A DESIGNED TEST PERFORMANCE OF KNOCK DOWN AUDIOMETRIC TEST BOOTH

TUKSIN SOONTORN

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Thesis
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A DESIGNED TEST PERFORMANCE OF KNOCK DOWN AUDIOMETRIC TEST BOOTH

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ABSTRACT

The objective of this study was to study the design effectiveness of the knock down audiometric test booth. The designed components of the booth are 28 inches deep, 38 inches wide, and 61 inches high. It has 7 parts of knock down and each part is composed of layers : 0.03 inch thick steel being the outermost layer, then a layer of 2 inch thick polyurethane foam, followed by a layer of 1/4 inch thick plywood and finally a layer of 0.03 inch thick perforate steel.The door frame is L-shape steel. The plenum chamber silencers are 10 inches deep, 12 inches wide, and 50 inches high with 1 inch fiberglass lining on the inner side of the wall. The inside plenum chamber silencer consists of four parallel baffles(inlet), three parallel baffles(outlet) and the thickness dimension of each baffle is 1 inch. The method used to measure the noise reduction accordance from ASTM E596-96.

The results of the study were that the knock down audiometric test booth had sound transmission class(STC) = 21 dB. The comparison test of octave band noise reduction of the knock down audiometric test booth was performed ten times and showed no significantly different.(p-value = 0.018 – 1.0) The octave band sound pressure level inside the knock down audiometric test booth at 125 Hz exceeded OSHA standards(p-value < 0.001), but octave band frequency 250-8,000 Hz did not exceed than OSHA standards(p-value<0.001) The volume of air supply was 25.4 – 32.71 Air change per hour.

The knock down audiometric test booth with ventilation system enabled the reduction of noise in accordance with the criteria of audiometric testing in the field. The volume of air supply in the test booth was sufficient for comfort of the subjects. The limitations of this study depended upon the designed material which could not reduce the interference noise, particularly at low frequencies. Therefore, it is recommended that further studies concentrate on other types of polyurethane materials.

KEY WORD : AUDIOMETRIC TEST BOOTH / NOISE REDUCTION / KNOCK DOWN

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(A DESIGNED TEST PERFORMANCE OF KNOCK DOWN AUDIOMETRIC TEST BOOTH)

ทักษิณ สุนทร 4536299 PHIH/M

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บทคัดย่อ

วัตถุประสงค์ของการศึกษาคือการออกแบบและการวัดประสิทธิภาพของตู้ตรวจวัดสมรรถภาพการได้ยินชนิดถอดประกอบได้ ซึ่งมีขนาดภายใน กว้าง 28 นิ้ว, ยาว 38 นิ้ว และสูง 61 นิ้ว สามารถถอดประกอบได้ 7 ส่วนด้วยน๊อต ทำจาก เหล็กหนา 0.03 นิ้ว, โพลียูลีเทนโฟมหนา 2 นิ้ว, ไม้อัดหนา 1/4 นิ้ว และแผ่นเหล็กเจาะรูหนา 0.03 นิ้ว ตามลำดับ ส่วนวงกบทำจากเหล็กฉาก มีการลดเสียงดังจากพัดลมด้วย Plenum chamber ขนาด กว้าง 10 นิ้ว, ยาว 12 นิ้ว และสูง 50 นิ้ว บุโดยรอบด้วยใยแก้วหนา 1 นิ้ว และมีไส้ดูดซับเสียงภายใน หนา 1 นิ้วด้านเข้า 4 ชิ้นและด้านออก 3 ชิ้น โดยทำการทดสอบการลดเสียงด้วยวิธีมาตรฐาน ASTM E 596-96

ผลการศึกษาพบว่า ตู้ตรวจวัดสมรรถภาพการได้ยินชนิดถอดประกอบได้ มีประสิทธิภาพในการลดเสียง (STC) = 21 เดซิเบล การทดสอบการลดเสียงเมื่อถอดประกอบ 10 ครั้ง พบว่าไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ(p-value= 0.018-1.0) ส่วนการเปรียบเทียบระดับเสียงภายในตู้ฯ กับมาตรฐานของOSHA พบว่าที่ความถี่ 125 Hz ระดับเสียงภายในตู้ฯมากกว่ามาตรฐานของOSHA อย่างมีนัยสำคัญทางสถิติ(p-value < 0.001) แต่ความถี่ 250 – 8000 Hz ระดับเสียงภายในตู้ฯน้อยกว่ามาตรฐานของOSHAอย่างมีนัยสำคัญทางสถิติ (p – value < 0.001) และมีการระบายอากาศ 25.4 - 32.7 Air change ต่อชั่วโมง

ผลการศึกษาสรุปได้ว่าตู้ตรวจวัดสมรรถภาพการได้ยินชนิดถอดประกอบได้นี้ สามารถลดเสียงได้ตามมาตรฐานการตรวจวัดสมรรถภาพการได้ยิน และมีการระบายอากาศเพียงพอสำหรับผู้ถูกตรวจ สามารถนำไปใช้ได้จริงในภาคสนาม แต่มีข้อจำกัดในช่วงความถี่ต่ำสามารถลดเสียงได้น้อย ควรที่จะทำการศึกษาเพิ่มเติมต่อไป

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CHAPTER I
INTRODUTION

1.1 Background and Rationale

Now, Thailand is promoting and developing industry. Noise is one of the greatest hazards in the workplace. Every year, approximately 30 million people in the U.S. are occupationally exposed to hazardous noise. The direct effects of noise exposure are temporary hearing loss and permanent hearing loss. And the indirect effect of noise exposure is cardiovascular, cause effects to accident.

In dealing with any situation involving sound perception and control, it is best to consider the process in terms of three parts: source, path, and receiver. The source is the equipment or process directly responsible for the sound generation. The path encompasses all media (such as air, water, or solid material) that sound waves encounter and react with as they travel from the sound source to the ultimate sound receiver. The receiver is the final destination of concern for the sound in question.

The control of noise can be accomplished by treating any or all these parts. However, because of the different physical properties of each part of the noise system, they must be treated separately when noise control is required. It is preferred to control the noise at the source because that would eliminate the noise problem most effectively. If control at the receiver should be used as a last resort because, for the reasons mentioned below, it is the least effective method that often ignores a problem that will eventually have to be solved.

The employer shall administer a continuing, effective hearing conservation program, whenever employee noise exposures equal or exceed an 8-hour time-weighted average sound level(TWA) of 85 decibels measured on the A scale (slow response) or equivalently, dose of fifty percent. Without regard to any attenuation provided by the use of personal protective equipment, the employer shall establish and maintain an audiometric testing program. Audiometric tests shall measure background noise level in the audiometric test room as required in table 1-1

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Table 1-1 Maximum allowable octave-band sound pressure level for audiometric test room

Octave-band center frequency (Hz).......	500	1000	2000	4000	8000
Sound pressure level (dB) ...	40	40	47	57	67

However, the background noise in audiometric test room(meeting room) in the field is not less than Maximum allowable octave-band sound pressure level, and this is unpractical to carry are audiometric test booth to the field, due to heavy weight and big size. Thus before conducting the test, it is suggested to measure background noise level. If background noise in audiometric test room is too high, the result of test is incorrect.

1.2 Objectives

General Objective

- This study aims to design, fabricate and determine for the effectiveness of the knock down audiometric test booth(KDB).

Specific Objective

1. To design and fabricate the knock down audiometric test booth.
2. To study effectiveness in reduction of interfering noise.
3. To compare noise reduction when knock down 10 times
4. To compare estimated octave band sound pressure levels inside the knock down audiometric test booth(KDB) and of maximum allowable octave-band sound pressure level for audiometric test room accordance to 29CFR 1910.95 Occupational noise exposure [Occupational Safety and Health Administration]
5. To compare hearing threshold level for test by the knock down audiometric test booth and reference booth.

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1.3 Hypothesis

1. Noise Reduction of the knock down audiometric test booth is not differentiate when knock down 10 times at frequency 125 Hz , 250 Hz , 500 Hz , 1000 Hz , 2000 Hz , 4000 Hz , 8000 Hz
2. Estimate octave band sound pressure level inside the knock down audiometric test booth(KDB) is less than maximum allowable octave-band sound pressure level for audiometric test room accordance to 29CFR 1910.95 Occupational noise exposure [Occupational Safety and Health Administration] at frequency 125 Hz , 250 Hz , 500 Hz , 1000 Hz , 2000 Hz , 4000 Hz , 8000 Hz

1.4 Limitations of This Study

- Octave band sound pressure level outside the knock down audiometric test booth is not greater than the following:

Table 1-2 Octave band sound pressure level inside room for audiometric testing in industrial workplace

Octave-band center frequency (Hz)......……..........	125	250	500	1000	2000	4000	8000
Sound pressure level (dB) …..	53	53.5	55.3	54	52	53	51.1

1.5 Glossary of Term and Definitions

1.5.1 Background Noise: Sound pressure level without the sound source operating.

1.5.2 Noise Reduction: is the difference between the space-averaged sound pressure level outside the knock down audiometric test booth and the space-averaged sound pressure level inside the knock down audiometric test booth.

1.5.3 Sound pressure level: a measure of the ratio of a sound wave relative to a reference sound pressure. Sound pressure level in decibels is typically referenced to 20 Pa. When used alone, a given decibel level implies an unweighed sound pressure level.

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1.5.4 Hearing conservative program : An effective hearing program is one that prevents hearing impairment as a result of exposure to noise while at work. With respect to existing workers compensation lows, an effective hearing program is one that limits the amount of compensatory hearing loss in the frequency range over which normal hearing is necessary in order to communicate. For compliance with OSHA requirements, an effective hearing conservative program is required if an employee's noise exposure exceeds current limits as defined in the OSHA standard 29 CRF 1910.95

1.5.5 The knock down audiometric test booth(KDB) : The booth used for audiometric testing. The knock down audiometric test booth is new design with ventilation system and construct has 7 parts. Each part have rubber seal between it. To assemble by bolt and nut.

1.5.6 Reference Booth : The Tracor mobile test booth model : AR 200EC. It import test booth.

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CHAPTER II
LITERATURE REVIEW

2.1Characteristic of sound(1)

When a sound source vibrates in air, it creates a series of high and low air pressure waves that move away from the source. The sound waves reach the human ear, causing the eardrum to vibrate and produce the sensation of hearing. These vibrations are so minute. They may not be visible, but when conducted through solid materials, they can often be felt. They do have very definite physical characteristics, which can be measured with the aid of electronic instruments.

A sound wave is one complete cycle or vibration, from normal pressure, through high pressure, back to normal, through low pressure, and back to high-low pressure combinations are propagated parallel to the motion of the wave and thus produce longitudinal waves.

When sound wave against the barrier (2) in figure 2-1. Some of the energy is transmitted through the structure. Some of it is absorbed within the material, and the remaining part is reflected back into the room .From the law of energy conservation, we may therefore write:

$$E_i = E_t + E_a + E_r$$

Ei = Energy incident

Et = Energy transmitted

Ea = Energy absorbed

Er = Energy reflected

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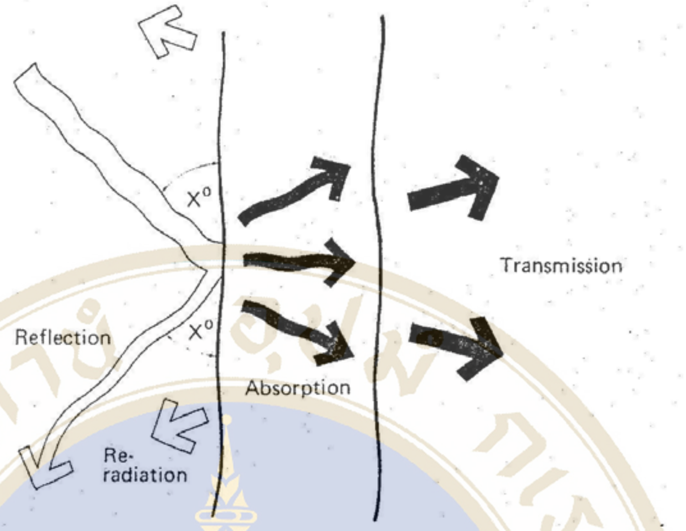

Figure 2-1 Reflection, Absorption, and transmission at a barrier

2.2 Noise Control Principles

In general, the basic principles are employed to reduce noise: absorption and isolation. The most effective solution to a noise problem can be developed at a minimum cost if each principle is understood.

Sound absorption: The sound energy reduces when transmitted through the media. The energy which is absorbed is usually the result of being converted into another form of mechanical energy which is generally heat and this may be achieved in several different ways.

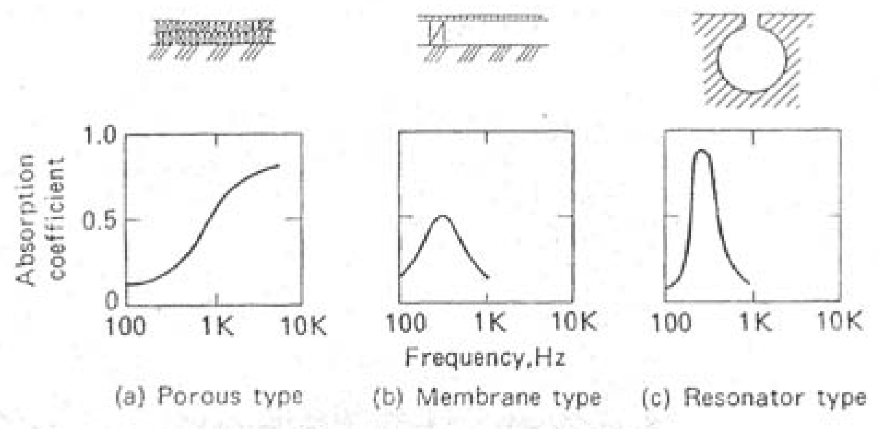

Figure 2-2 Type of absorption material

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Material absorption to classify 3 type(3)

1. Porous or Dissipative Absorber

Porous material are material that possesses a cellular structure of interlocking pores. It is within there interconnected open cell(4) that the sound energy is converted into thermal energy due to frictional and viscous flow in porous and vibration of the material's fiber. Porous material good absorbed in high frequency but poor absorbed in low frequency(3) in figure 2-2 . The absorption characteristics of a material depends on(4) its thickness, density, porosity, flow resistance and fiber orientation. Typical porous panels should not be painted because the paint can clog the holes in the panels and render them ineffective for absorption.(5) Example fiberglass, carpet, chaff (6)and coconut fiber(7)

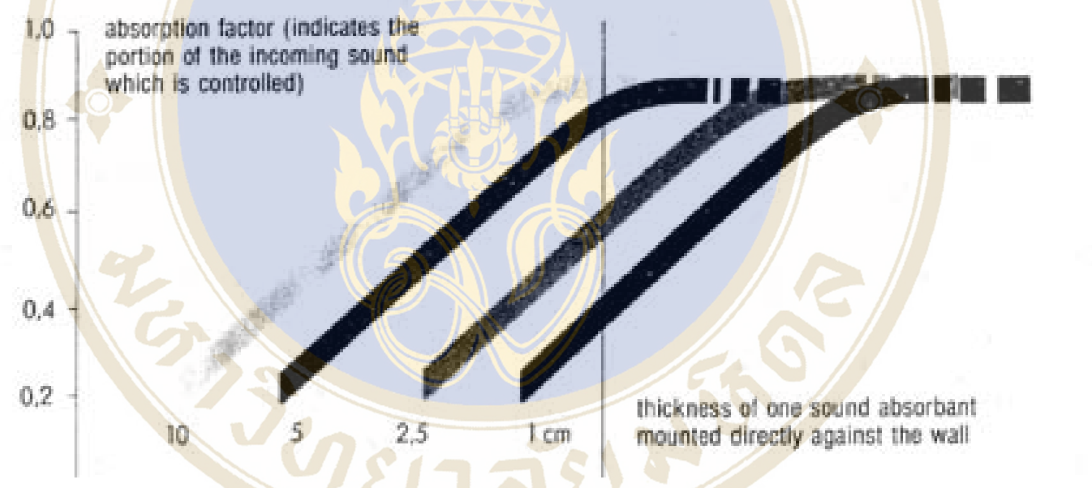

Figure 2-3 Thick, porous layers absorb both high and low frequency sound(8)

2. Membrane absorber

When sound wave strikes membrane absorption(2), membrane absorbers convert sound energy into heat as a result of bending deformations associated with the vibrations of the panel which are excited by the incident sound. As can be seen, the sound absorption of membrane absorbers is predominant at the lower frequencies.

In figure 2-2, the frequency of maximum absorption (resonant frequency) is determined by the mass of the panel and the stiffness and depth of airspace behind it from the following expression (4) :

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$$f_{res} = \frac{60}{\sqrt{md}}$$

f_{res} = Frequency ofmaximum absorption

m = mass of the pannel (kg/m2)

d = depth of the airspace in meters

example : Thin Plywood, Canvas

3. Resonator or cavity absorber (9) (often called Helmholtz rasonators)

Resonator is cavities which confine a volume of air which communicates with the atmosphere by means of a small hole or channel in the surface of the cavity. If the dimensions of the cavity are very small compared with the wavelength of sound reaching the opening of the cavity, the resonator "tunes" to a specific frequency. The fundamental vibration of the confined air volume is a periodical airflow through the channel into and out of the cavity, and the air in the cavity acts as a spring. The kinetic energy of the vibration is essentially that of the air in the channel moving as an incompressible and frictionless fluid.

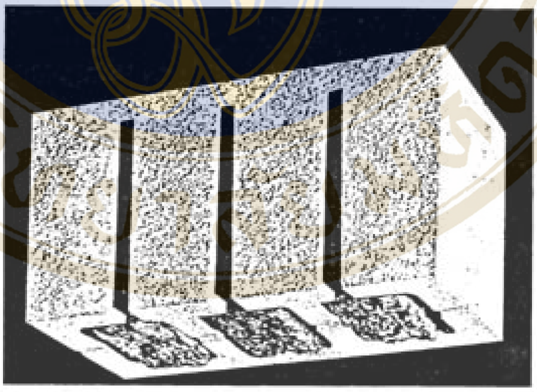

Figure 2-4 Concrete block

Sound absorption coefficient ($\propto$) (2) is described as the ratio of sound energy absorbed to the sound energy incident, we may write:

$$\propto = \frac{Ei - Er}{Ei}$$

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In general (5) , materials having absorption coefficients less than 0.15 are considered to be reflective and these having absorption coefficients greater than 0.4 are considered to be absorptive.

Noise Reduction Coefficient (NRC) (4) is defined to be the arithmetic average of the material's sound absorption coefficients at 250,500,1000 and 2000 Hz. We may write:

$$NRC = \frac{\propto 250 + \propto 500 + \propto 1000 + \propto 2000}{4}$$

Table 2-1 Acoustic Absorption Performance of common Materials(5),(6),(9),(10)

Material	Absorption Coefficient (α)						
	Octave Band Center Frequency (Hz)						
	125	250	500	1000	2000	4000	NRC
Carpet							
1/8 – in. pile height	0.05	0.05	0.10	0.20	0.30	0.40	0.15
¼ – in. pile height	0.05	0.10	0.15	0.30	0.50	0.55	0.25
3/16 – in. pile and pad	0.05	0.10	0.10	0.30	0.40	0.50	0.25
5/16 – in. pile and pad	0.05	0.15	0.13	0.40	0.50	0.60	0.30
Glass							
¼ –in. sealed, large panes	0.05	0.03	0.02	0.02	0.03	0.02	0.05
24 – oz operable windows, closed	0.10	0.05	0.04	0.03	0.03	0.03	0.05
Gypsum board, ½ –in ., nailed to 2 x 4 studs, 16 –in. off center,painte	0.10	0.08	0.05	0.03	0.03	0.03	0.05
Hard plywood paneling, ¼ -in. thick, wood frame	0.58	0.22	0.07	0.04	0.03	0.07	0.10
Resonator block, 8-in., painted	0.20	0.95	0.85	0.49	0.53	0.50	0.70
Spray-on cellulose fiber, 1-in.	0.08	0.29	0.75	0.98	0.93	0.76	0.75
3/8 –in Plywood	0.28	0.20	0.17	0.09	0.10	0.10	
¼ in Plywood, on studs	0.60	0.30	0.10	0.10	0.10	0.10	

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Table 2-1 Acoustic Absorption Performance of common Materials(5),(6),(9),(10) (continue)

Material	Absorption Coefficient (α)						
	Octave Band Center Frequency (Hz)						
	125	250	500	1000	2000	4000	NRC
2 –in. Solid Plywood	0.01	0.05	0.05	0.04	0.04	0.04	
3/8 –in sprayed fibrous material	0.08	0.30	0.70	0.90	0.90	0.75	
1 –in. fiberglass panel solid backing	0.03	0.02	0.60	0.85	0.95	0.96	
2 – in Polyurethane foam open cell	0.35	0.51	0.82	0.98	0.97	0.95	
Chaff 3 - in	0.88	0.89	0.94	0.80	0.93	0.99	
Chaff 4 - in	0.92	0.93	0.96	0.82	0.98	0.99	
Chaff 5 - in	0.97	0.98	0.99	0.93	0.93	0.99	

Note : Ceilings & Interior Systems Construction Association(CISCA), 579 W. North Avenue,Suite 301, Elmhurst, IL(1984)(with permission); Hedeen(1980)
: NIOSH, compendium of Material for Noise control, June 1975

Sound Transmission(11)

The energy which is transmitted will give rise to a new sound field on the other side of the boundary. When a wave front reaches a barrier, the barrier is set into motion. The barrier, then, becomes a sound source, and sets into motion the air on the other side. Some of the energy is transmitted to the air on the opposite side of the barrier; some of the energy is reflected back toward the source; and some is lost in moving the partition.

Factors affecting sound transmission(2) :

1. Homogeneity or Uniformity : If there is a hole in the barrier, sound energy or pressure is released, transmissions will pass through the hole
2. Weight: the average sound reduction indices of solid partitions are plotted against their weight per unit area. It will be seen that in general there is an increase in insulation of about 5 dB for each doubling of weight in figure 2-5

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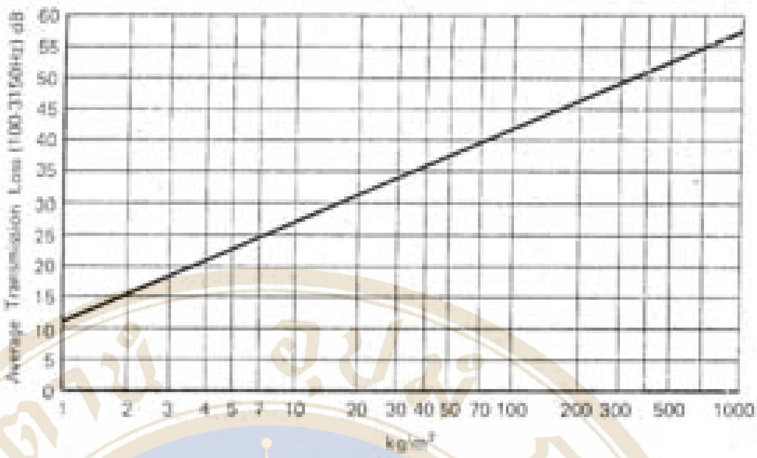

Figure 2-5 Mass law curve

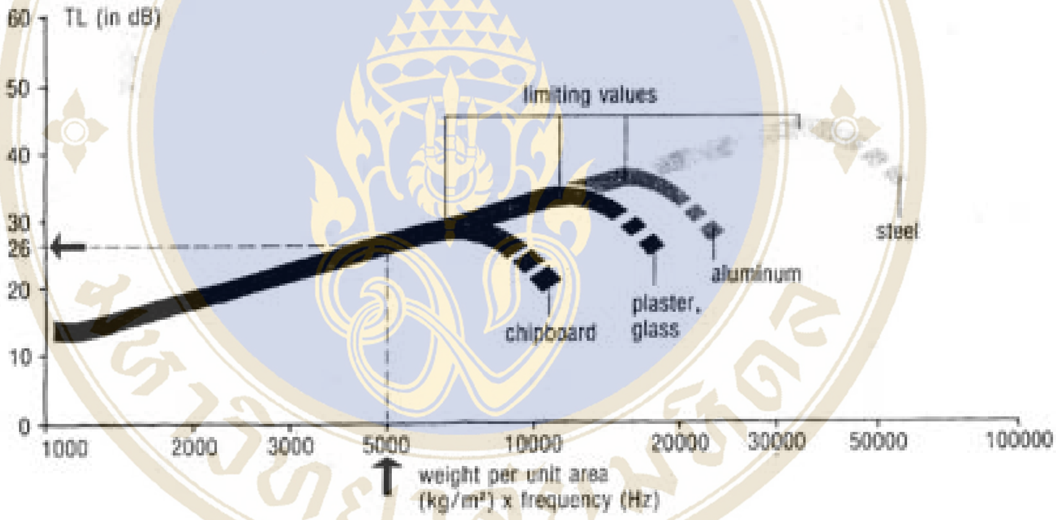

Figure 2-6 The TL of a single wall is estimated from its surface weight(8)

3. Discontinuity or Isolation is the lock of a rigid connection between sides of each partition, such as staggered studs or studs connected to walls through resilient channels

Transmission Loss (TL) (11),(12) is the energy transmitted through the material relative to energy incident on the material. We may write:

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$$TL = 10 \log \frac{\text{(Incident energy)}}{\text{(transmission Energy)}}$$

Noise reduction (NR) (9),(12) is the difference between the space-averaged sound pressure level outside the knock down audiometric test booth and the space-averaged sound pressure level inside the knock down audiometric test booth

$$NR = SPL_{(outside)} - SPL_{(inside)}$$

Table 2-2 Acoustic insulation Performance of common Partitions[(4),(5),(10),(13)]

Partition design	Transmission Loss (dB)						
	Octave Band Center Frequency (Hz)						
	125	250	500	1000	2000	4000	STC
Laminated glass							
9/32 in	25	28	33	36	35	39	36
1/2 in	31	34	38	40	37	46	40
3/4 in	34	36	41	43	41	50	43
Plywood, ¼ -in., 0.7 lb/ft^2	17	15	20	24	28	27	
Plywood, 3/4 -in., 2 lb/ft^2	24	22	27	28	25	27	
2 ½ -in solid wood	28	27	28	28	34	32	
Steel, 18 gauge, 2 lb/ft^2	15	19	31	32	35	48	
Steel, 16 gauge, 2.5 lb/ft^2	21	30	34	37	40	47	
Single sheet 0.025 – in, Aluminium	-	18	13	18	23	25	
Single sheet 0.03 – in, steel	-	25	20	29	35	32	
Single sheet 1/8 – in, lead	-	31	27.2	37.5	43.8	32.6	
Single sheet 1/16 – in, lead	-	31.8	33.2	32.	32.1	32.5	
Gypsum board shaft wall	24	40	48	53	55	52	
5/8 –in gypsum board on 2 ½ metal studs	30	39	45	44	46	46	

Note : BIA(1988); DuPree(1988); Hedeen(1980); NCMA(1990)

: NIOSH, compendium of Material for Noise control, June 1975

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2.3 Polyurethane Foam Technology(14)

Polyurethane foam is the end product in the chemical reaction of two components. The two liquid components react quickly to form rigid, closed-cell foam. Component A is the accelerator and component B is the resin. Polyurethane foam expands in place to fill and seal cavities as it assumes the shape to the cavity. The density range is 2-30 pounds per cubic foot and the corresponding expansion range is 3200% to 200%. Depending on the density, if it is used for acoustic and/or structural applications. The low-density foam effectively seals the cavity and blocks noise and air leakage. The data is collected and placed into a chart to graphically show acoustical performance.

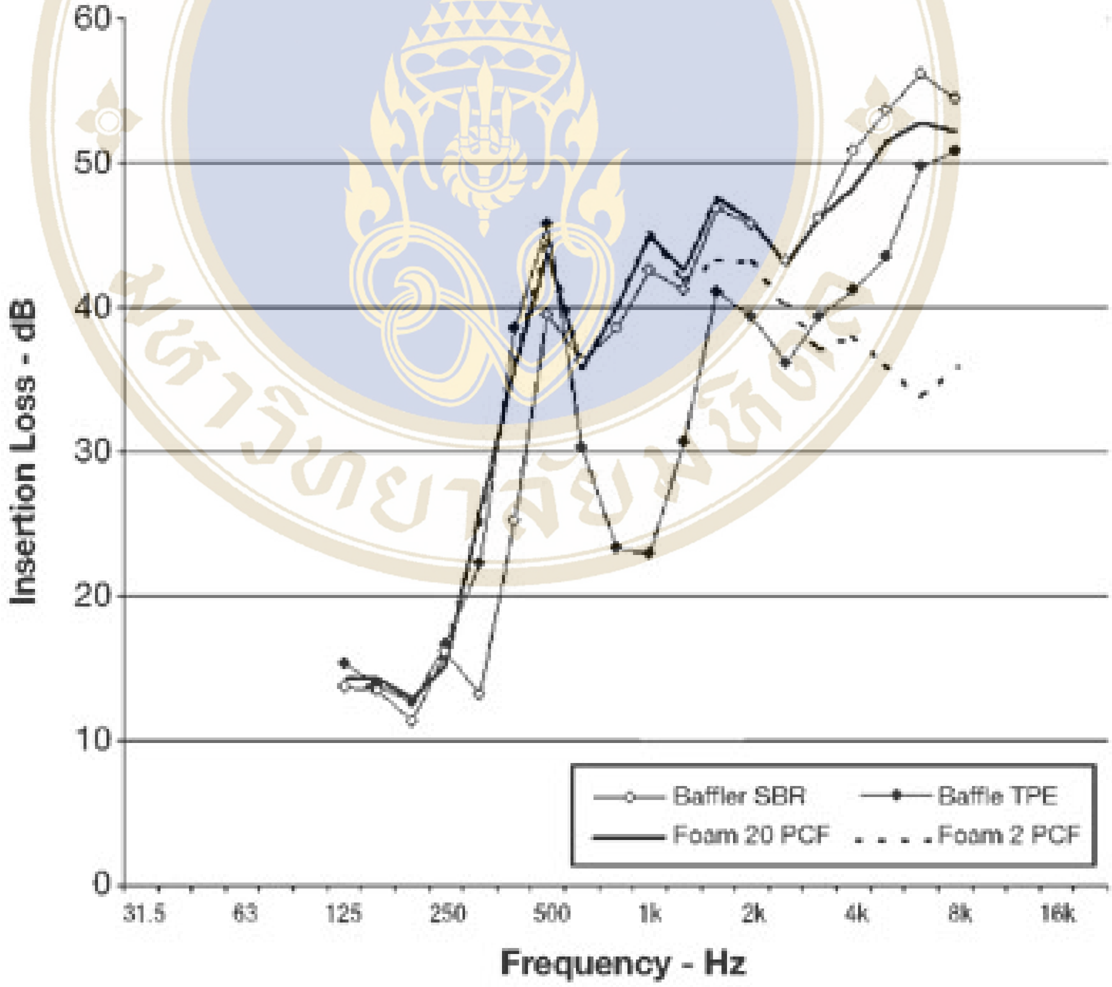

Figure 2-7 The insertion loss of polyurethane foam

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2.4 Selection of fan noise control (12)

1. Change number of blades. This can alter the frequency of the noise emitted by the fan based on the following expression

$$f = \frac{NK}{60}$$

where: f = frequency of noise fan

N = shaft rotational speed revolution per second

K = number of blades

2. Controlling the noise generated by air moving equipment would be by properly mounting the device. Mechanical isolation between the fan and the supporting base would be the simplest solution. There are three major types of isolator: Springs, Elastomeric mounts and resilient pads.

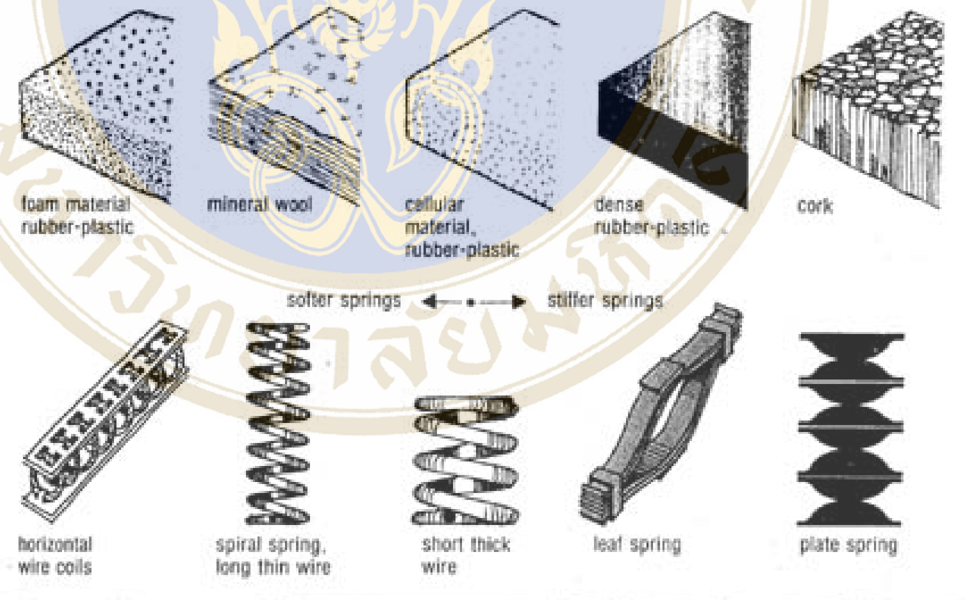

Figure 2-8 Type of spring and Resilient pads

3. Mufflers or silencer have 2 types

- Reactive muffler does not depend on the absorptive properties of material but on the reflection of the sound waves. These mufflers have smaller than absorptive type muffler but have high pressure drop and low mass flow.

- Absorptive mufflers have fibrous or porous material as sound absorbers to reduce noise. The acoustical performance associated with this type of muffler depends

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on: thickness of absorbing materials, spacing of bafflers and length of baffles. Drawback associated with this type of muffler is that as flow velocities increase, its acoustical performance decrease. The performance of this type of muffler can be estimated by:

$$TL = 4.2 \propto 1.4(L/d)$$

L = Length of bafflers

d = spacing of bafflers

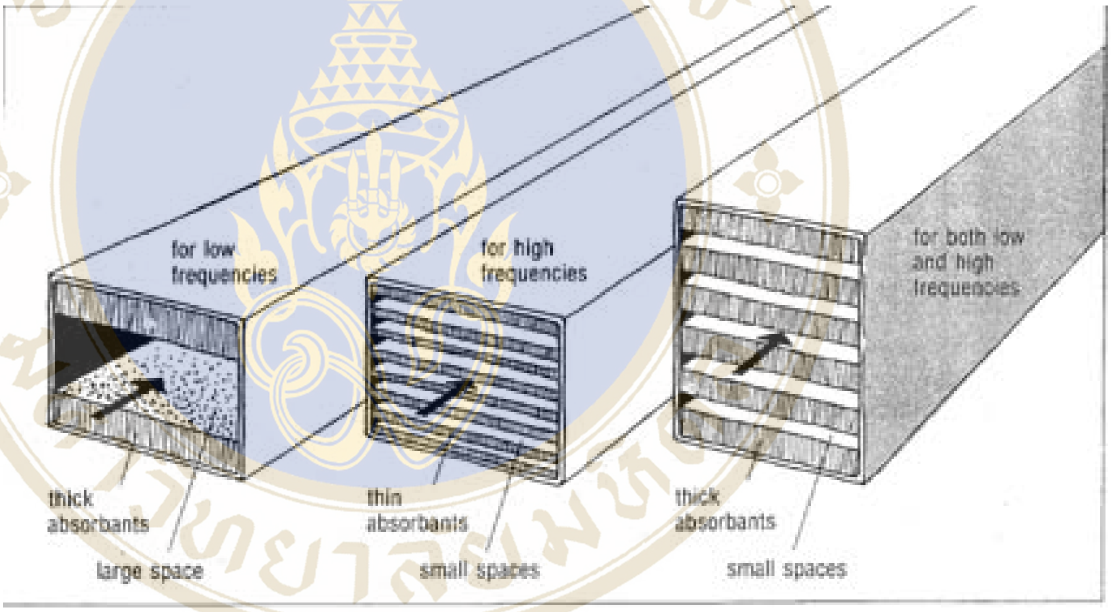

Figure 2-9 Absorption mufflers are effective over a broad range of frequencies(8)

Plenum Chambers(4)

The plenum chamber is one type of Absorptive muffler. These units are large volume chambers which interconnect two ducts, as shown in figure 2-10. The interior of the chamber is lined with absorbing material, and thus part of the sound energy which enters the chamber is absorbed due to multiple reflections within the unit. Facing material may or may not be required, depending on the temperature and velocity of the gas stream. Although classified here as an absorptive muffler, the

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plenum chamber also acts as a reactive device, owing to the discontinuities that exist at both the inlet and outlet of the chamber.

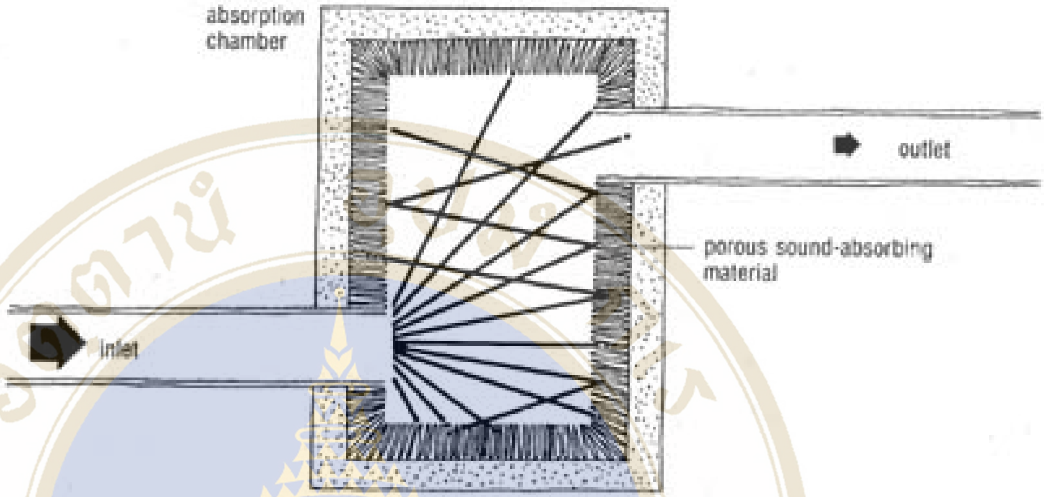

Figure 2-10 Unused areas can be absorption chambers(8)

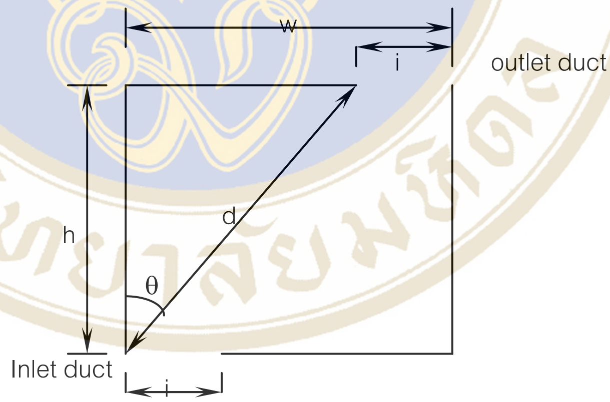

Figure 2-11 Layout of a single chamber plenum

Typically, the attenuation ranges from about 10 dB at low frequencies to approximately 20 dB in the frequency range above 1 kHz. This performance can be improved by increasing the thickness of the absorbing lining, blocking the direct line of sight from chamber inlet to outlet either through the use of a sound-absorbing panel or by using multiple chambers, and by increasing the cross-sectional area of the chamber for a given size of inlet and outlet duct.

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The following approximate expression for determining the attenuation of the plenum shows in equation :

$$\text{Attenuation} = -10 \log [s ((\cos \theta/2\pi d^2)+((1-\propto)/(\propto S_w)))] \quad \text{dB}$$

Where $\propto$ = Average absorption coefficient of the plenum lining

S = plenum inlet or exit area (m^2 or ft^2)

S_W = plenum wall area (m^2 or ft^2)

d = slant distance from input to output (m or ft)

d^2 = $(W-l)^2 + h^2$ (m^2 or ft^2)

$\cos\theta$ = h/d

This equation yields results that are fairly accurate at high frequencies, conservative for low frequencies; it thus provides a reasonable, practical measure of the plenum's performance.

4. The location of a fan in a ventilation system was an important factor because fan noise can be attributed to: abrupt entry, abrupt exits, fan orientation, upstream interference and sharp turns

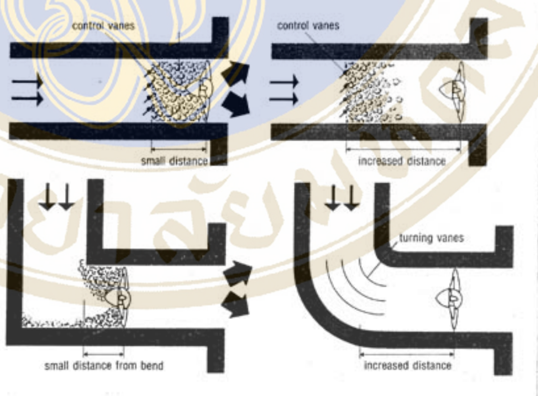

Figure 2-12 The location of a fan

5. Properly balancing a fan is a factor in keeping the fan quiet. One of major sources of noise associated with a fan is being on an imbalance condition

2.6 Criteria for Audiometric test booth (15)

Background noise is the first important factor for industrial hearing testing. Therefore, background noise exceeding those in table 2-3 accordance with 29CFR

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1910.95 Occupational noise exposure(OHSA) and the recommendation from the Division of Occupational Health, Ministry of Public Health for audiometric test.

Table 2-3 Maximum allowable octave-band sound pressure levels for Audiometric Test Booth

Octave-band center frequency (Hz)........……..........	500	1000	2000	4000	8000
Sound pressure level (dB) ...	40	40	47	57	67

Other important factors for industrial hearing testing: humidity and temperature. Because both factors take effect to test subject hot feeling, uncomforted and will hurry testing. Audiometric test booth is not air intake. Therefore, test subject getting inside during short time will increase temperature. Therefore, audiometric test booth shall effective ventilation and not make background noise over standard.

The ministerial regulation of ministry of industry issue 2nd determine ventilation for workstation not to keep and/or use toxic material, chemical, flammable, explosion material or other material may be have toxic or dust not less than 18.5 CFM (0.5 m^3/min/man)

ASTM D6245 determines ventilation for control carbon dioxide not exceeding 700 ppm and not feeling to smell from sweat for sitting person not less than 16.66 CFM (0.45 m^3/min/man)

2.7 Review Literatures

Grzesilk J,Kowalska H and Pawlas K, (16) modified a caravan for the purpose of audiometric testing in the neighborhood of industrial workplaces. The sound insulation of the caravan increased due to the use of double glasses in the windows, special tightening of the doors and covering the walls with sound absorbing material. The gained insulation enables the testing of the threshold of hearing in a surrounding where the ambient noise does not exceed following octave-band noise level: 49 dB-

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125 Hz, 59 dB – 250 Hz, 57 dB – 500 Hz, 74 dB – 1000 Hz, 81 dB – 2000 Hz, 91 dB – 4000 Hz, and 100 dB – 8000 Hz.

Vichai. (17) The objective of this study was to investigate the design and the effectiveness of a plenum chamber silencer with and without parallel baffles to reduce the noise from a blower. In the design, the plenum chamber silencer was 1.5 meters wide 1.5 meters long and 2.5 meters high. The plenum chamber silencer had a fiberglass lining on the inner side of the wall. The fiberglass had 50 millimeters of thickness and weighed 48 kilograms per cubic meter. Inside the plenum chamber silencer, there were 7 parallel baffles with each baffle about 125 millimeters from the next. Each baffle had a 900 millimeter width, 1400 millimeter length and 200 millimeters of thickness. The method used to measure the noise attenuation from this silencer utilized 3 measurements, dynamic insertion loss, noise reduction and noise contour. The results of the study revealed that the noise from the plenum chamber silencer with and without parallel baffles could reduce the noise at all frequencies in all 3 measurements. The method of measuring dynamic insertion loss showed a significantly reduced value (p-value < 0.001). The comparison of the plenum chamber silencer with and without parallel baffles showed a difference. The dynamic insertion loss and noise reduction of the plenum chamber silencer with parallel baffles showed it could reduce the noise more than the plenum chamber silencer at a low frequency, but at a high frequency it could not reduce the noise as effectively. In summary, the plenum chamber silencer is effective in reducing noise from a blower but parallel baffles inserted inside the plenum chamber silencer can only enhance the efficiency of the plenum chamber silencer at a low frequency.

Charin(18) . One obstacle in performing field audiometric testing is the unavailability of the mobile laboratory or booth. Thus, most of the time audiometric testing is performed in a room with substandard background noise levels. This study aimed to investigate correction factors to adjust for background noise levels in order to have more accurate audiometric measurements. This study was a comparative experimental study of normal hearing thresholds and hearing thresholds masked by ambient noise at the frequencies of 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz.

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Sixty one subjects were selected from college students whose ages were 17-23 years old and had audiometric thresholds less than 25 dB at all frequencies. Various maskings of broadband noise at the levels of 40, 50, 60, 70, and 80 dB were generated into the test booth in order to see the impact on the pattern of hearing threshold. Results of the study revealed that the hearing threshold shift depended upon the level of ambient noise present. At all frequencies, the hearing threshold shift showed significant difference from normal hearing threshold at 60 dB ambient noise level except that at the test of 1000 Hz frequency with 50 dB level. Prediction equations of a change in the hearing threshold shift were as follows: at the frequencies of 500, 1000, 2000 and 3000 Hz, ? = 17.9986-.9883x+0.0131x2 with .939 coefficient of determination (R2); at the frequencies of 4000 and 6000 Hz, ? = 22.4775-1.0576x-0.0124x2 with R2 =.983; at the frequency of 8000 Hz, ? = 18.5546-.8285x+0.0095x2 with R2 = .980 (? = hearing threshold shift and X = ambient noise levels [dB(A)]). The adjusted corrective constant factors were demonstrated as both a graphic form and a table form for field practice. Field investigation to determine the actual hearing threshold shift by using the quadratic equation or correction factor in the workplace should also be undertaken.

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CHAPTER III
MATERIALS AND METHODS

3.1 Research study design

An experimental research was designed and Construct knock down audiometric test booth , test noise reduction accordance with ASTM E 596-96,compare Sound pressure level inside audiometric test booth and of maximum allowable octave-band sound pressure level for audiometric test booth accordance to 29CFR 1910.95 Occupational noise exposure [Occupational Safety and Health Administration]

3.2 Design a knock down audiometric test booth

3.2.1 Design the dimension of the knock down audiometric test booth

The audiometric test booth used to test hearing loss by audiometer. Sampler was to sit in the chair inside the audiometric test booth. This research used the anthropometric data from report to survey and research of anthropometric in Thai people is show in table 3-1.

Table 3-1 Anthropometric data of Thai people.(inch)

Body dimension	Mean	S.D.	Min	Max	P5	P95
Sitting height	34.4	1.3	30.7	39.0	32.1	36.7
Popliteal height	16.7	0.9	14.4	19.4	15.4	18.2
Shoulder breadth	17.0	1.0	11.9	53.5	21.1	18.8
Bottock-Knee length	22.5	1.2	16.6	27.4	20.7	24.5

So, interior dimension of the audiometric test booth in research would like to comfortable and appropriate the anthropometric data of Thai people and minimized the cost of construct.

The height used data from sum of 95^{th} percentile of Sitting height and Popliteal height and 6.1 inch increase for clearance, then it was 61 inch.

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The width used data from 95th percentile of Bottock-Knee length and 13.5 inch increase for clearance, then it was 38 inch.

The depth used data from 95th percentile of Shoulder breadth and 9.2 inch increase for clearance, then it was 28 inch.

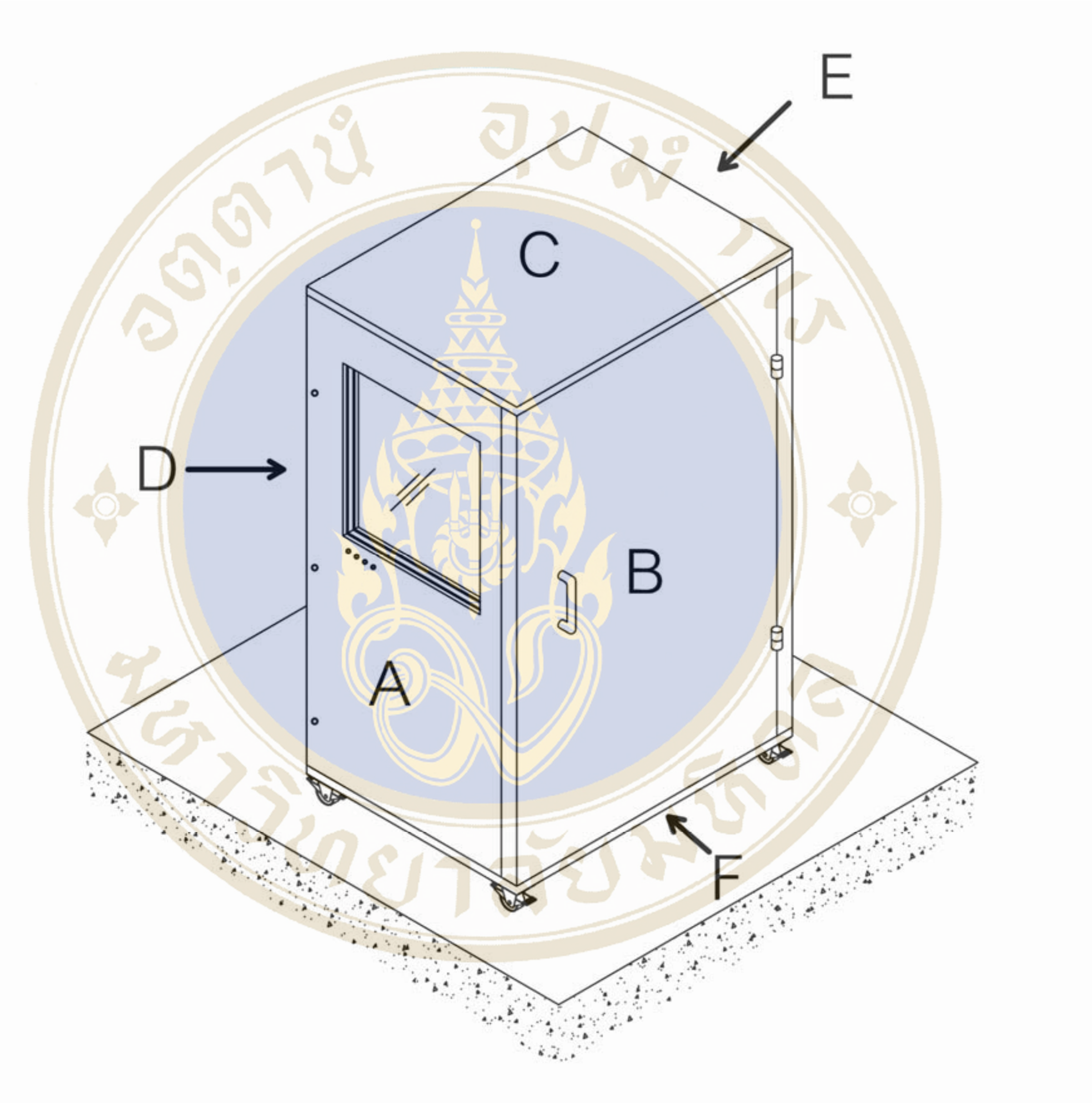

Figure 3-1 Dimension of the knock down audiometric test booth

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3.2.2 Material selection

Each material has a difference of sound absorption coefficient, transmission loss, which depend on characteristic of material. For this research, the material to outside wall is steel 0.03 inch because it has high sound transmission loss at all frequency and thin.

Second layer is polyurethane foam 2 inch because it has sound transmission loss very high at all frequency and light weighting.

Third layer is plywood ¼ inch because it has sound transmission loss at low frequency higher than other type material

Fourth layer is Perforate steel 0.03 inch because it will improve low frequency absorption

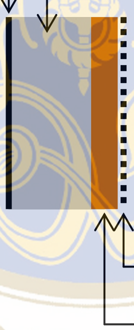

Figure 3-2 lining of material of wall' the knock down audiometric test booth

Table 3-2 The Sound transmission loss and sound absorption coefficient

Partition design	Transmission Loss (dB)					
	Octave Band Center Frequency (Hz)					
	125	250	500	1000	2000	4000
Single Steel 0.03 inch	-	25	20	29	35	32
Plywood, ¼ -inch., 0.7 lb/ft^2	17	15	20	24	28	27
Polyurethane foam 2 inch	15	19	42	43	42	46
Laminated glass 9/32 inch	25	28	33	36	35	39

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Window is double glazed 9/32 inch laminate glass size 21 inch x 23 inch with an air space 6/8 inch between it is show in figure 3-3

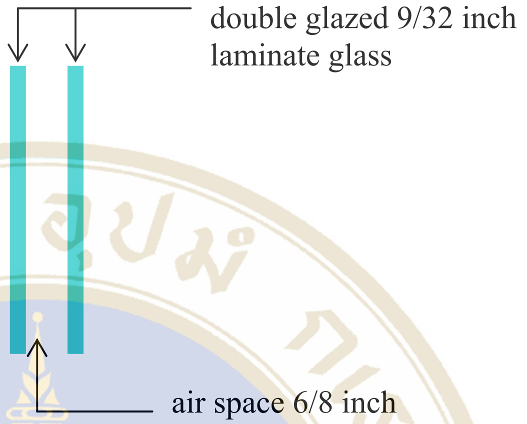

Figure 3-3 Dimension of window

Jack panel is four 3 conductor phone jack

Door seal is perimeter magnetic seal

Floor lay with polyurethane foam 2 inch

Assemble – The knock down audiometric test booth has 7 parts. Each part have rubber seal between it. To assemble by bolt and nut.

3.2.3 Estimation of noise reduction with partial enclosures with line ducts

An enclosure with openings, an approximation to the equivalent absorption of the enclosure surfaces can be made by assuming that the sound absorption coefficient of the opening is 1.0. The total absorption of an enclosure with openings would be computed for one frequency band from:

$$\Sigma \propto_I S = \propto_1 S_1 + \propto_2 S_2 + \ldots\ldots 1.0 S_0$$

Where : $\propto_1 S_1$ = the absorption, in sabins, for surface 1.

$\propto_2 S_2$ = the absorption, in sabins, for surface 2 , etc.

S_0 = the total open area of the enclosure.

The amount of acoustic power escaping the enclosure through an opening is the acoustic power incident on the open area. Since the sound field was assumed to be homogeneous inside the enclosure, the ratio of acoustic power incident on the opening to the sound power generated by the enclosure noise source becomes equal to the absorption ratio which reduces to the relation in Equation :

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$$\frac{W_{incident}}{W_{source}} = \frac{S_{open}}{S_{open} + \Sigma \propto_i S_i}$$

Where : S_{open} = The open area of the enclosure.

$\Sigma \propto_i S_I$ = The absorption, in sabins, for the treated inside surface areas.

$W_{incident}$ = sound power incident on openings.

W_{source} = sound power of the source.

The sound power incident on the open areas must be corrected by means of a radiation factor to account for the directivity and diffraction effects of the opening location compared to the field point of interest. Each opening has a radiation coefficient, η, depending on the location of the opening , and given in table 3-3. For more than one opening exists for the partial enclosure, the resulting effective sound power is obtained by summation :

$$\frac{\text{Total effective power}}{\text{Total source power}} = \frac{\Sigma W_R}{W_S} = \frac{\Sigma \eta_k S_{ok}}{S_{oT} + \Sigma \propto_i S_i}$$

Where : W_R = the effectiveradiated sound power

η_k = accounts for the radiation coefficient for the various openings in the enclosure.

S_{ok} = the area of the various openings.

S_{oT} = the total open area of the enclosures

$\propto_i$ = the acoustic absorption coefficient for the i^{th} material inside the enclosure

S_i = the surface area of the i^{th} material inside the enclosure

Table 3-3 Acoustic radiation coefficient (η) as a function of opening location.

Location of open area	Acoustic radiation coefficient, η
Front	1.00
Side*	0.30
Top*	0.30
Back*	0.15

* If the side, top, or back of the enclosure is near a reflective surface, the corresponding value of η in the table should be doubled.

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The noise reduction(NR), for a source enclosed with a partial enclosure can be estimated from :

$$NR = -10 \log (W_R / W_S) \quad dB$$

To achieve greater noise reduction with a partial enclosure, the opening can be fitted with acoustically lined ducts, for an enclosure treated with a lined duct, the duct attenuation is obtained from equation :

$$\text{Duct attenuation} = 12.6\,(P/S)\propto^{1.4} \quad dB/ft$$

Where : P = Acoustically lined perimeter of ducts , in

S = Cross-sectional open area of duct , in^2

$\propto$ = Reverberant room determined absorption coefficient for the duct liner material.

For this give the attenuation transmission coefficient (β) is found from :

$$\beta = \log_{10}^{-1}[(12.6\,(P/S)\propto^{1.4}\ L)/10]$$

Where : L = Length of the lined duct.

From this duct transmission coefficient the effective power radiated from the opening

$$\frac{\Sigma W_R}{W_S} = \frac{\Sigma \beta_k \eta_k S_{ok}}{S_{oT} + \Sigma \propto_i S_i}$$

The effect of the lined duct is to reduce the sound power incident on the opening by a factor, β , before it reaches the radiating end of the duct.

3.2.4 Design the plenum chamber silencer

Sound attenuation of plenum chamber silencer is calculated by

$$\text{Attenuation} = -10 \log [s\,((\cos\theta/2\pi d^2)+((1-\propto)/(\propto Sw)))] \quad dB$$

Where $\propto$ = Average absorption coefficient of the plenum lining

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S = plenum inlet or exit area (m^2 or ft^2)

Sw = plenum wall area (m^2 or ft^2)

D = slant distance from input to output (m or ft)

d^2 = $(W-l)^2 + h^2$ (m^2 or ft^2)

Cosθ = h/d

The noise attenuation depends on the Sw , d and cos θ , which depends on the dimension of plenum chamber silencer . So, the bigger size of plenum camber silencer can reduce the noise more than the smaller size. In this research, it is meant to appropriate the size of knock down audiometric test booth. So, the dimension of plenum chamber silencer in this research is selecting the size 10 inch x 12 inch x 50 inch is show in figure 3-4

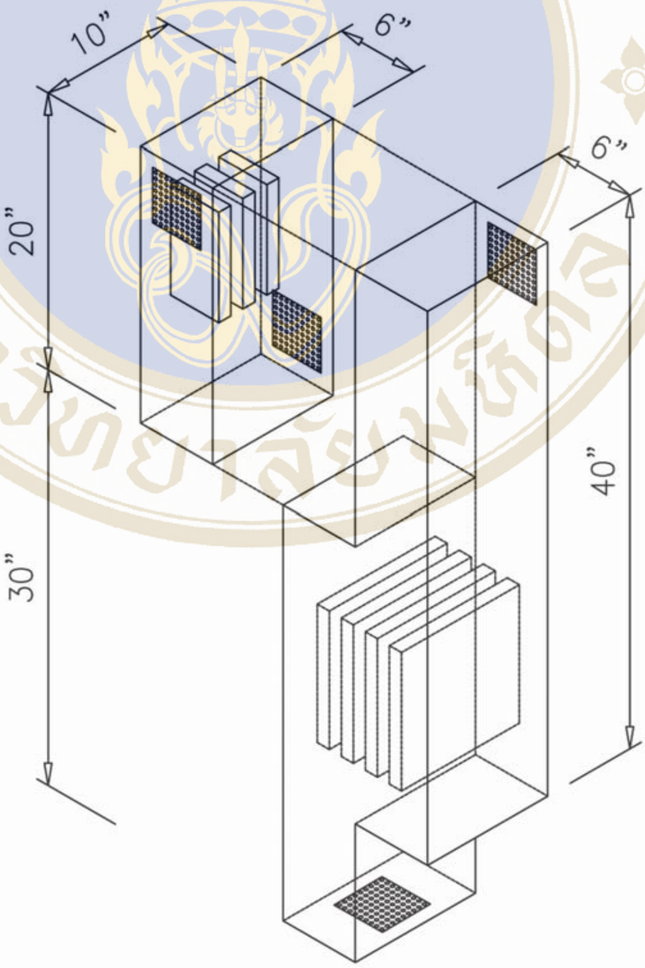

Figure 3-4 Dimension of the plenum chamber silencer

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Baffles are a technique to increase the noise attenuation by inserting the absorption material along the way the duct or chamber. The equation to use for this design is

$$TL = 4.2 \propto 1.4 \ (L/d)$$

Where $\propto$ = absorption coefficient of the plenum lining

L = Length of bafflers

D = spacing of bafflers

For this equation, noise reduction depends on sound absorption coefficient of lining baffle , length of baffle and spacing of baffle

3.3 Standard test method ASTM E596-96

In this research, the noise reduction in accordance with ASTM E596-96 : Standard test method for laboratory measurement of noise reduction of sound isolating enclosures. These requirements include:

3.3.1 Reverberation room

– actual room volume minus the volume occupied by the audiometric test booth shall not be less than 200 m^3 and the sound absorption in the reverberation room shall be no greater than the following :

$$A = V^{2/3} / 3$$

Where

V = room volume , m^3

A = room sound absorption in metric sabins.

3.3.2 The audiometric test booth placement

3.3.2.1 No audiometric test booth wall is parallel to a reverberation room wall.

3.3.2.2 The audiometric test booth is at least one-haft wavelength away form the reverberation room walls and ceiling and any diffusing surfaces at the center frequency of the lowest one third octave band in which the noise reduction is to be measured. (125 Hz shall not be less than 1.38 m.)

3.3.2.3 The audiometric test booth is mounted on the floor in the same way as when it is in normal use.

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3.3.3 The audiometric test booth preparation

3.3.3.1 Operate ventilating system for at least 10 min, turn the system off, and test without further adjustment.

3.3.3.2 After the procedure of 3.3.3.1 has been completed, open and close each enclosure door and access opening at least ten times and test without further adjustment.

3.3.4 Test signal

3.3.4.1 The test signals shall be bands of random noise at least one-third octave wide and including every one-third octave band within the range(125,250,500,1000, 2000,4000,8000 Hz)

3.3.4.2 The signal source shall be placed so that the audiometric test booth is not in direct field; the minimum distance from the source to any part of the audiometric test booth shall be :

$$r \geq 0.63\ A^{1/2}$$

Where A = the sound absorption in the reverberation room with the audiometric test booth present.

3.3.4.3 The signal level shall be at least10 dB above the measured background noise inside the audiometric test booth at each test frequency.

3.3.5 Inside measuring positions

– Select at least four microphone positions inside the audiometric test booth as follows:

3.3.5.1 Determine the useful volume of the audiometric test booth.

3.3.5.2 Distribute microphone positions evenly throughout the useful volume.

3.3.5.2.1 Microphone positions should not be located within 0.30 m of the audiometric test booth interior walls unless the useful volume necessarily includes these regions.

3.3.5.2.2 Microphone positions should not approach one another to within a distance of one-half-wavelength at the lowest frequency of interest.

3.3.5.2.3 For low frequencies, it is almost never possible to select four microphone positions that satisfy the requirement of 3.3.5.2.2. Whenever this is the case, microphone position inside the audiometric test booth should be selected to get

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the best estimation of the space-time average sound pressure level within the useful volume, disregarding spatial correlation among positions.

3.3.6 Outside measuring position

–Select at least six independent microphone positions in the reverberation room. Microphone positions shall not be less than one-half wavelength or 1 m, whichever is less, away from any solid surface at the lowest test frequency. In addition, outside measuring positions should not lie within the direct field of the signal source as defined in 3.3.4.2

3.3.7 Measurement

– The purpose of these measurements is to obtain the difference between the space-averaged, one-third octave band sound pressure level outside the audiometric test booth and the space-averaged, one-third octave band sound pressure level inside the audiometric test booth. Use one microphone to measure sound pressure levels both inside and outside the knock down audiometric test booth and one outside.

3.3.8 Repeat 3.3.1-3.3.7 by Knock down at least 10 times.

3.3.9 Measurement Uncertainty

– It is strongly recommended that the uncertainty of the noise reduction measurement be monitored to determine if more microphone positions would be beneficial. The overall uncertainty is derived from the uncertainty of the outside and inside sound pressure level measurements. The procedure is to calculate the 95 % confidence interval for both sound fields and then combine them to calculate the uncertainty for NR. Precision requirements is recommended that the noise reduction uncertainty shall be no greater than 3 dB for the one-third octave bands centered on 125 and 160 Hz, 2 dB for bands on 200 and 250 Hz, and 1 dB for the bands centered in the range 315 to 4000 Hz.

3.4 Inspection of air supply in the knock down audiometric test booth

The equipment which is used was a velocicalc plus, Model 8386 A-M-GB, Serial No. 3120366, Cal date. December 2003. The volume was measured in terms of wind velocity (ft/min). Velocity at tube was measured in the cross section of tube. This research used a paper tube with a diameter 6 inch, measurement of wind velocity

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was measured for twelve points and eight replications. Velocity measured at three speed of fan.

3.5 Measurement of Hearing Threshold Level .

The equipment which is used was a Tremetrics RA 500 audiometer, Serial No. 961813. Cal date.25/01/05. Measurement hearing threshold level frequency at 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 8000 Hz. To compare hearing threshold level for test by the knock down audiometric test booth(KDB) and reference booth. Each test uses three replications, and testing two volunteers.

3.6 Instruments use in this study

3.6.1 B&K dual channel real time frequency analyzer, type 2133, Serial No.1389330

3.6.2 B&K sound source, type 4224, Serial No. 2021790

3.6.3 B&K pressure field ½ inch microphone, type 4192, Serial No.2114594

3.6.4 B&K falcon Range ½ inch Microphone preamplifier, type 2669, Serial No. 2084101

3.6.5 B&K pistonphone calibrator,type 4228, Serial No. 203497

3.6.6 Velocicalc plus, Model 8386 A-M-GB, Serial No. 3120366

3.6.7 Tracor AR 200EC test booth.

3.6.8 Tremetrics RA 500 audiometer, Serial No. 961813.

3.7 Data collection

3.7.1 To assemble the knock down audiometric test booth in the same way as when it is in normal use.

3.7.2 Measurement of volume of air supply of three speed of fan

3.7.3 Measurement of background noise outside and inside the knock down audiometric test booth with the sound source and ventilation system not operating.

3.7.4 Measurement of Noise Reduction.

- Operate ventilation system for least 10 minute.

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- Measurement of one-third octave band sound pressure level at four microphone positions inside the knock down audiometric test booth at frequency for three replications

- Measurement of one-third octave band sound pressure level at Six microphone positions outside the knock down audiometric test booth at frequency for three replications

3.7.5 Repeat 3.6.4 by knock down at 10 times

3.7.6 Measurement of hearing threshold level.

3.8 Statistical Analysis

The data were analyzed according to following statistics.

3.8.1 Descriptive statistics

- mean and standard deviation are analyzing the noise reduction at any frequency and volume of air supply.

3.8.2 Inferential statistics

- Analysis of variance the noise reduction when knock down 10 time by ANOVA
- To compare sound pressure level inside the knock down audiometric test booth and of maximum allowable octave-band sound pressure level for audiometric test room accordance 29CFR 1910.95 Occupational noise exposure [Occupational Safety and Health Administration] by One sample t-test

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CHAPTER IV
RESULTS

The results presented in this research were divided into 2 parts as follow:

Part I Result of design.

4.1 The characteristic of the design of the knock down audiometric test booth.

4.2 The design characteristic of ventilation system.

Part II Result of testing.

4.3 General characteristics of reverberation room.

4.4 The assessment for noise reduction in the knock down audiometric test booth.

4.5 The test performance of the ventilation system.

4.6 Measurement of hearing threshold level inside the KDB

Part I Result of design

4.1 The characteristic of the design of the knock down audiometric test booth

This research selected the size interior 28 inch x 38 inch x 61 inches because the researcher would like to comfortable and appropriate the anthropometric of Thai people. The dimension and weight of each parts of the knock down audiometric test booth is shown in table 4-1.

Table 4-1 The dimension and weight of each parts

Side	Dimension (inch)	Weight (Kg)
Front	63x30.25x2.25	31
Left	63x40.25x2.25	33.1
Right – Door	62x39x2.25	37.5
- Door Frame	63x40.25x2.25	10
Back	63x30.25x2.25	22.5
Top	42.5x32.5x2.25	17.2

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Table 4-1 The dimension and weight of each parts(Continues)

Side	Dimension (inch)	Weight (Kg)
Floor	42.5x32.5x2.25	22
Ventilation System	50x12x10	15

The result of this design which selects each material. It can forecast the noise reduction of the knock down audiometric test booth in all frequency is show in table 4-2.

Table 4-2 Forecasts of noise reduction of the knock down audiometric test booth.

Item	Noise reduction (dB)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
KDB	29.12	27.51	27.72	29.84	29.509	28.77

4.2 The design characteristic of the ventilation system

The result of calculation noise attenuation at each frequency of plenum chamber silencer size 10 inch x 12 inch x 50 inch and lining with fiberglass 1 inch is show in table 4-3

Table 4-3 The result of calculation noise attenuation of plenum chamber silencer

Item	Noise attenuation (dB)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Inlet	2.11	0.31	17.97	21.74	23.61	23.82
Outlet	0.95	-0.85	16.94	20.90	22.96	23.20

The result of parallel baffles is made by fiberglass, and the surface with a sieve, The parallel baffles are 4 baffles size 8 inch x 10 inch x 1 inch (inlet), 3 baffles size 4 inch x 10 inch x 1 inch (out let) and spacing between each baffles is 1 inch. The location of parallel baffles is located in the middle between inlet and outlet of silencer. The calculation transmission loss of parallel baffle when install inside the plenum chamber silencer.

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Table 4-4 The result of calculation sound transmission loss of plenum chamber silencer

Item	Sound transmission loss (dB)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Inlet	1.47	0.98	29.4	41.65	46.55	47.04
Outlet	1.47	0.98	29.4	41.65	46.55	47.04

Part II Result of testing

4.3 General characteristics of reverberation room

In this research, testing at Mason Acoustics Aero Acoustical Reverberation Laboratory and Development Center, these are built and operated in accordance with following standard: ASTM E90-90

ISO-140

BS-2750

The effective room volume is 332.6 m^3 . The dimension of reverberation room size 5.51 x 6.9 x 8.75 meter. Sound absorption in reverberation room is less than 14.66 sabins.

Background noise is sound pressure level with the sound source not operate. The background noise of this reverberation room is show in table 4-5.

Table 4-5 the background noise of this reverberation room

Frequency (Hz)	Background noise (dB)		
	inside	Outside	Noise uncertainty
125	16.9	18.4	2.33
250	10.3	10.7	0.53
500	11.5	9.7	0.69
1000	13.5	11.2	0.79
2000	15.8	13.6	1.00
4000	18.8	16.4	0.65
8000	21.7	19.7	0.77

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4.4 The assessment for noise reduction in the knock down audiometric test booth.

Measurement results of noise reduction were show in table 4-6. In term of noise reduction at each frequency, it is found that the knock down audiometric test booth has minimize noise reduction 7.33±0.26 dB at 125 Hz and Maximum noise reduction 35.11±0.52 dB at 8000 Hz

Table 4-6 Octave band noise reduction of the knock down audiometric test booth

Frequency (Hz)	Noise reduction	
	Average	S.D.
125	7.33	0.26
250	14.85	0.44
500	20.85	0.18
1000	18.90	0.21
2000	27.14	0.49
4000	32.39	0.27
8000	35.11	0.52

This result of octave band noise reduction can plot graph is shown in figure 4-1 of which the graph found that octave band noise reduction were trend increase when increase frequency.

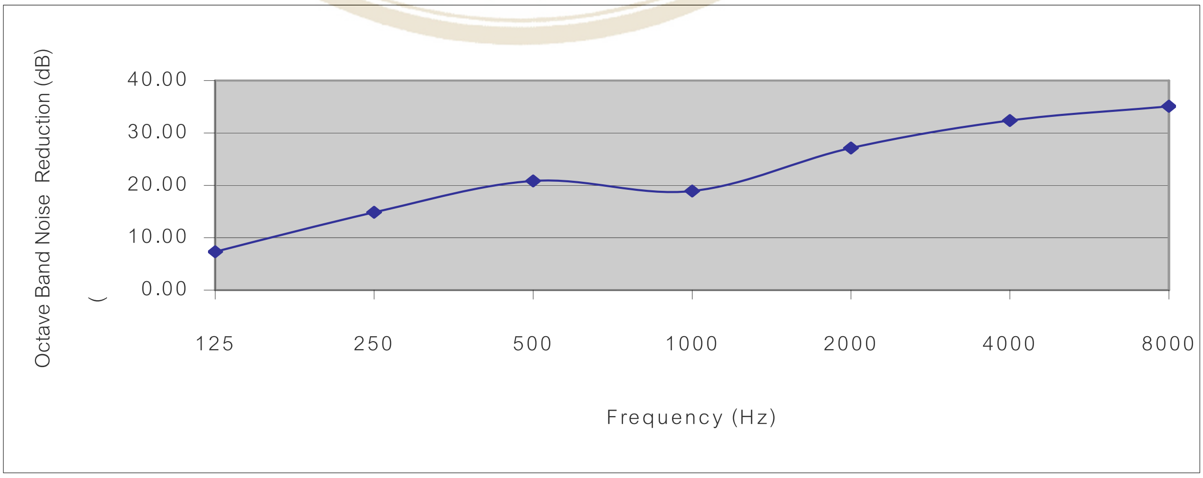

Figure 4-1 Octave band noise reduction at each frequency

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From measurement noise reduction of the knock down audiometric test booth (KDB) of the 10 test performance found that differencetial of sound pressure level outside and inside booth is show in figure 4-2

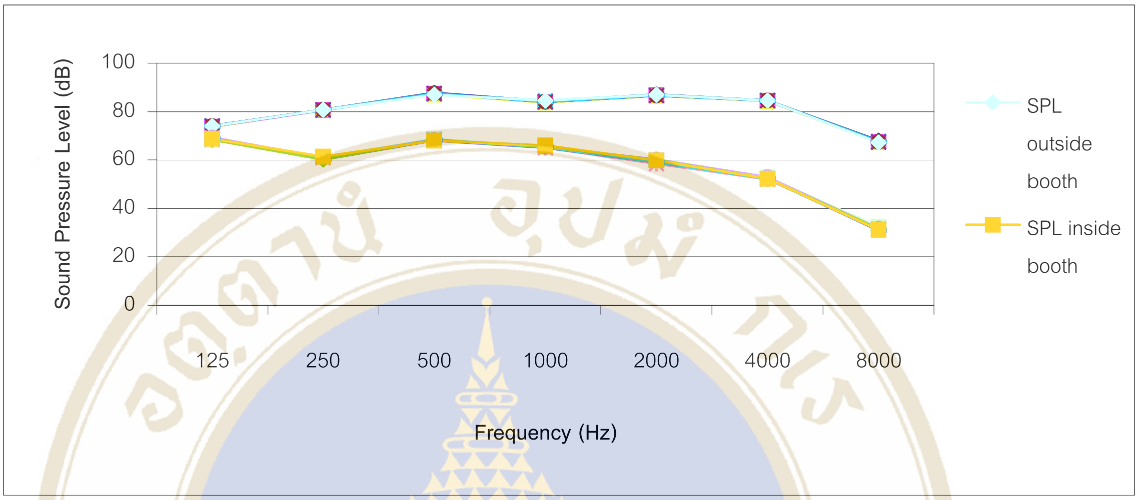

Figure 4-2 Differential of sound pressure level outside and inside the knock down audiometric test booth when knock down 10 times.

When compare the octave band noise reduction of the knock down audiometric test booth between calculation and measurement were shown in table 4-7.

Table 4-7 The comparison of octave band noise reduction of the knock down audiometric test booth between calculation and measurement at each frequency.

Frequency (Hz)	Noise reduction		
	calculation	measurement	Difference
125	29.12	7.33	21.79
250	27.51	14.85	12.66
500	27.72	20.85	6.87
1000	29.84	18.90	10.94
2000	29.51	27.14	2.37
4000	28.77	32.39	-3.62
8000	28.77	35.11	-6.34

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The result indicated that the knock down audiometric test booth has octave band noise reduction less than calculate about 125 Hz = 21.79 dB, 250 Hz = 12.66 dB, 500 Hz = 6.87 dB, 1000 Hz = 10.94 dB, 2000 Hz = 2.37 dB, except at 4000 Hz and 8000 Hz noise reduction measurement more than calculate 3.62 dB and 6.34 dB, as shown in figure 4-3

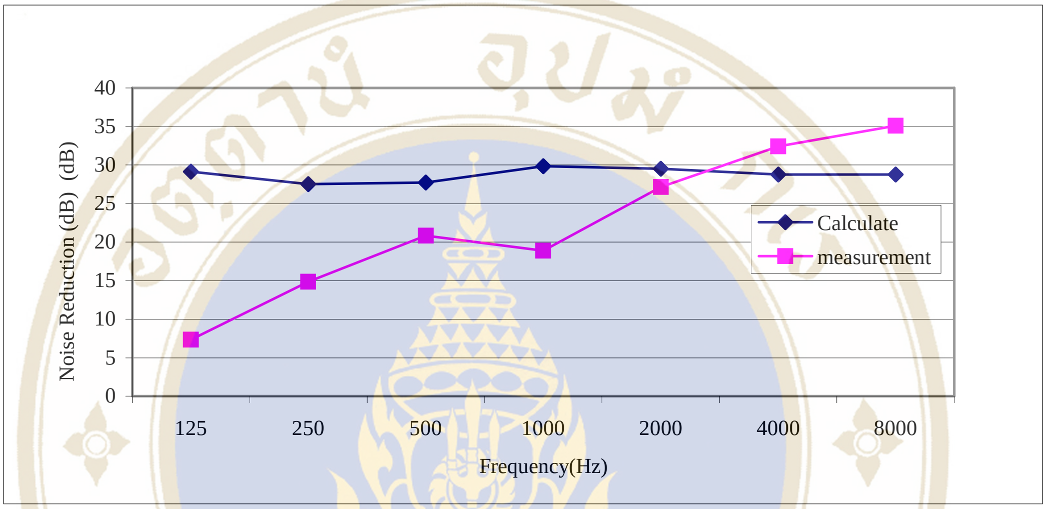

Figure 4-3 Comparison of octave band noise reduction between calculate and measurement of the knock down audiometric test booth at frequency 125-8000 Hz

ANOVA was used to test difference of octave band noise reduction of the knock down audiometric test booth when knock down 10 times were shown in table 4-8.

Table 4-8 The comparison of octave band noise reduction of KDB when knock down 10 times were test by ANOVA

Frequency	average	S.D.	n	d.f.	F	p-value
125	7.33	0.26	90	9	0.190	1.0
250	14.85	0.44	90	9	0.050	1.0
500	20.85	0.18	90	9	0.083	1.0
1000	18.90	0.21	90	9	0.318	0.967
2000	27.14	0.49	90	9	0.617	0.780
4000	32.39	0.27	90	9	1.145	0.342
8000	35.11	0.52	90	9	2.412	0.018

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The result indicated that the octave band noise reduction at all frequency were not significantly different (p-value ;125 Hz = 1.0, 250 Hz = 1.0, 500 Hz = 1.0, 1000 Hz = 0.967, 2000 Hz = 0.780, 4000 Hz = 0.342, 8000 Hz = 0.018). It means that the octave band noise reduction at all frequency were not different when knock down 10 times at 99 % confident limit, as shown in figure 4-4.

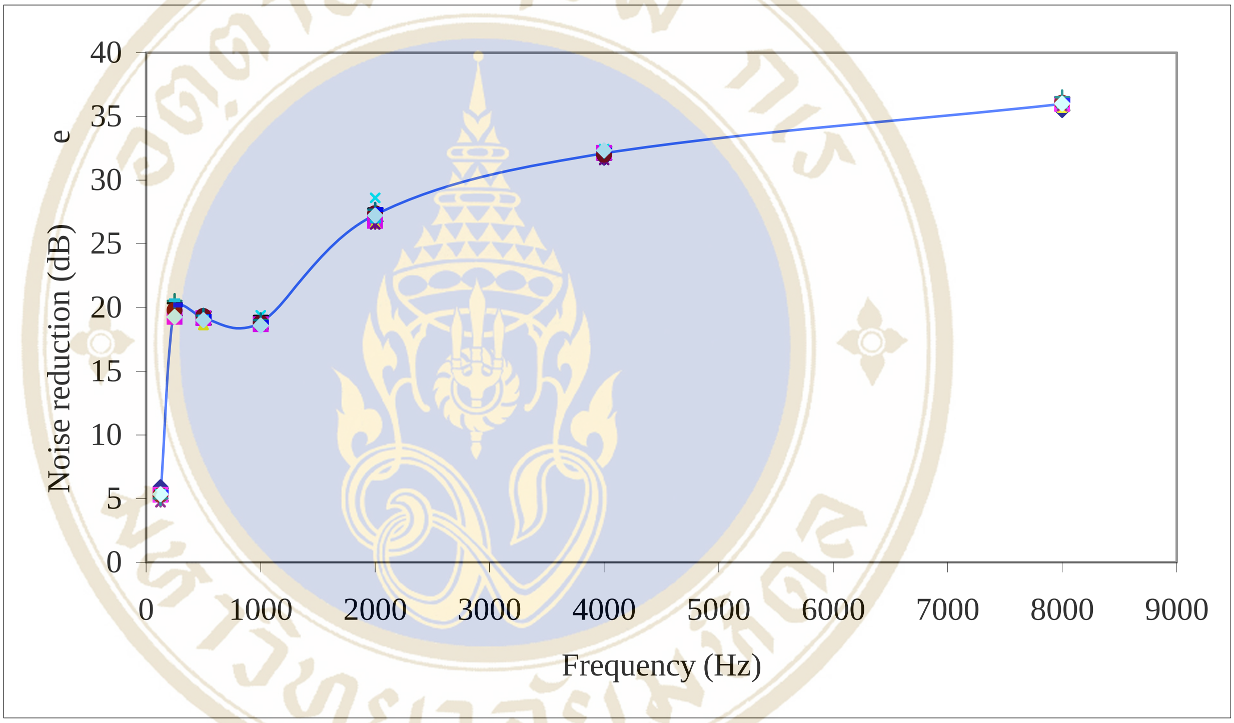

Figure 4-4 Distribution and comparison of octave band noise reduction of the knock down audiometric test booth at frequency 125-8000 Hz

One sample t-test was used to test difference of estimate octave band sound pressure level inside the knock down audiometric test booth(KDB) [it is the estimate sound pressure level from sound pressure level inside room which used to audiometric test at each factory minus with octave band noise reduction of the knock down audiometric test booth] and maximum allowable octave-band sound pressure level for audiometric test room accordance 29CFR 1910.95 Occupational noise exposure [Occupational Safety and Health Administration] as shown in table 4-9.

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Table 4-9 The comparison of estimate octave band sound pressure level inside KDB and OSHA standard by One sample t-test

Frequency (Hz)	29 CFR 1910.95	average	S.D.	n	d.f.	t	p-value
125	40	45.67	0.26	10	9	69.58	<0.001
250	40	38.65	0.44	10	9	-9.73	<0.001
500	40	34.45	0.18	10	9	-99.97	<0.001
1000	40	35.10	0.21	10	9	-72.64	<0.001
2000	47	24.86	0.49	10	9	-143.02	<0.001
4000	57	20.61	0.27	10	9	-428.23	<0.001
8000	67	15.99	0.52	10	9	-311.34	<0.001

The result indicated that estimate octave band sound pressure level inside the knock down audiometric test booth(KDB) at all frequency (250 Hz =38.65±0.44 dB, 500 Hz = 34.45±0.18 dB, 1000 Hz = 35.10±0.21 dB, 2000 Hz = 24.86±0.49 dB, 4000 Hz = 20.61±0.27 dB, 8000 Hz = 15.99±0.52 dB) was significantly less than of maximum allowable octave-band sound pressure level for audiometric test room accordance 29CFR 1910.95 Occupational noise exposure at 95 % confident limit(p<0.001). Except frequency 125 Hz, estimate sound pressure level inside the knock down audiometric test booth (45.67±0.26 dB) was significantly more than of maximum allowable octave-band sound pressure level for audiometric test room accordance 29CFR 1910.95 Occupational noise exposure at 95 % confident limit(p<0.001)

4.5 The test performance of the ventilation system

At inlet of ventilation system inside the knock down audiometric test booth, the wind velocity, volume and air change of air supply were shown in table 4-10. The result indicated that volume of air supply at maximum speed of fan was 579.9±4.51 LPM, moderate speed of fan was 498±11.67 LPM, minimum speed of fan was 579.9±7.38 LPM. that each speed of fan was 32.71±0.66, 28.09±0.25 and 25.44±0.42, respectively.

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Table 4-10 Wind velocity and volume of air supply at three speeds of fan

Item		Velocity(ft/min)	Volume		Air
			CFM	LPM	Change
Maximum	Average	110	21.48	579.9	32.71
	S.D.	0.85	0.17	4.51	0.66
Moderate	Average	94.1	18.44	498	28.09
	S.D.	2.2	0.43	11.67	0.25
Minimum	Average	85.2	16.7	451	25.44
	S.D.	1.39	0.27	7.38	0.42

4.6 Measurement of hearing threshold level inside the booth

To confirm that the KDB in this study can be used for audiometric measurement, the testing with 2 volunteers for audiometric testing have been performed with KDB and the reference audiometric booth for audiometric measurement result comparison, as per result in table 4-11 and table 4-12 data, it proved that the 2 volunteers' measured hearing threshold level in each frequency and with the same volunteers' ears have no difference found.

Table 4-11 Comparisons of hearing threshold level for volunteer 1st between test by the knock down audiometric test booth(KDB) and the reference booth.

Frequency	Left			Right		
Hz	KDB		Reference Booth	KDB		Reference Booth
	Jack	Seal	Seal	Jack	Seal	Seal
500	15	15	10	15	15	10
1000	15	15	15	15	15	15
2000	10	10	10	10	10	10
3000	15	15	10	10	10	10
4000	10	10	10	15	15	15
6000	15	15	10	15	15	15
8000	25	15	20	5	5	5

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Table 4-12 Compare hearing threshold level for volunteer 2nd between test by the knock down audiometric test booth(KDB) and the reference booth.

Frequency Hz	Left			Right		
	KDB		Reference Booth	KDB		Reference Booth
	Jack	Seal	Seal	Jack	Seal	Seal
500	15	10	10	10	10	10
1000	10	10	10	15	10	15
2000	10	10	10	10	10	10
3000	25	20	20	15	15	15
4000	10	15	15	15	15	15
6000	15	25	20	20	20	20
8000	-5	-5	-10	10	5	10

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CHAPTER V
DISCUSSION

5.1 Discussion of Study Design

This research is a design and experimental study of noise reduction of the knock down audiometric test booth with ventilation system.

The objective of this research is find out the effectiveness of the knock down audiometric test booth. The concept of design of the knock down audiometric test booth is selected material which it have sound transmission loss and sound absorption coefficient cover all frequency. The limitation of this research is to select the material because the researcher would like the specific of sound transmission loss and sound absorption coefficient from literature review.

5.2 Pitfalls and limitation of this study

This research has the limitation on the background noise of reverberation room. It could not to be controlling the background noise to exactness. So, the researcher used high test signal level.

To prevent error from using the B&K dual channel real-time frequency analyzer, the researcher was to check and calibrate everyday before starting the experiment.

In this research, the researcher used one microphone to measure sound pressure level both inside and outside the knock down audiometric test booth. So, the difference of time, duration of measure sound pressure level between inside and outside the knock down audiometric test booth could affect the result of measurement.

The researcher attempted to find out the effect of potential factor and try to control all involvement and influence:

5.2.1 The vibration of floor of reverberation room

The vibration of floor of reverberation room is a factor that effects the sound pressure level inside the knock down audiometric test booth. So, when constructing

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this, the knock down audiometric test booth has heavy duty in locking casters to reduce the vibration from floor of reverberation room.

5.2.2 The vibration of fan

The vibration of fan is a factor that effects the sound pressure level inside the knock down audiometric test booth. So, it inserts a flexible joint between the fan and plenum chamber silencer to reduce the vibration from fan.

5.2.3 The number blade of fan

The number blade and speed of fan is a factor that effects the frequency of noise fan. Therefore, the researcher selected the fan that has 5 blades to make frequency of noise fan -- 130.8 Hz., which was not the frequency for audiometric testing(500-6000 Hz.).

5.3 Discussion of Study Result.

5.3.1 Noise reduction.

The average octave band noise reduction of the knock down audiometric test booth at frequency 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz were 5.31 dB, 19.85 dB, 19.18 dB, 18.82 dB, 27.26 dB, 32.11 dB and 35.98 dB, respectively. This result indicated that the noise reduction at frequency 125 Hz was lower than other frequency because it was same from fan. And the ventilation system has good noise reduction since frequency at 500 Hz. And the material for constructing the knock down audiometric test booth has high efficiency since the frequency is at 500 Hz. But this frequency does not effect the audiometric test booth because this frequency does not require audiometric test. And this result found that octave band noise reduction 250-8000 Hz were trend increase when increases frequency. It was also found out that the same pattern occurred in the sound transmission loss of material.

5.3.2 The comparison of noise reduction of knock down audiometric test booth when knock down 10 times

The result showns that the octave band noise reduction at 125 – 8000 Hz was not significantly different (p-value =0.018-1.0) To notice, p-value were trend decrease when increase frequency. It is because microphone has random-incidence response trend increase since 4000 Hz and uncertainty 0.2 dB.

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5.3.3 The comparison of estimate sound pressure level inside the knock down audiometric test booth(KDB) and maximum allowable octave-band sound pressure level for audiometric test room accordance to 29CFR 1910.95 Occupational noise exposure

At frequency 125 Hz, estimated sound pressure level inside the knockdown audiometric test booth was significantly more than of maximum allowable octave-band sound pressure level for audiometric test room accordance 29CFR 1910.95 Occupational noise exposure at 95 % confident limit (p-value <0.001). It means that sound pressure level inside the knock down audiometric test booth at frequency 125 Hz can not be used for audiometric test if sound pressure level outside the knock down audiometric test booth over 47.33 dB. But at frequency 250 Hz – 8000 Hz estimated sound pressure level inside the knock down audiometric test booth were significantly less than of maximum allowable octave-band sound pressure level for audiometric test room accordance to 29CFR 1910.95 Occupational noise exposure at 95 % confident limit (p-value<0.001). It means that sound pressure level inside the knock down audiometric test booth at frequency 250 Hz- 8000 Hz less than maximum allowable octave-band sound pressure level for audiometric test room accordance 29CFR 1910.95 Occupational noise exposure. So, it can be used for audiometric test because audiometric test requires test frequency including as a minimum 500, 1000, 2000, 4000, and 6000 Hz.

5.3.4 Wind velocity and volume of air supply

At inlet of ventilation system inside the knock down audiometric test booth, the volume of air supply at maximum speed of fan was 579.9±4.51 LPM, moderate speed of fan was 498±11.67 LPM, minimum speed of fan was 451±7.38 LPM. So, the volume of air supply of the knock down audiometric test booth sufficient to make comfortable and not feeling to smell. And in accordance with the ministerial regulation of ministry of industry issue 2nd determine ventilation for workstation not to keep and/or use toxic material, chemical, flammable, explosion material or other material may be have toxic or dust not less than 18.5 CFM (0.5 m^3/min/man) and ASTM D6245 recomdation ventilation for control carbon dioxide not exceeding 700 ppm and not feeling to smell from sweat for sitting person not less than 16.66 CFM (0.45 m^3/min/man)

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5.3.5 Measurement of hearing threshold level inside the booth.

To compare the hearing threshold level in each frequency with the same volunteer’s ear, these is no difference in the hearing threshold level. This means that the KDB can be used for audiometric test.

The limitation of this testing is, the audiometer must be directly operated with 5 dB increasing and decreasing incrimination which will effect the hearing threshold level, and the nuisance noise(outside the booth), which occurred during the testing period may effect with the hearing threshold level.

From this testing, the researcher found out that KDB has the limitation with the low frequency noise reduction, but the low frequency noise will not effect with the practical audiometric testing result which confirmed by the audiologist.

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CHAPTER VI
CONCLUSION AND RECOMMENTDATION

6.1 Conclusion

This research is a design, construct and experimental study of noise reduction of the knock down audiometric test booth with ventilation system. It was interior size 28 inches depth, 38 inches width, and 61 inches height. It had 7 parts which it makes to steel 0.03 inches, polyurethane foam 2 inches, plywood 1/4 inches and perforate steel 0.03 inches, respectively. The door frame was L-shape steel. The plenum chamber silencer was 10 inches depth, 12 inches width, and 50 inches height, which had fiberglass 1 inch thickness lining on the inner side of wall. Inside the plenum chamber silencer, there were 4 parallel baffles (inlet), 3 parallel baffles(outlet) with each baffle about 1 inch thickness. The results from this experiment were summarized as follow:

The average octave band noise reduction of the knock down audiometric test booth at frequency 125 – 8000 Hz were 5.31 dB, 19.85 dB, 19.18 dB, 18.82 dB, 27.26 dB, 32.11 dB and 35.98 dB, respectively. The octave band noise reduction of the knock down audiometric test booth when knock down 10 time at 125 – 8000 Hz were not significantly different (p-value =0.018-1.0)

The estimated sound pressure level inside the knock down audiometric test booth at frequency 125 Hz was significantly exceed than of maximum allowable octave-band sound pressure level for audiometric test room accordance to 29CFR 1910.95 Occupational noise exposure at 95 % confident limit (p-value<0.001). The estimate sound pressure level inside the knock down audiometric test booth at frequency 250 - 8000 Hz did significantly not exceed the maximum allowable octave-band sound pressure level for audiometric test room accordance to 29CFR 1910.95 Occupational noise exposure at 95 % confident limit (p-value<0.001).

The volume of air supply at maximum speed of fan was 579.9±4.51 LPM, moderate speed of fan was 498±11.67 LPM, minimum speed of fan was 451±7.38 LPM. The volume of air supply was 25.4 – 32.71 Air change per hour.

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6.2 Recommendation

6.2.1 Recommendation for using of the knock down audiometric test booth.

In this research, the results indicated that the knock down audiometric test booth effectively reduces the sound pressure level outside the knock down audiometric test booth. In particular, the gained noise reduction enables the audiometric test in surrounding where the sound pressure level outside does not exceed the following octave band noise level : 125 Hz = 47.33 dB, 250 Hz = 54.85 dB, 500 Hz = 60.85 dB, 1000 Hz = 58.9 dB, 2000 dB = 74.14 dB, 4000 Hz = 89.39 dB, and 8000 Hz = 102.11 dB.

6.2.2 Recommendation of further study

- The next study should consider the difference types of material. It is because in this study, low noise reduction at low frequency make to hearing conversation outside the booth.

- To increase thickness of steel surround each part to harden, since this study used thin steel, it caused weld difficult and weakly. But it may increase weight.

- In this research, right part of the knock down audiometric test booth had heavy weight (48.1 Kg.) because this part had ventilation system. So, next study it is suggested to change fabricate ventilation system at back part, or change construct ventilation system inside wall.

- For validity, the next study should to jack panel testing by audiometer calibrator unit placing in the booth instead use volunteer.

- The next study should construct handle type hole inside door for comfortable open-close and mobile.

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APPENDIX

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Figure A-1 Demonstration of the knock down audiometric test booth.

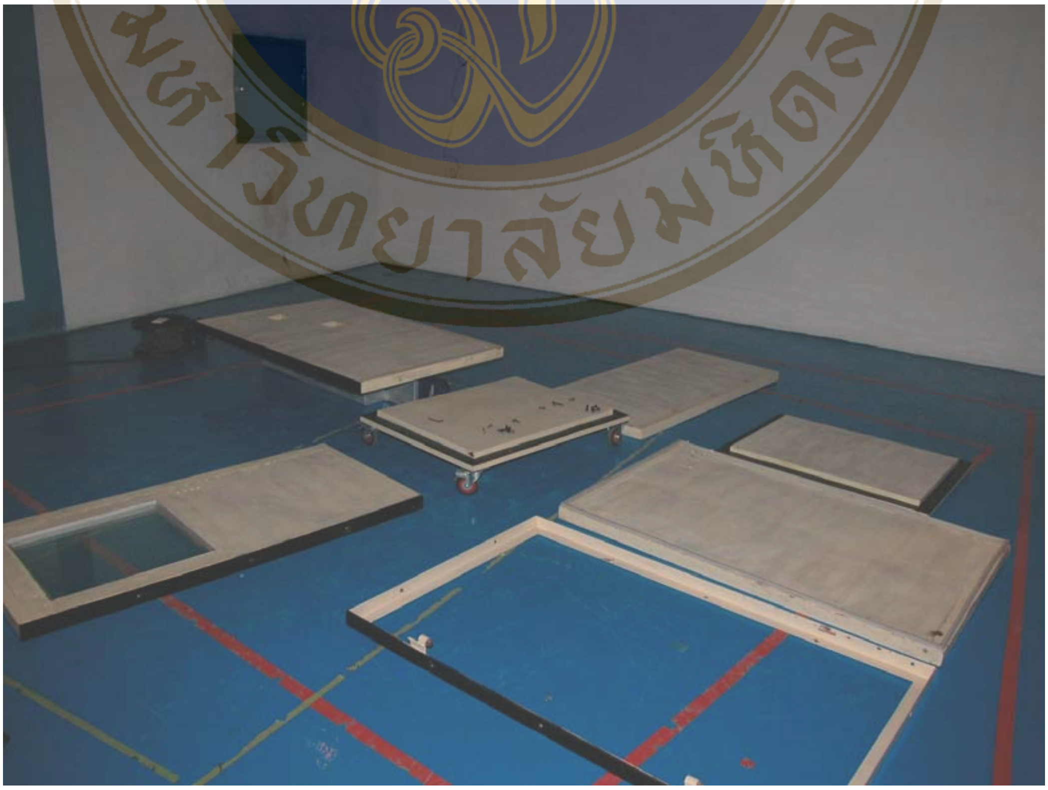

Figure A-2 Demonstration of each part the knock down audiometric test booth

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Figure A-3 Demonstration of assembly

Figure A-4 Demonstration of &K dual channel real time frequency analyzer

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Figure A-5 Demonstration of B&K sound source, type 4224

Figure A-6 Demonstration of B&K pressure field ½ inch microphone

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Figure A-7Demonstration of reverberation room.

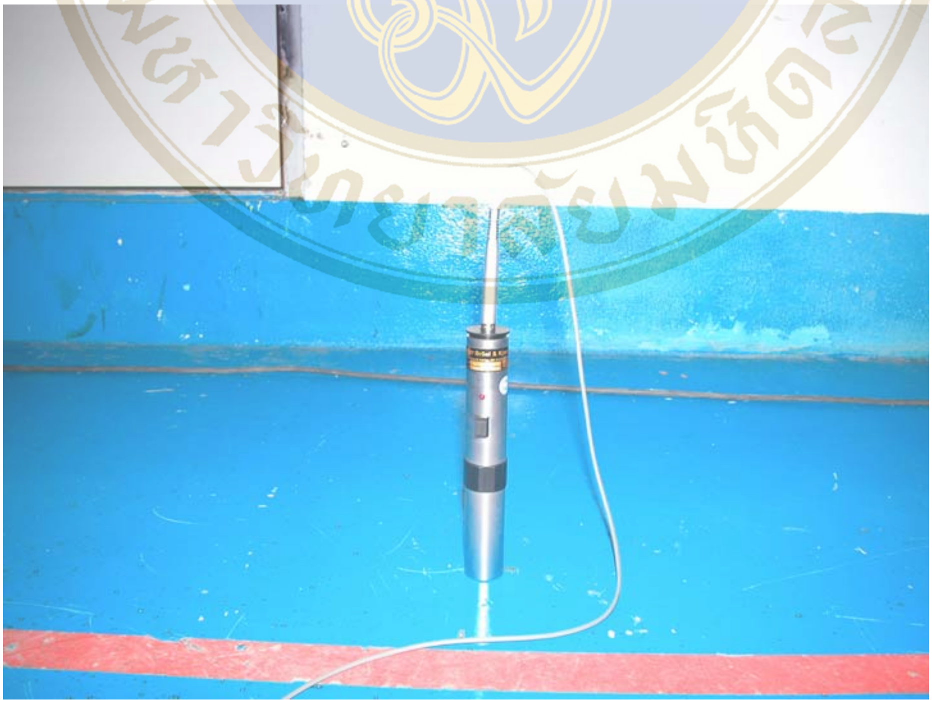

Figure A-8Demonstration of calibration microphone

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Figure A-9Demonstration position of B&K pressure field ½ inch microphone inside the knock down audiometric test booth

Figure A-10 Demonstration position of B&K pressure field ½ inch microphone outside the knock down audiometric test booth

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Figure A-11Demonstration of measurement wind velocity

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Calibration Certificate of Piston phone

NATA Accredited Lab No 1301

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Head Office: Suite 2, 6-10 Talavera Road, North Ryde NSW 2113
Phone: 02-9889 8888 Fax: 02-9889 8866
Email: bk.service@spectris.com.au www.bksv.com.au

Acoustic & Vibration Measurements

CALIBRATION CERTIFICATE

No: B.K. 93710803

Owner: Mason Acoustics Co. Ltd.
49/11 Moo 4, Soi Kingkaew Rd, Rachatheva, Bangplee, Samutprakarn 10540
Bangkok, Thailand

Manufacturer: Brüel & Kjær

Equipment Description: Pistonphone

Model No: 4228 **Serial No:** 2034997 **Type:** N/A

Associated Microphone Type: N/A **Serial No:** N/A

Tests Performed: Measured Sound Pressure Level: 123.9 dB
re 20 µ Pa at reference conditions (1013 hPa)
Measured Frequency: 251.0 Hz
Uncertainty, 95% confidence level +/-0.15 dB

Conditions of Test

Ambient Pressure: 1013 hPa
Temperature: 23 °C
Relative Humidity: 31 %

These measurements are traceable to NML - National Measurement Laboratory, CSIRO, West Lindfield, Australia.

An endorsed Test Document may not be published or reproduced except in full without the permission in writing of this Testing Authority.

This laboratory is accredited by the NATIONAL ASSOCIATION OF TESTING AUTHORITIES OF AUSTRALIA. The tests reported herein have been performed in accordance with its terms of accreditation

Test/Issue Date: 19/08/2003 **Authorised Signatory:**

Page 1 of 1

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SERVICE REPORT

Brüel & Kjær Australia

P.2

Company Name: Palmer Acoustics (Australia) Pty Ltd

Job No: 74194/93

Checked according to manufacturers specifications

Calibration	Passed	Failed	Not Applicable
Instrument No. 1	19/08/2003		

Description of Repair

Instrument No. 1: Pistonphone
Type: 4228 **S/N:** 2034997
Unit output well below spec. (121.3 dB) and frequency erratic between 250Hz - 500Hz
Pistons and cam cleaned. NOTE Large quantities of grease were removed from the pistons & cams.
This grease should not be used on this instrument.
Unit checked and traceable calibration performed as requested,
Certificate No 93710803

Service Engineer Craig Patrick

A Division of Spectris Australia Pty Ltd - ABN 51 001 216 128

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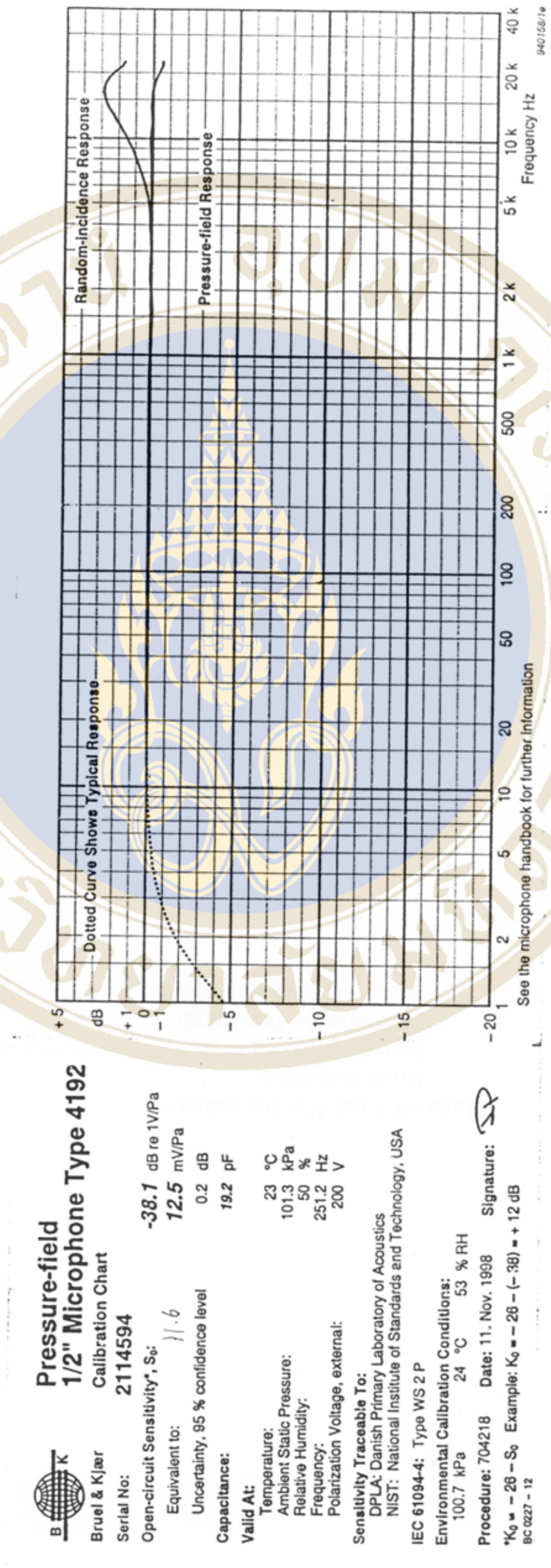
Calibration Certificate of Microphone



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Data of Test Performance

Table A- 1 1/3 Octave Band Noise Reduction of the 10 test performance at 100-10000 Hz , three replications

Frequency (Hz)	1/3 Octave Band Noise Reduction									
	1	2	3	4	5	6	7	8	9	10
100	6.61	6.61	6.40	6.10	6.18	6.62	6.47	6.02	6.67	6.70
	7.30	6.56	6.72	5.94	5.89	6.05	6.12	6.44	6.42	6.41
	6.50	6.33	6.36	6.13	6.25	6.05	6.55	6.57	6.73	6.79
125	6.04	5.37	4.85	5.14	4.61	4.93	5.22	5.25	5.57	5.35
	6.10	5.17	5.80	5.37	4.68	5.50	4.87	5.92	5.39	5.21
	5.49	5.33	5.24	4.98	4.88	5.36	4.96	5.29	5.86	5.46
160	15.31	14.59	15.05	15.35	14.83	14.89	14.78	14.65	14.95	14.45
	16.16	14.88	15.00	15.40	15.05	15.21	15.09	15.19	15.25	14.89
	15.33	14.60	14.94	15.52	15.24	15.22	14.85	15.03	15.14	14.65
200	10.31	9.57	10.07	11.09	10.92	11.10	10.83	10.81	11.02	10.07
	11.17	9.82	10.69	11.36	10.77	10.95	10.77	10.49	11.13	10.37
	10.46	9.87	10.93	11.42	11.42	11.56	10.59	11.08	11.07	10.50
250	19.77	19.31	20.62	19.55	19.63	19.67	20.43	20.11	20.46	19.12
	19.82	19.21	19.82	19.67	19.87	19.84	20.53	20.48	20.76	19.03
	19.53	19.24	19.90	19.29	19.64	19.87	20.56	19.95	20.45	19.62
315	24.16	24.01	24.32	25.34	25.01	24.20	24.73	24.88	25.46	23.08
	24.34	24.29	24.11	25.41	24.98	24.14	24.84	25.05	25.51	23.29
	24.28	23.97	24.25	25.47	25.03	24.11	24.81	24.77	25.51	23.41
400	23.17	23.42	23.15	23.85	23.66	23.20	23.65	23.46	24.00	23.31
	23.14	23.59	23.15	23.66	23.45	23.13	23.64	23.28	23.86	23.37
	23.09	23.94	22.99	23.74	23.79	23.55	23.57	23.96	24.24	23.14
500	19.18	19.27	18.86	19.10	19.50	19.48	19.57	19.42	19.45	19.07
	19.06	18.98	18.32	19.23	19.10	19.30	19.20	19.08	19.36	19.00
	19.03	19.25	18.74	19.32	19.23	19.26	19.30	19.36	19.04	18.93
630	20.79	21.03	20.61	21.06	20.91	20.73	20.49	20.91	20.77	20.68
	20.92	21.13	20.80	21.06	21.24	20.79	21.00	20.95	20.88	20.62
	20.98	21.34	20.83	20.96	21.23	21.09	21.06	21.23	20.69	20.90
800	18.29	17.51	17.52	18.04	17.95	17.98	17.97	17.67	17.83	17.53
	18.20	17.82	17.69	18.15	17.50	17.86	18.01	17.51	17.73	17.45
	18.13	18.27	17.77	17.67	17.81	17.67	17.82	17.80	17.59	17.16
1000	18.79	18.66	18.94	19.35	18.51	18.73	18.85	18.61	18.55	18.49
	19.05	18.88	18.67	19.43	18.65	18.64	19.08	18.84	18.74	18.88
	18.67	18.50	18.89	19.36	18.74	18.95	19.15	18.98	18.81	18.42
1250	20.98	20.83	20.45	21.24	20.07	20.52	20.62	20.62	20.12	20.19
	20.98	20.44	20.22	20.85	19.88	20.27	20.48	20.62	19.96	20.62
	20.53	20.91	20.54	21.20	20.16	20.42	20.61	20.69	20.16	20.05
1600	26.10	25.52	24.80	26.06	24.94	25.63	25.61	24.97	25.51	25.03
	25.86	25.46	24.81	26.65	25.13	25.54	25.61	25.39	25.51	24.93
	26.05	25.36	24.76	26.24	24.90	25.47	25.53	25.23	25.21	25.37

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Table A- 1 1/3 Octave Band Noise Reduction of the 10 test performance at 100-10000 Hz , three replications (Continue)

Frequency (Hz)	1/3 Octave Band Noise Reduction									
	1	2	3	4	5	6	7	8	9	10
2000	27.41	26.74	26.94	28.55	26.69	27.73	27.66	27.87	26.74	27.17
	27.41	26.61	26.45	28.67	26.55	27.39	27.74	27.68	26.84	27.13
	27.34	27.08	26.38	28.61	26.30	27.07	27.58	27.49	26.63	27.31
2500	30.24	30.10	30.00	30.71	28.93	29.84	30.06	29.49	29.20	29.52
	30.44	29.64	29.85	30.65	28.97	29.76	29.93	29.03	29.14	29.15
	30.67	29.94	29.93	30.79	28.89	29.65	30.14	29.30	29.42	29.51
3150	31.81	32.00	31.31	32.03	31.06	31.43	32.02	32.29	31.65	31.51
	31.79	31.98	31.90	32.20	31.34	31.79	32.43	31.79	31.52	31.62
	31.81	32.09	32.04	32.54	31.14	31.55	32.39	32.26	31.95	31.48
4000	31.85	32.09	32.22	32.44	31.60	32.05	32.51	32.12	32.07	32.28
	31.92	32.18	31.93	32.35	31.34	31.93	32.25	32.52	32.17	32.29
	31.54	32.13	32.11	32.53	31.79	32.01	32.09	32.43	32.37	32.48
5000	33.28	33.64	33.19	33.63	33.09	32.99	33.61	33.42	33.38	33.71
	33.20	33.61	32.82	33.61	32.91	33.04	33.74	33.38	33.29	33.96
	33.55	33.52	33.12	33.56	32.97	33.06	33.73	33.23	33.34	33.90
6300	35.12	35.15	35.38	35.33	34.87	35.31	35.32	35.40	35.39	35.36
	35.42	35.53	35.22	34.81	34.77	35.33	35.51	35.61	35.46	35.15
	35.06	35.58	35.20	35.31	35.08	35.52	35.55	35.85	35.72	35.39
8000	35.50	35.94	35.66	36.10	35.77	36.16	36.56	36.47	35.89	35.90
	35.50	35.99	35.80	36.28	35.67	36.02	36.43	35.94	35.60	36.01
	35.53	35.99	35.62	36.20	35.99	36.08	36.54	36.39	35.80	36.10
10000	34.52	33.64	33.62	36.36	32.79	34.58	35.38	35.03	33.07	33.70
	34.24	33.76	33.35	36.42	33.26	34.51	35.70	35.03	33.03	33.60
	34.50	33.52	33.34	36.28	33.18	34.66	35.70	35.19	33.01	33.58

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Table A- 2 Mean of octave band noise reduction of the 10 test performance at 125-8000 Hz

Frequency Hz	octave band noise reduction of the 10 test performance										Mean	S.D.
	1	2	3	4	5	6	7	8	9	10		
125	7.83	7.34	7.35	7.12	6.89	7.24	7.16	7.40	7.58	7.40	7.33	0.26
250	14.75	13.91	14.70	15.30	15.11	15.22	14.92	14.94	15.25	14.37	14.85	0.44
500	20.74	20.96	20.45	20.95	20.99	20.88	20.94	20.96	20.95	20.67	20.85	0.17
1000	19.16	18.93	18.83	19.29	18.71	18.88	19.05	18.87	18.73	18.59	18.90	0.21
2000	27.58	27.01	26.62	28.18	26.53	27.24	27.39	27.05	26.86	26.89	27.14	0.49
4000	32.24	32.53	32.26	32.72	31.85	32.16	32.70	32.57	32.36	32.48	32.39	0.27
8000	35.02	34.89	34.68	35.87	34.45	35.31	35.83	35.63	34.59	34.86	35.11	0.52
STC	21	21	21	22	21	21	21	21	21	21		

Table A- 3 Mean of estimate octave band sound pressure level inside the knock down audiometric test booth of the 10 test performance at 125-8000 Hz

Frequency Hz	estimate octave band sound pressure level inside KDB										Avg
	1	2	3	4	5	6	7	8	9	10	
125	45.17	45.66	45.65	45.88	46.11	45.76	45.84	45.60	45.42	45.60	45.67
250	38.75	39.59	38.80	38.20	38.39	38.28	38.58	38.56	38.25	39.13	38.65
500	34.56	34.34	34.85	34.35	34.31	34.42	34.36	34.34	34.35	34.63	34.45
1000	34.84	35.07	35.17	34.71	35.29	35.12	34.95	35.13	35.27	35.41	35.10
2000	24.42	24.99	25.38	23.82	25.47	24.76	24.61	24.95	25.14	25.11	24.86
4000	20.76	20.47	20.74	20.28	21.15	20.84	20.30	20.43	20.64	20.52	20.61
8000	16.08	16.21	16.42	15.23	16.65	15.79	15.27	15.47	16.51	16.24	15.99

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Table A-4 Velocity, Volume and Air change for test 12 position in cross section and eight replications at Maximum fan speed.

Test No.	Velocity (ft/min)															Volume(Q)		Air change
	1	2	3	4	5	6	7	8	9	10	11	12	Min	Max	Avg	cfm	LPM	
1	120	121	105	89	101	101	73	73	87	126	142	154	73	154	108	21.1	569.8	32.14
2	127	125	117	78	87	92	71	72	79	125	148	148	71	148	106	20.73	559.6	31.57
3	143	129	116	93	96	92	68	68	82	140	155	148	68	155	111	21.72	586.5	33.09
4	137	140	113	75	100	90	77	85	89	130	144	150	75	150	111	21.72	586.5	33.09
5	134	133	111	76	93	93	66	80	91	129	137	152	152	152	108	21.15	571.1	32.22
6	139	131	113	75	92	103	79	74	84	118	154	160	74	160	110	21.59	583	32.89
7	139	137	124	81	91	105	65	84	89	128	154	149	65	154	112	21.98	593.6	33.49
8	135	138	112	83	94	96	65	81	100	127	141	163	65	163	111	21.81	588.7	33.21
Average															110	21.48	579.9	32.71

Table A-5 Velocity, Volume and Air change for test 12 position in cross section and eight replications at Moderate fan speed.

Test No.	Velocity (ft/min)															Volume(Q)		Air change
	1	2	3	4	5	6	7	8	9	10	11	12	Min	Max	Avg	cfm	LPM	
1	108	116	101	74	83	80	59	53	74	113	132	142	53	142	94.6	18.54	500.5	28.24
2	110	117	97	64	79	78	63	62	77	106	125	135	62	135	92.8	18.18	490.8	27.69
3	103	102	111	83	97	86	57	61	72	109	129	132	57	132	95.2	18.65	503.6	28.41
4	115	117	106	66	78	88	53	58	67	104	135	137	53	137	93.7	18.36	495.7	27.96
5	108	111	113	76	83	88	57	60	75	110	128	122	57	128	94.3	18.47	498.8	28.14
6	112	118	110	74	77	80	61	66	69	107	131	135	61	135	93.5	18.32	494.6	27.90
7	113	111	99	74	86	95	59	56	62	105	129	136	56	136	93.8	18.38	496.1	27.99
8	112	114	101	78	81	78	59	69	73	112	129	136	59	136	95.2	18.65	503.6	28.41
Average															94.1	18.44	498	28.09

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Table A-6 Velocity, Volume and Air change for test 12 position in cross section and eight replications at Minimum fan speed.

Test No.	Velocity (ft/min)															Volume(Q)		Air change
	1	2	3	4	5	6	7	8	9	10	11	12	Min	Max	Avg	cfm	LPM	
1	107	110	100	64	76	70	59	52	62	99	113	109	52	113	85.1	16.68	450.3	25.40
2	112	108	94	62	68	66	55	68	66	98	115	112	55	115	85.3	16.73	451.6	25.48
3	109	111	98	68	66	77	57	55	73	80	113	125	55	125	86	16.86	455.1	25.67
4	109	105	97	61	69	78	65	58	69	96	117	118	58	118	86.8	17.02	459.5	25.92
5	104	112	87	64	73	71	56	66	62	106	116	122	56	122	86.6	16.97	458.2	25.85
6	107	108	93	59	70	76	52	61	79	101	116	104	52	116	85.5	16.76	452.5	25.52
7	102	97	103	64	63	75	54	48	73	100	114	113	48	114	83.8	16.43	443.6	25.03
8	96	105	92	63	74	72	53	63	65	94	106	109	53	109	82.7	16.2	437.5	24.68
Average															85.2	16.7	451	25.44

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Dimensions of a knock down adiometric test booth and plenum chamber silencer

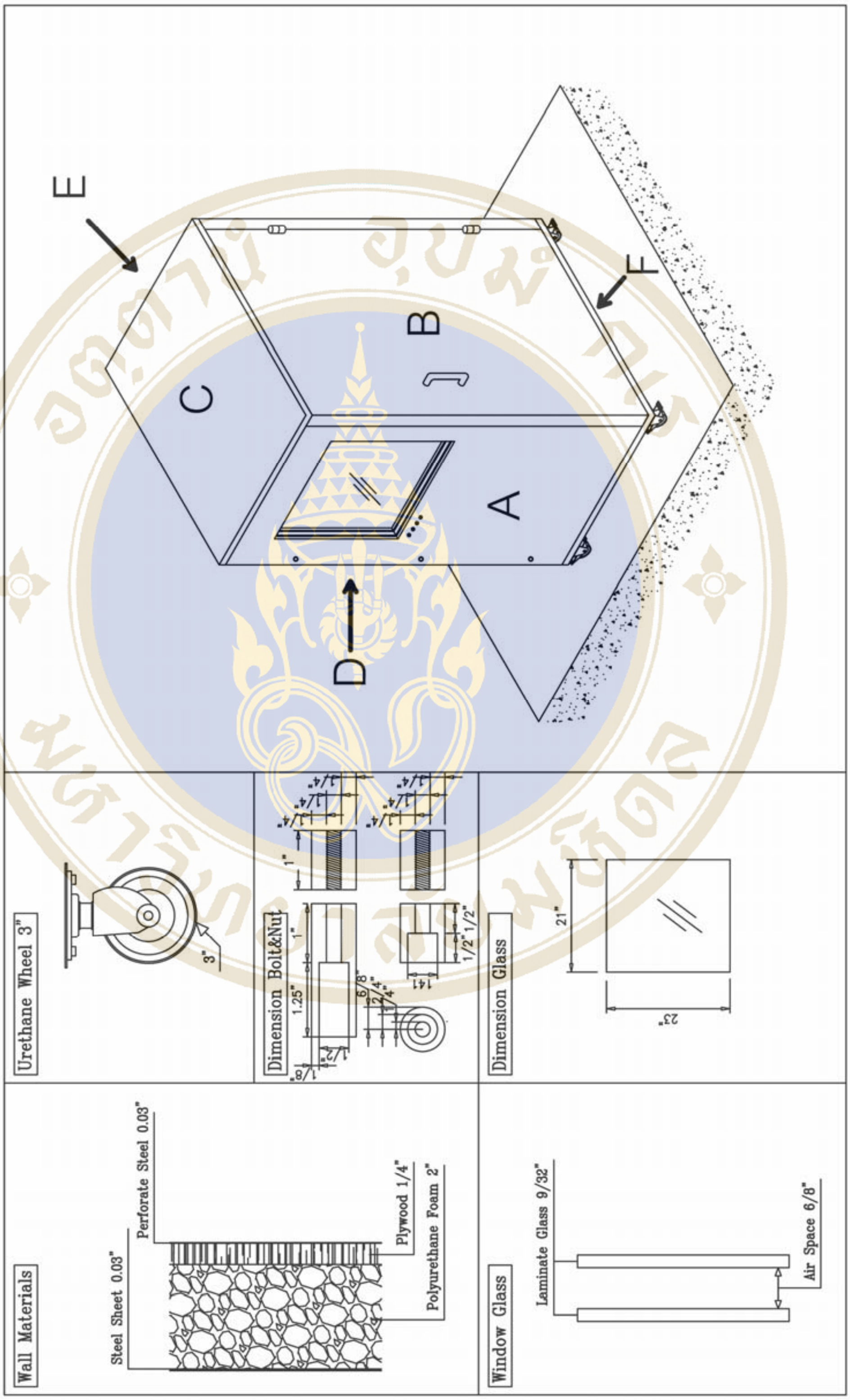

Figure A-12 Material detail of a knock down audiometric test booth

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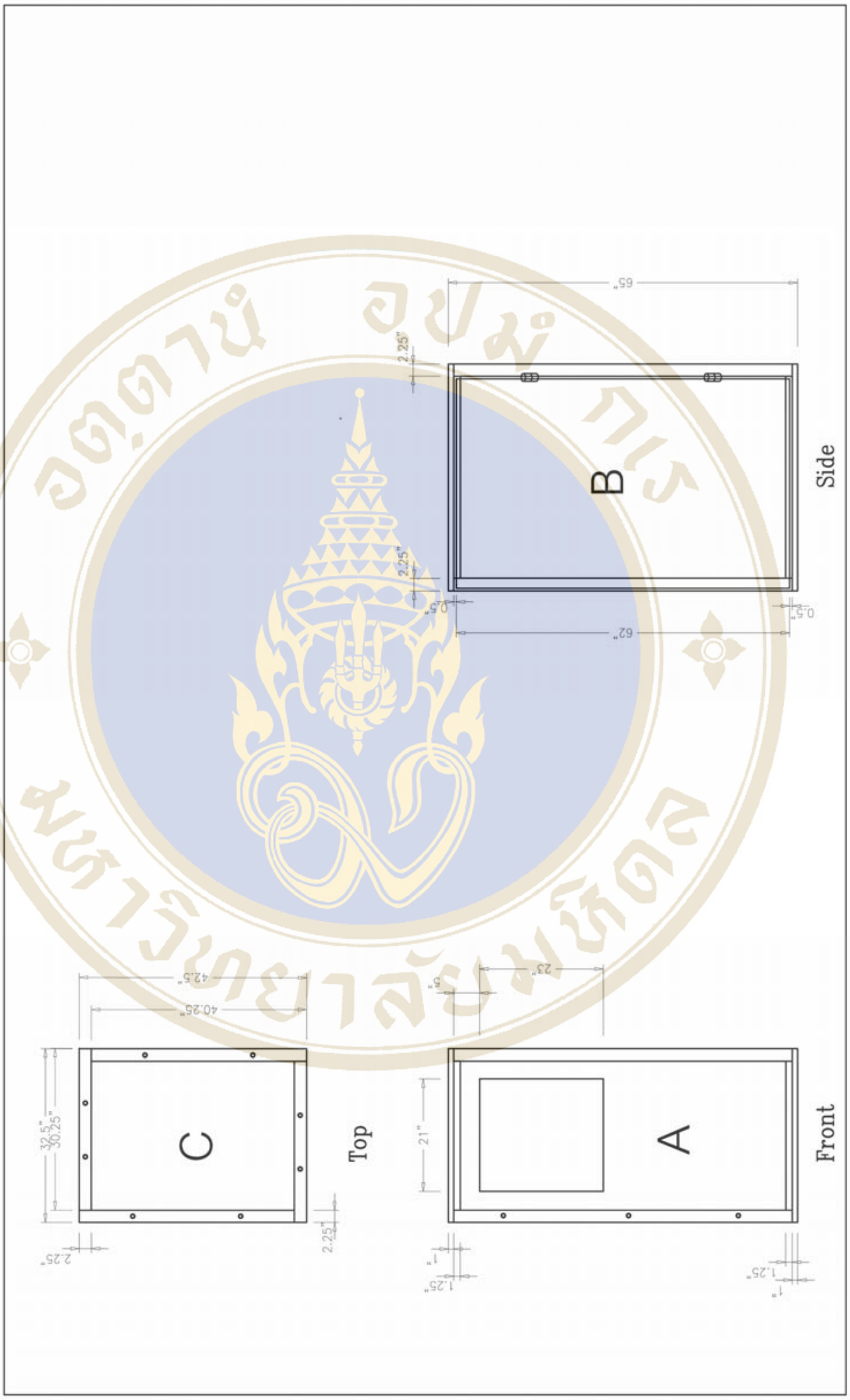

Figure A-13 Dimension of a knock down audiometric test booth

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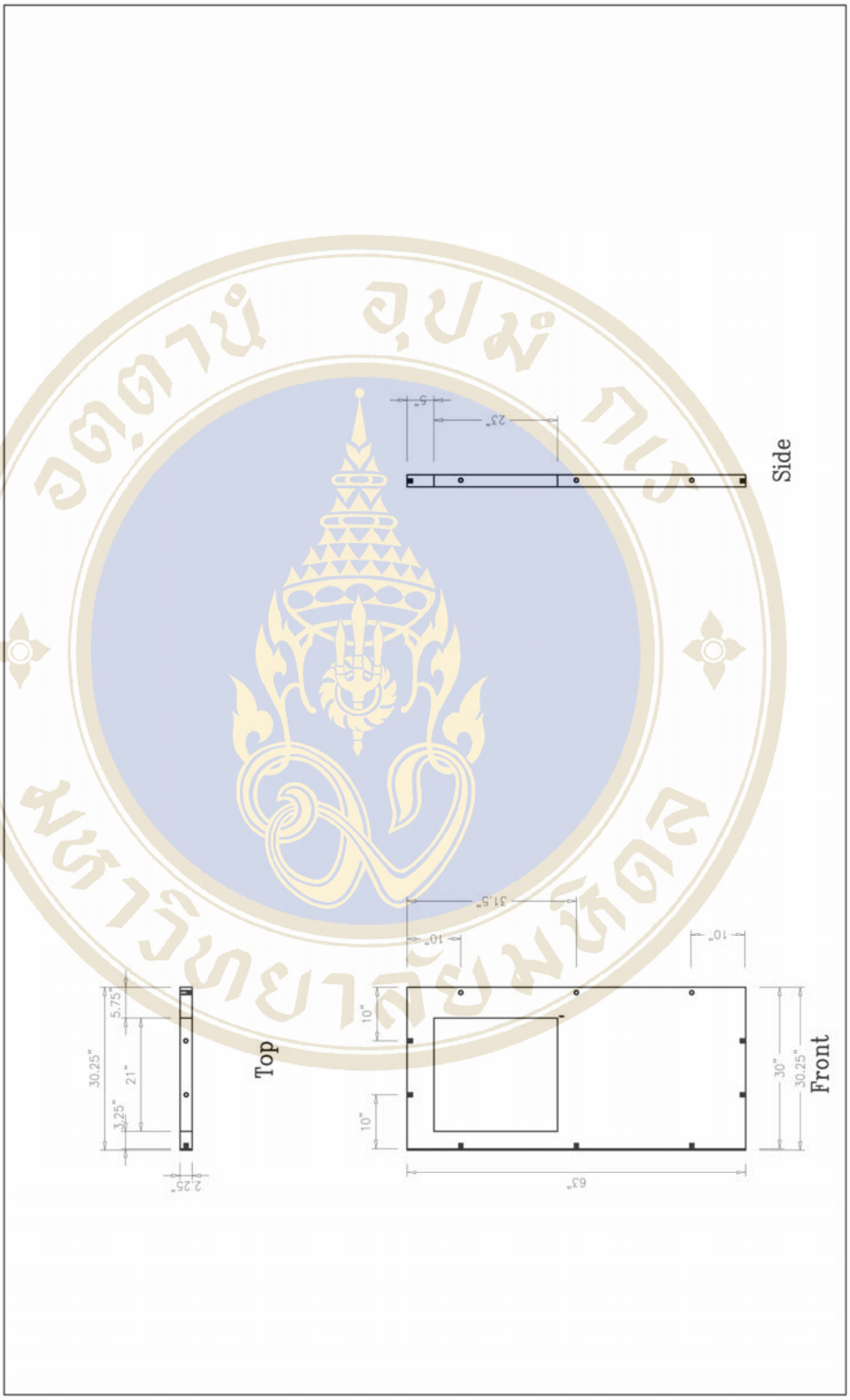

Figure A-14 Dimension of part A

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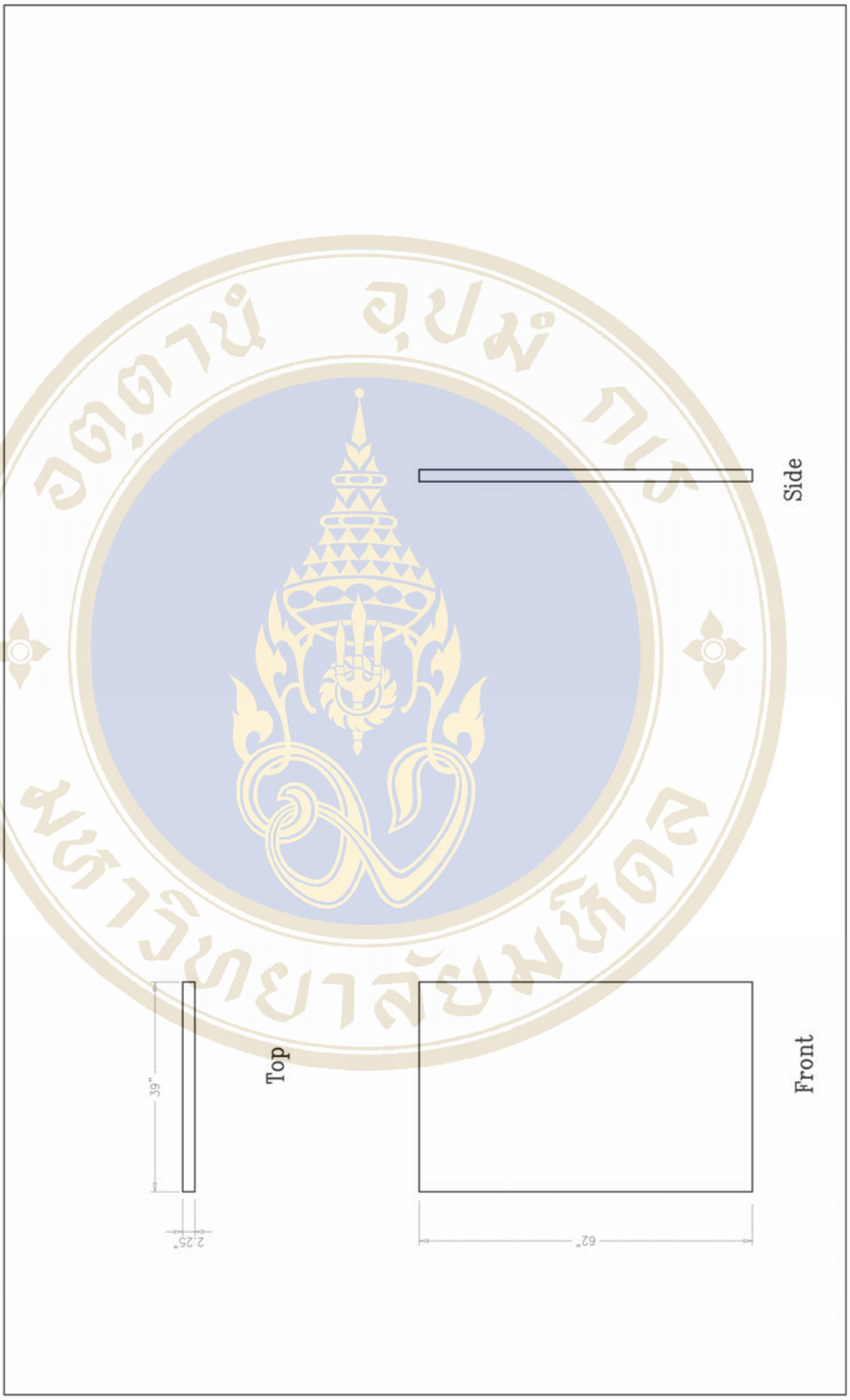

Figure A-15 Dimension of part B (door)

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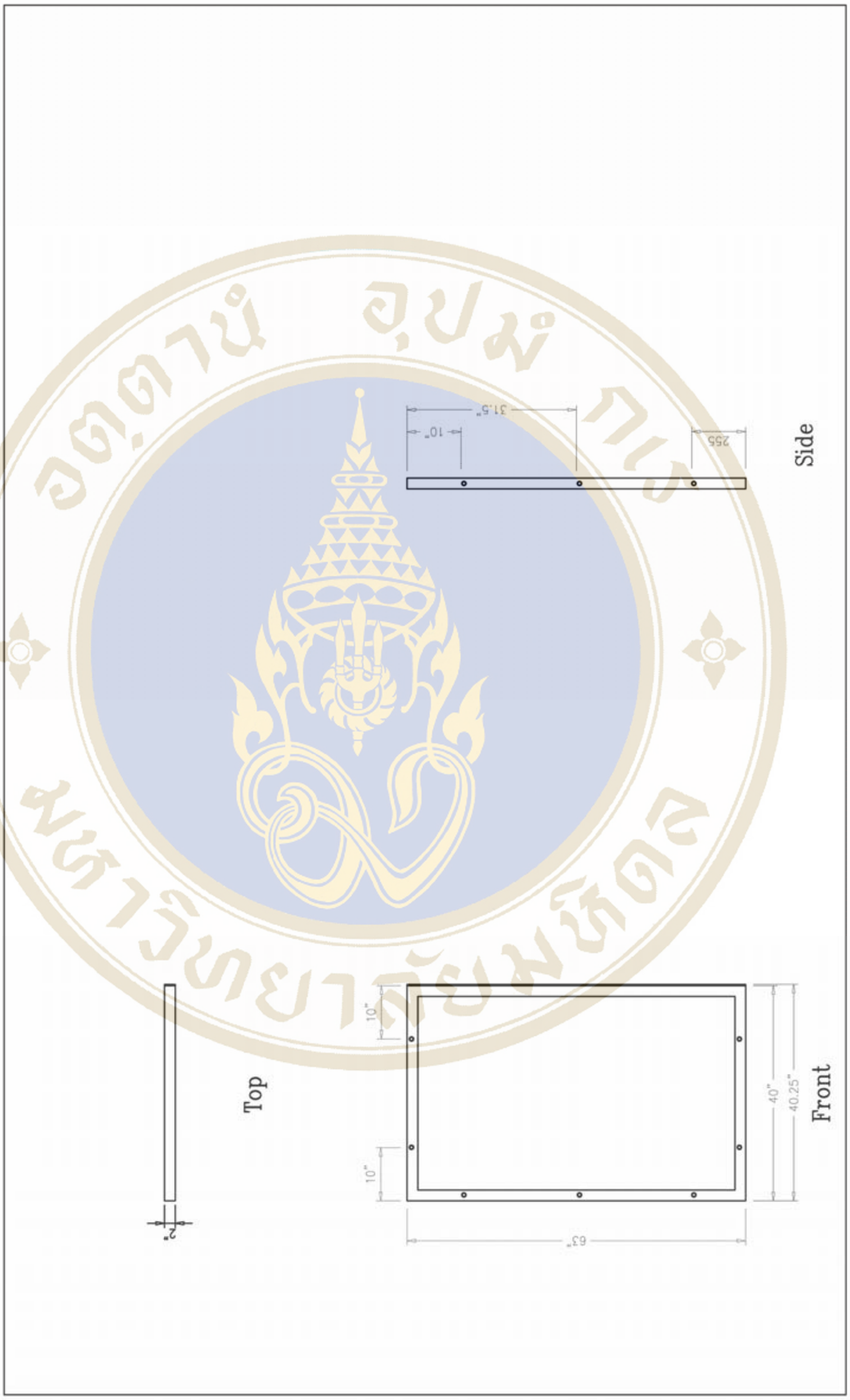

Figure A-16 Dimension of part **B (door frame)**

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Figure A-17 Dimension of part C

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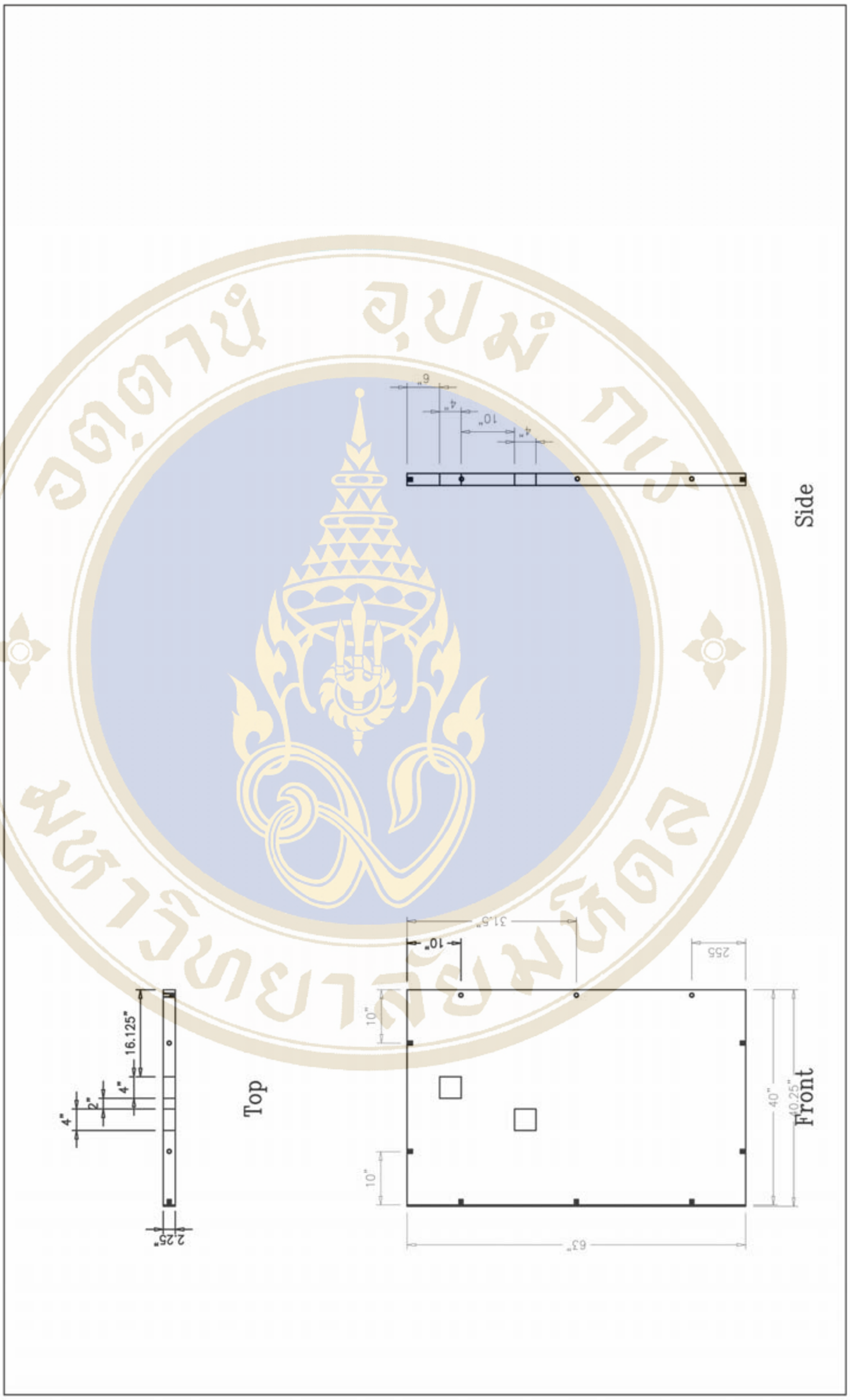

Figure A-18 Dimension of part D

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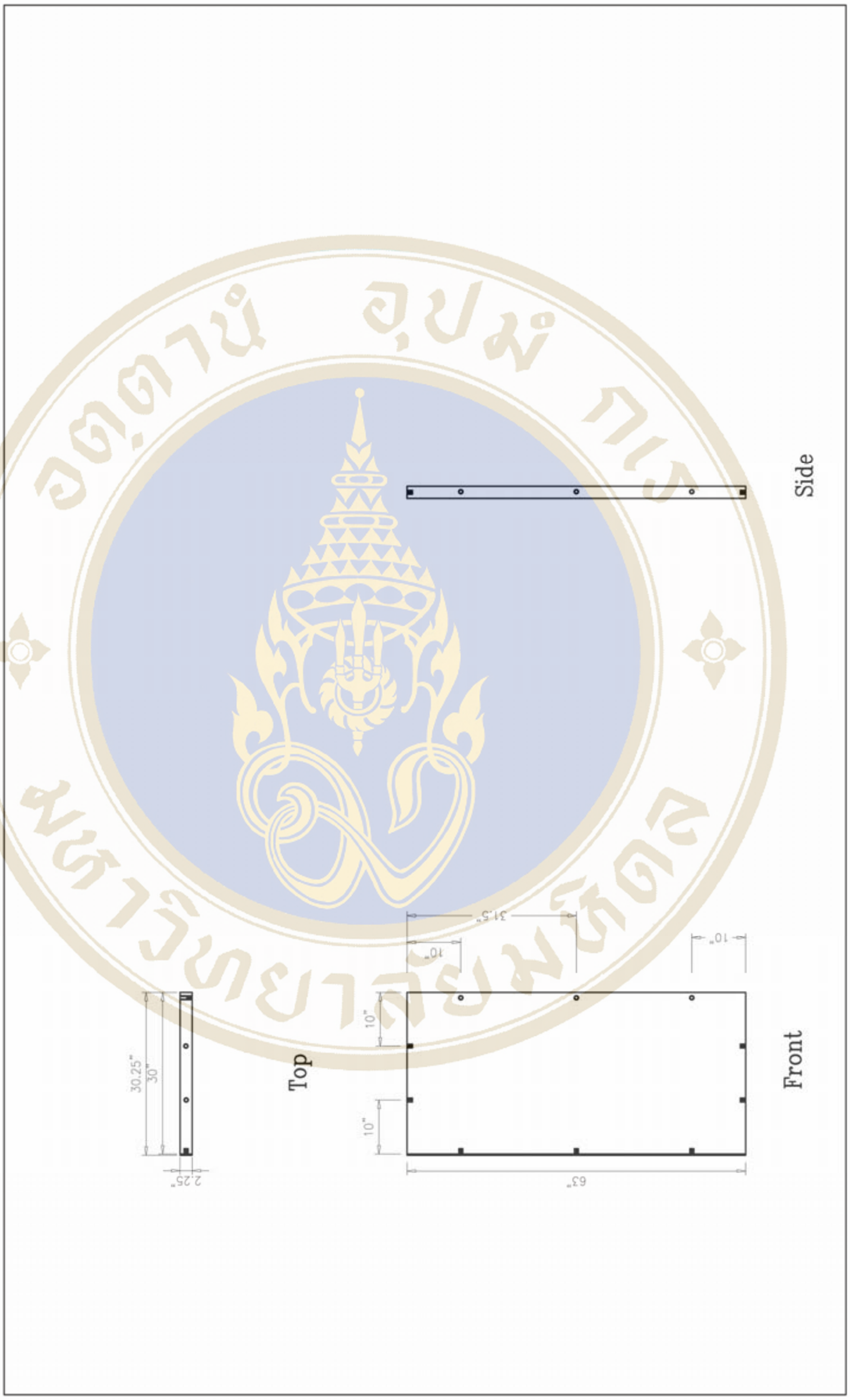

Figure A-19 Dimension of part E

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Figure A-20 Dimension of part F

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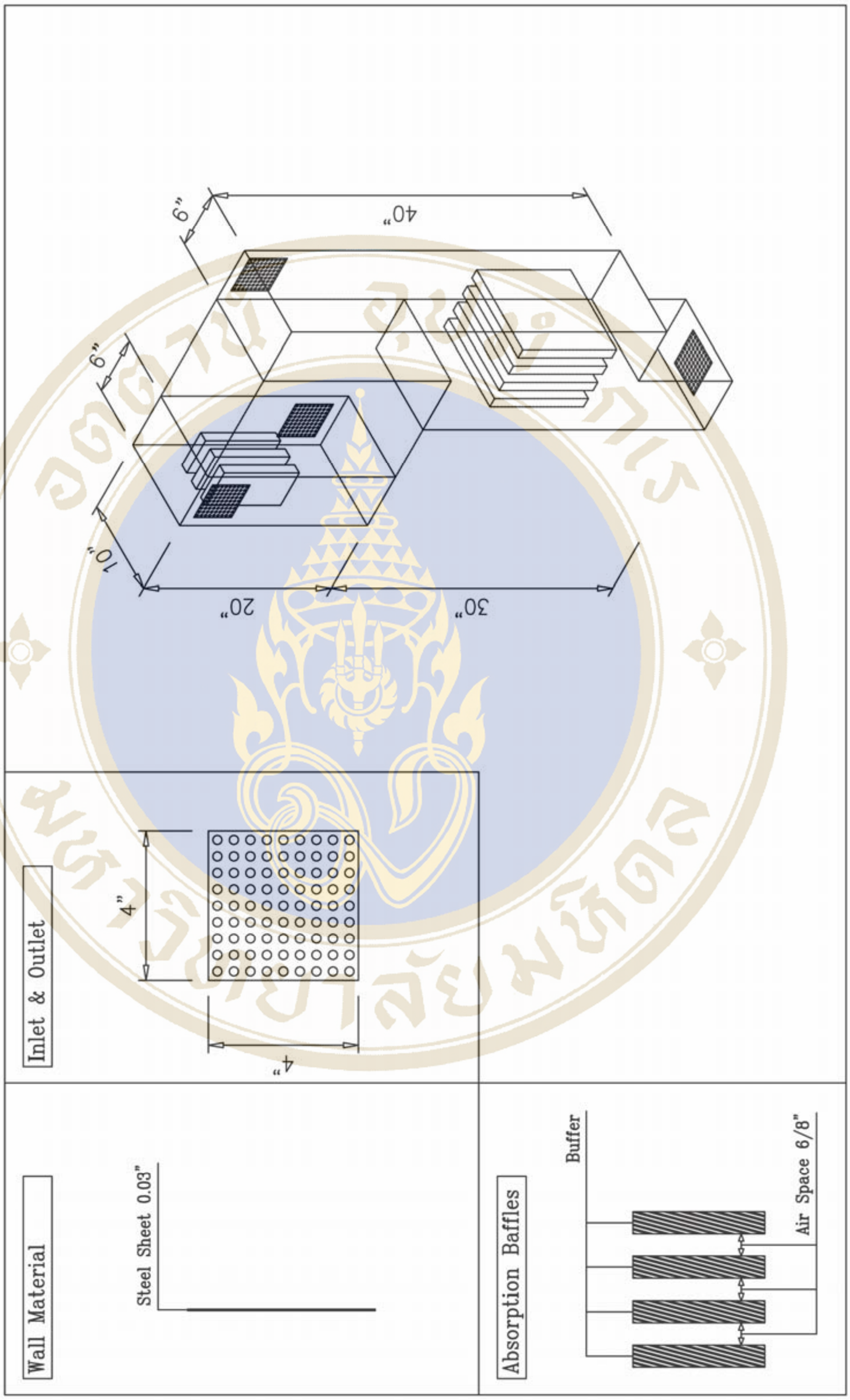

Figure A-21 Material detail of plenum chamber silencer

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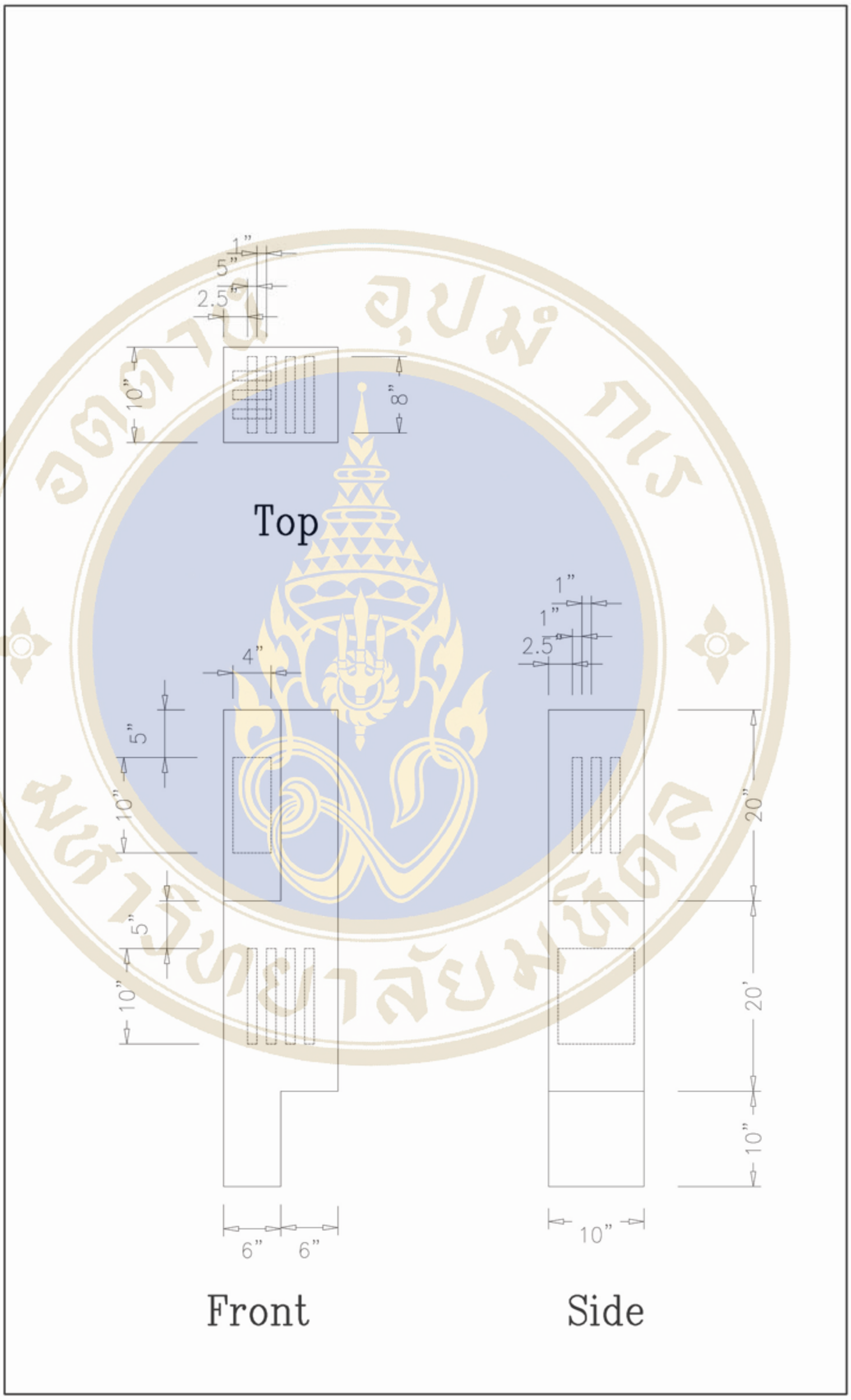

Figure A-22 Dimension of plenum chamber silencer

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BIOGRAPHY

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