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DESIGN AND CONSTRUCTION CONSIDERATIONS FOR AUTOMOTIVE AND AUTOMOTIVE COMPONENT ACOUSTIC TEST FACILITIES

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Abstract

The topic of this paper is the complete system design consideration necessary to meet the testing requirements for automotive NVH applications including engineering data for Anechoic and Hemi-Anechoic Chambers.

Different design criteria must be established so that the facility design takes into account all elements of the client's testing needs. A detailed checklist is compiled that contains all issues that must be addressed to ensure the highest levels of performance and accuracy.

Engineering and design considerations will focus on the following areas: attenuating structures (enclosures), anechoic wedges, doors, windows, working floors, vibration isolation systems, ventilation, silencers, lighting and electrical systems, instrumentation hangers and penetration sleeves.

1. Introduction

Acoustic test facilities for automotive applications must integrate the principle structural aspects of the Test Chamber with its operating systems and auxiliaries to provide the noise reduction to meet interior ambient noise level requirements as requested by the user. Interior acoustical characteristics shall conform to the requirements of ISO 3746 and ANSI 12.35 1990 (R1996) testing standards.

2. Attenuating Structures

To simulate a free field, which is needed for the accurate measurement of directivity and sound power for diagnosing the contribution of the different parts of the equipment to the total noise radiation, the anechoic wedges are installed on the interior surfaces of the enclosure. The purpose of the sound attenuating enclosure is to prevent noise from the exterior entering the enclosure proper. The enclosure may be one of several types of construction which may be built on an existing floor, floated on springs or other vibration isolation material, or onto a floor into which has been integrated a chassis roll dynomometer or other test fixture. Other sound attenuating structures located inside the room may be employed to enclose dynomometers used for engine and drive-train testing. Masonry room enclosures are the usual type of construction found in existing buildings or when the anechoic facility is planned as an integral part of a new building. A desirable type of enclosure is the panelized room that is usually built of 4" thick modular acoustic panels. The advantage of the panel room is that it can be completely prefabricated in the factory and can be quickly erected in the field and dismantled and re-erected without loss of any part of the original enclosure structure. Single wall modular panel enclosures will satisfy most sound isolation requirements. However, in some instances, additional noise reduction is needed and a double wall will be necessary. (Noise reduction data as follows)

Noise Reduction Data
Single Wall Panel Room

Measured noise reduction through a 4” Acoustic Panel Anechoic Chamber

Frequency Hz	62.5	125	250	500	1000	2000	4000	8000
Noise Reduction dB	25	38	58	59	60	62	64	55

Noise Reduction Data
Double Wall Panel Room

Measured noise reduction through a 4” Acoustic Panel and 8” Masonry Wall

Frequency Hz	62.5	125	250	500	1000	2000	4000	8000
Noise Reduction dB	45	59	80	90	92	95	90	90

3. Key Operational Elements

Incorporated into the attenuating room enclosure structure are the key elements of the chamber: the interior sound absorbing wall treatment; wedge lined access doors; windows; working floor; vibration isolation; ventilation; silencers; lighting and electrical systems along with other utilities including such things as closed circuit televisions, fire suppression systems, instrument hangers and penetration sleeves and penetration silencers. All these elements must be coordinated to achieve the vibration isolation , noise reduction and interior room performance outlined in current ISO and ANSI standards.

Chamber Interior Performance Standards
ISO 3745 – ANSI 1235 1996 (R1996)

Maximum Allowable Variations From Inverse Square Law

Frequency 1/3 octave Band	< 630 Hz	200 Hz to 5000 Hz	> 6300 Hz
Hemi- Anechoic	+/- 2.5	+/- 2.0	+/-3.0
Anechoic	+/- 1.5	+/- 1.0	+/-1.5

The vast majority of test chambers used in automotive applications are Hemi-Anechoic Rooms to accommodate a full vehicle or component system such as a transmission, steering gear or other vehicle component as shown in Figs. 1 and 2.

Fig. 1
Vehicle Hemi Anechoic Chamber -BMW SC.

Fig. 2
Component Hemi Anechoic Chamber -Nacam KY

Full Anechoic Chambers have been constructed for vehicle testing in the past as shown in the Figs. 3 and 4. However, they are more commonly used for component testing today where a full anechoic environment is needed with sound absorbing treatment on the floor as well as the walls and ceiling.

Fig. 3
Old Full Anechoic Chamber, Ford Motor Co. 1958

Fig. 4
Anechoic Chamber With Cable Floor System.
Johnson Controls.

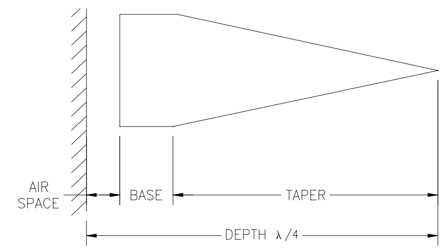
4. Wedges

The basic dimensions and physical characteristics of wedges were initially worked out in the United States at Cruft Laboratory, Harvard University in 1942, under a grant from the office of Scientific Research and Development. The data was published in ORSD Report No. 4190 and in the Journal of the Acoustical Society of America, July 1946 "The Design and Construction of Anechoic Sound Chamber"[1]

[1] [1] Leo L. Beranek et al "The design and construction of anechoic sound chambers", J. Acous. Soc. Of America, Vol –18 NO. 1 PP 140-150 July 1946

authored by Leo L. Beranek and Harvey P. Sleeper, Jr. While this data is still basically correct, some modifications in the base and taper dimensions had been required to adjust the impedance of the wedge unit for the presently available fibrous sound absorbing materials to accomplish the desired cut-off. Construction or mounting considerations have also been factors in the design dimensions of the wedge unit. The final wedge design should be determined experimentally in an impedance tube (per ASTM C384-90A) where the fixed design parameters can be duplicated and variable parameters such as the airspace, bases and taper dimensions adjusted for optimum performance.

Fig. 6 Typical Depth of Anechoic Wedge Treatment vs Low Frequency Cut – Off for Automotive Applications



Low Frequency Cut Off	Air Space	Base	Taper	Overall Depth Of Treatment
80 Hz	3.9”	6.7”	31.8	42.4
100Hz	3.1”	5.4”	25.4	34
125 Hz	2.5”	4.3”	20.3	27
150 Hz	2.1”	3.8”	17	22.6

Various materials have been used for the interior acoustical treatment in Hemi-Anechoic and Anechoic Chambers. The wedge type of sound absorbing wall treatment, shown in Fig. 5A, is the most common, utilizing fiberglass, mineral wool or urethane foam as the sound absorbing material covered with fiberglass cloth, hardware cloth, or perforated metal to encapsulate the acoustic fill. For automotive applications the newer perforated metallic wedge designs, shown in Fig. 5B, have become the most popular. Typical dimensions of such wedges are given in Fig . 6.

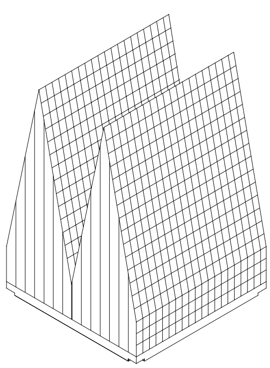


Fig. 5A
Original fiberglass wedge with cloth or hardware cloth mesh cover.

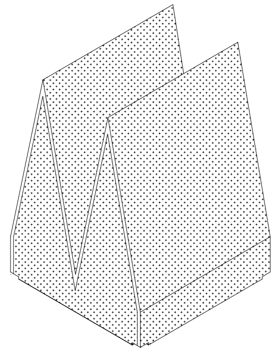


Fig. 5B
Perforated metal wedges have been developed for use in anechoic chambers. EMW metallic wedge shown is available from Eckel Industries, Inc.

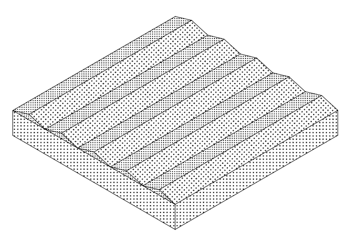


Fig. 5C
“Free Field” acoustic liner panel treatment, perforated metal face, 4” or more fiberglass fill and air space.

Other acoustical wall treatments have been developed for vehicle and component tests. These are known as compact panel absorbers or “Free Field” acoustic liner panels, shown in Fig. 5C. They utilize a perforated metal facing or laminated acoustic foam construction. Generally, these designs are of interest where the desired cut off frequency is 200 Hz or higher or where the room is a very large size and the anechoic wedge treatment becomes too expensive. Figs. 7 and 8 show chambers with free field acoustic liner panels.

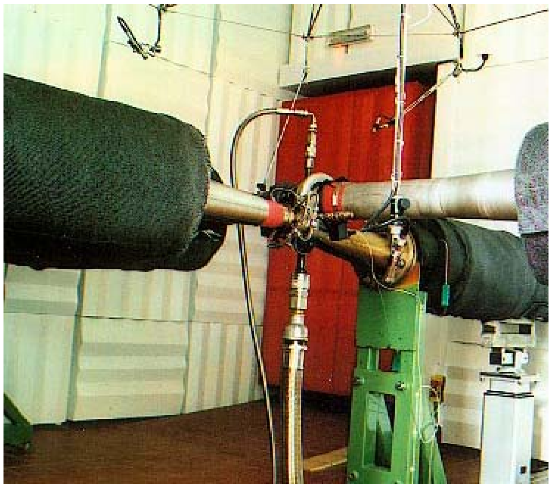


Fig. 7
Compact Absorber Chamber Holset Engineering – U.K.

Fig. 8
Large Free Field Chamber, York International PA. U.S.A.

5. Doors

The entrance door or doors to an Anechoic or Hemi-Anechoic Chamber should provide the same relative noise reduction as the structural portion of the chamber. On the inside of the chamber, the presence of a door should not compromise the anechoic qualities.

As shown in Fig. 9, single wall enclosure chambers, the pair of sound attenuating doors are usually installed so that the exterior sound doors swing outward and the interior cage doors swing open to the inside of the chamber and it contains anechoic wedges in its cage frame. In some Anechoic Chamber installations, the sound attenuating door and wedge door are combined into one unit, which swings inward. In double walled chamber construction, a heavy-duty sound attenuating door is installed in the outer wall structure and swings outward. The inner attenuating door is normally combined with the wedge door and swings inward.

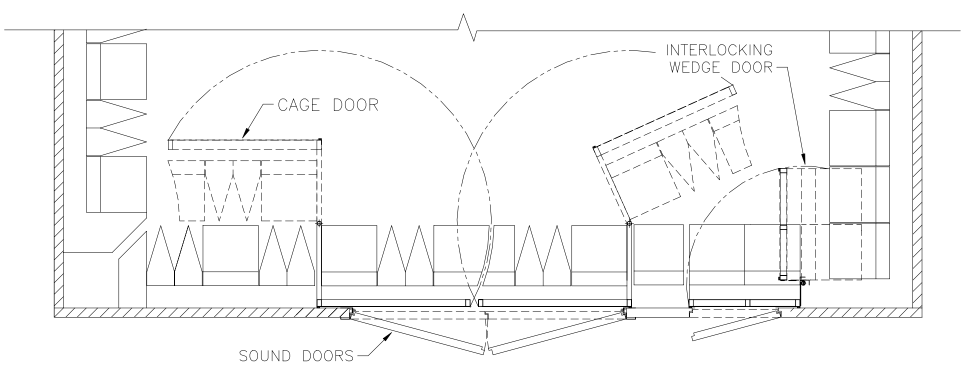


Fig. 9
Double In-Swing Cage Door w/Interlocking

Within the Anechoic Chamber, a most desirable entry way is provided by an interlocking wedge door on which all the wedges are installed with the dihedrals set in a horizontal direction and are offset one half wedge thickness from the similarly disposed wedges on the adjacent wall. The interlocking wedge door is pivoted on hinges in line with the bottom of the wedge taper. When the inner door is fully opened to access the chamber, the door wedges interlock with those mounted on the adjacent wall, resulting in a minimum of lost space in the chamber. Where the wedge door cannot be located adjacent to a side wall, the wedges are installed in a fabricated steel cage or frame pivoted at an outer corner so that the wedge cage rotates 180 degrees to provide a full opening into the chamber. Where wide openings are required, a combination of the interlocking wedge door and the cage or two pivoted cages must be provided.

6. Working Floors

Hemi-Anechoic Chambers incorporate the floor of the attenuating structure as its working floor. The floor of the chamber and isolation system are usually recessed into the floor of the surrounding structure so that the chamber floor and surrounding floor are flush. In some instances, the floor system will incorporate a dynomometer or other major test system component. In these cases, the floor design should be incorporated in the overall facility design taking into account the nature of the facility. It is good practice to retain a qualified engineer and design firm to coordinate this integration of the other elements of any major new construction project. When anechoic chambers used for testing the sound radiation of equipment, that generate large vibration forces at their mounting point they may require a foundation that is structurally separated from the chamber floor. For existing buildings, a chamber may be purchased directly from one of several experienced and qualified suppliers who use a floor design with integral vibration isolation. Floors may be constructed of reinforced steel panels or steel-reinforced concrete. The vibration isolation system is designed to achieve the specified isolation, typically the resonance frequency 3 - 5 Hz for steel spring isolation systems and 1 Hz for air spring systems.

Full Anechoic Chambers always require that their working floor is separate from that of the enclosure. Since the nature of anechoic wedges is such that they have limited structural strength and cannot support load, a working floor must be provided above the top of the wedge points. There are two types recommended for general use: spring tensioned cable floors and expanded metal grating floors.

Expanded metal or honeycomb working floors should be removable so that only those parts of the floor, which are necessary to support the test equipment, remains in place during testing. Floor gratings are supported from posts set between the joints of the floor wedges. Posts must be stabilized to maintain uniform spacing. A catch screen should be provided between the tops of the wedges and the working floor. This screen will prevent dropped articles from falling into the valleys of the wedges and make them easier to retrieve. Fiberglass or nylon insect screening may be used for this purpose.

7. Auxiliaries

Auxiliaries, including electric lighting and power, must be integrated into the chamber along with a properly designed and silenced ventilation system.

Electric lights should be incandescent and should always be installed to comply with local or underwriter's approved regulations. Electric light conduits usually penetrate the wedge structure through the valleys and terminate in the socket without a reflector that results in a minimum of hemispherical surface of the bulb to extend below the ceiling wedge points. (See Fig. 10C) Flood lights are very satisfactory for anechoic chamber service. Electrical outlets can be provided in a similar fashion in the chamber walls with outlet boxes connected to conduit through the valleys of the wall wedges. Instrumentation hangers and pipe sleeve penetrations can be incorporated in the wedges in a similar way.

In all Anechoic Chambers provisions should be made in the ceilings, and in some cases in the walls, for the installation of hangers or brackets to support instrumentation or test specimens (see Figs. 10A and 10B) or to provide for a network of cable or wires which may divide the room into coordinates or provide support for instrumentation.

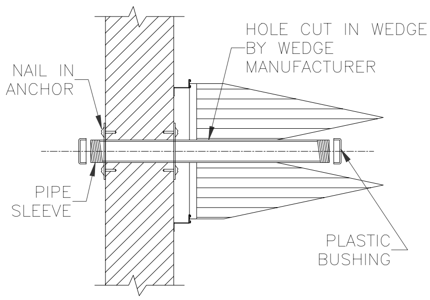


Fig. 10A Instrument Sleeve

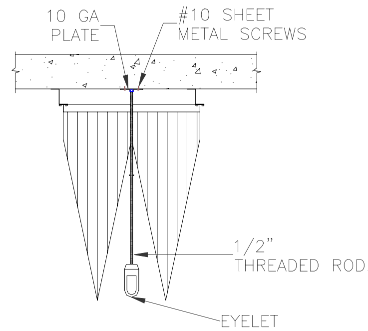


Fig. 10B Instrument Hanger

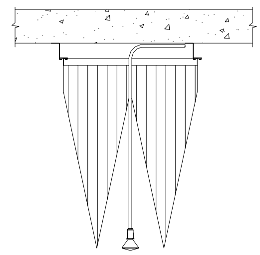


Fig. 10C Light Detail

Pipe sleeves through the basic structure and through wedges are the conventional means of bringing introducing power, instrumentation or communication wiring and other services into the chamber. Pipe penetrations should be carefully planned so that they enter the chamber through the valleys of the wedges and not the joints between the wedge units.

8. Ventilation

Ventilation is needed in Anechoic Chambers to:

1. Maintain a uniform temperature
2. Provide fresh air for the maintenance of humans or animals, or combustion requirements for air consuming equipment
3. Remove heat from lights, mechanical and electrical equipment and body heat from personnel

Ten to twelve air changes per hour of the free field volume will generally maintain temperature, provide ample fresh air for occupants and remove heat from lights, body radiation and instrumentation. Where large quantities of heat are to be dissipated the volume of ventilation air must be determined and provided accordingly.

Air is introduced and removed from the chamber through specially designed "ventilation wedges". Air velocities of up to 250 fpm through the ventilation wedges usually will not generate excessive noise.

As shown in Fig. 11, air entering or leaving a ventilation wedge unit passes through the wall or ceiling plenum which customarily incorporates a silencer. All silencers, including the distribution plenums, should have attenuating jackets to prevent exterior noise into the chamber from flanking through the casings. Attenuating jackets are vibration isolated from and have no mechanical connections to the basic silencer inner casings. The specific path of the air flow in the chamber is determined by functional requirements. Cool air is normally introduced near the floor line and warm air exhausted at or near the ceiling. Supply and exhaust wedges should be located at opposite ends of the room to make the air flow to traverse the room. When heavier-than-air gases are encountered, air is introduced high and exhausted at the lowest possible level.

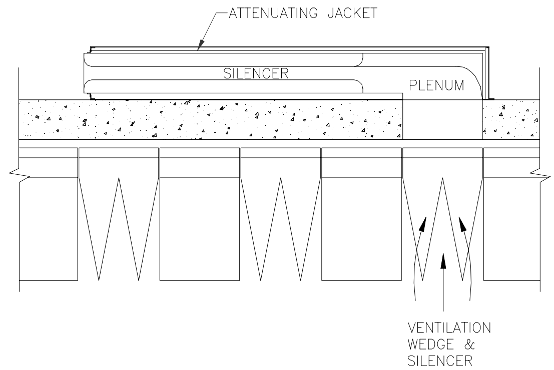


Fig. 11 Typical Air Path

9. Conclusion

The successful integration of the various elements of the design and construction of the Anechoic Chamber will take into account the end user's specific needs. These should included the required low frequency cut-off of the anechoic wedge lining and the frequency spectrum of interest as well as the maximum allowable internal ambient noise levels, adequate vibration isolation and a silenced ventilation system. The chamber must have ample free field dimensions to accommodate the test specimen and sufficient space to make measurements according to the governing test standards.

The completed structure shall be tested to verify that it meets the requirements of the prevailing standards for the precision methods for determining sound power levels of noise sources in Anechoic and Hemi-Anechoic Rooms (ANSIS12.35 - 1990 (R1996) or ISO 3745). The test report should include the graphic plots and the measured level versus distance data at all frequencies for each specific microphone traverse to verify that the chamber qualifies to be within the maximum deviations (from the inverse square law) allowed by the standard.