratio of the sound power of the source to a reference sound power. The reference sound power level in air is normally taken to be 10^{-12} W.

$$\text{Sound Power Level} = 10 \log_{10} \frac{(\text{sound power})}{(\text{reference power})} \quad (\text{Eq. 1})$$

where:

reference power = 10^{-12} W

SOUND PRESSURE LEVEL (SPL): The sound pressure level of a source is expressed in decibels (dB) and is equal to 20 times the logarithm to the base 10 of the ratio of the sound pressure of the source to a reference sound pressure. The reference sound power level in air is normally taken to be $2 \times 10^{-5} \text{ N/m}^2$.

$$\text{Sound Pressure Level} = 10 \log_{10} \frac{(\text{sound pressure})^2}{(\text{reference pressure})^2} \quad (\text{Eq. 2})$$

where:

$$\text{reference pressure} = 2 \times 10^{-5} \text{ N/m}^2$$

3. ALLOWABLE NOISE LIMITS

One of the most commonly misunderstood concepts about test cell acoustics is: "What is the normal (or standard) allowable noise limit from a test cell?" In reality, there is no uniform, regulated, national, or international standard for allowable noise from a test cell. In practice, the test cell owner and acoustic contractor must establish the agreed-upon noise level from the test cell in full consideration of myriad sources. It should be noted that in some cases, and in some locations, little or no regulations may exist. Due diligence is required to research and establish the noise limit criteria based on all applicable ordinances or regulations.

3.1 Test Cell Noise Regulations

3.1.1 Test Cell Location

The first consideration is the location and site of the test cell. Is the test cell on extremely remote land where noise regulations do not exist? If a remote location, will future land development in the surrounding area be a factor? Is the test cell to be located on airport property? In an industrial park? Near a residential community? Near a wildlife refuge? Near agricultural animals? Near other office buildings or facilities? Near a property line? Near sensitive or precision manufacturing facilities? Answers to these questions will be the first step to identify any and all applicable ordinances or regulations.

3.1.2 Local Airport or Industrial Park Regulations

In the case of test cells built on airport property (the most common location), the first source for establishing the allowable test cell noise and any physical height restrictions is the local airport regulations. If such regulations exist, they may establish the allowable noise, from any source, that may impinge on other facilities or locations on the airport property. They may also establish the allowable noise, from any source, at the property line. Regulations on maximum building height elevations will also often drive an acoustic design as well as drive the location of the test cell stacks on the property. Consideration and provision should be allowed in the design to be able to comply with possible future changes in local ordinances. Provision for adding more acoustic treatment to an existing building design can account for this future proofing for new ordinances. Periodic acoustic surveys and testing may be required by local ordinances.

3.1.3 Local Community Ordinances

Many residential communities may have established local ordinances that limit the noise from sources within, or adjacent to, the community. In some cases, there may be different noise limits for daytime or nighttime, from fixed or mobile sources, or for limits on the duration of the noise.

An area of concern with some local ordinances may be in the fact that the noise requirements are lower than the background noise, such as highway or aviation traffic in the vicinity of the facility. This poses a difficulty in evaluating the noise performance of the test cell to assure compliance, as the background noise must be eliminated or filtered out to collect meaningful noise data from the test cell.

3.1.4 AICUZ - Air Installations Compatible Use Zones

To balance the needs of aircraft operations and community concerns, the goal of the Department of Defense's (DoD's) Air Installations Compatible Use Zones (AICUZ) is to protect the health, safety, and welfare of those living near military airfields while preserving the defense flying mission. The AICUZ guidelines define zones of high noise and accident potential and recommend uses that are compatible within these zones. Local planning agencies are encouraged to adopt these guidelines.

3.1.5 OSHA - Occupational Safety and Health Administration

The U.S. Occupational Safety and Health Administration established a number of guidelines regarding noise, primarily to protect the health of personnel. The OSHA guidelines are used primarily in and around the test cell rather than noise radiated to the community. Often, the OSHA requirements can be met by design of the test cell, the use of hearing protection devices, or both.

3.1.6 HSE - Health and Safety Executive

The British Health and Safety Executive established a number of guidelines regarding noise, primarily to protect the health of personnel. The HSE guidelines are used primarily in and around the test cell rather than noise radiated to the community. Often, the HSE requirements can be met by design of the test cell, the use of hearing protection devices, or both.

3.1.7 Company Standards and Regulations

Many companies have their own requirements and regulations regarding construction, employee health and safety (EH&S), security, etc. In addition, many companies have regulations or recommendations levied by their insurance carriers and underwriters. All these requirements and recommendations must also be taken into account in the planning, contracting, and design of test cells and test cell acoustic systems.

3.2 Usual Industry Practice for Noise Reduction Standards

In the absence of governing local or community regulations, there have been a considerable number of test cells constructed over the last 40 years that have struck a balance between noise reduction and cost. These test cells have been constructed, and acoustic elements installed, which provide a generally accepted adequate noise reduction with minimal disturbance or nuisance to neighbors or operating personnel.

This baseline test cell noise performance, in the audible range, is 75 dBA at a radius of 75 m (246 feet) from the test cell. In the absence of regulated noise levels, this has been an acceptable noise level at many test facilities. Noise inside the facility is generally considered acceptable at 70 dBA in the control room, 75 dBA in the center of the adjacent preparation room/building, and 70 dBA or less in other occupied spaces of the facility.

3.3 Infrasound

There currently are very few regulations of any kind regarding infrasound. Infrasound is sound vibrations that are below the normal human hearing range. Its effect is felt rather than heard, often in the rattling or vibration of nearby structures or buildings or by a general nausea or uneasy feeling in some people. Considerable studies are being done by a number of organizations to study the causes and effects.

Infrasound is often measured in dBG in accordance with ISO 7196, which weights levels in certain frequency bands to which the human body is susceptible to.

Very few local communities have written infrasound provisions into their noise ordinances. Those that have are often misunderstood or misinterpreted or very restrictive to test cell construction.

There is no widely accepted standard or baseline infrasound performance in test cells. This is partially because the measured infrasound levels cannot be easily correlated to an acceptable or unacceptable level of annoyance from infrasound vibrations. Therefore, it is difficult to write a regulation or specification to specific, measurable, infrasound levels, making it very difficult to establish contractual responsibility or liability for infrasound.

DIN 45680 is a European standard that defines threshold limits for infrasound. These limits are applied in various test cells across Europe and are recommended only when stricter infrasound control is necessary.

The reader should refer to AIR5303 for more information on the infrasound phenomenon in engine test cells.

3.4 Perceived Noise Sensitivity and Susceptibility

It must be noted that different people are more or less sensitive to noise than others. What some people find acceptable, others may find objectionable. This sensitivity may be to different noise levels or even different frequencies. Many test cell owners/operators find that they are in compliance with all local and required ordinances, but they may still receive complaints from local residents or neighboring businesses.

Test cell owners/operators may well be advised to be knowledgeable about noise regulations, noise issues, and noise control technology when planning engine test cell installations. Then they should execute a plan of education and public relations to inform the neighboring public of the plans, regulations, all steps taken to control noise, and expectations.

4. BASICS OF TEST CELL NOISE AND NOISE REDUCTION

4.1 What is Sound?

All things that move (if they don't move too slow or too fast) make sound.

As things move, they "push and pull" at the molecules of the surrounding air (or the water or whatever medium they occupy), causing pressure variations (compressions and rarefactions). Those pressure variations, which propagate as sound waves, are what we hear as sound.

4.2 What is Noise?

Simply put, noise is unwanted sound.

4.3 Turbofan Engine Noise

Turbofan engine noise sources principally come from the fan (including the stator), the exhaust nozzle (also referred to as the jet noise), the compressor, the combustor, and the turbine.

Fan noise is a strong function of the rotational tip speed and fan pressure ratio. When the rotating fan blades impinge on the air entering the inlet of the engine, the fan creates the characteristic "buzz saw noise" often heard in jet engines when the fan tip Mach number exceeds 1 (supersonic). When the fan tip speed is under Mach number 1 (subsonic), broadband fan noise becomes dominant, and the source of this noise is the turbulence in the fan wakes striking the stators and the resulting unsteady pressure field that becomes acoustic waves and radiates from the engine fan duct.

Jet noise is generated outside of the exhaust nozzle. High-frequency noise is generated by the small-scale eddies near the nozzle. Low-frequency noise is generated by large-scale turbulence further downstream.

Finally, a small component of the overall engine noise is produced by the turbomachinery of the engine, such as compressor, combustor, and turbine. As gears, shafts, and bearings all move against each other, vibrations are set up that produce tonal and broadband noise.

The typical noise produced by a turbofan engine can be 110 to 140 dBA at the engine source. Noise levels generated by a turbofan engine inside a test cell typically range from 110 to 150 dBA. Some afterburning engines can produce up to 150 to 180 dBA or even higher.