



UNIVERSITY OF ALBERTA

**LABORATORY MEASUREMENT OF  
SOUND ABSORPTION OF  
SONOGLASS SPRAY-ON TREATMENT  
IN THREE CONFIGURATIONS**

Prepared for:

**MONOGLASS INC.**  
922-1200 West 73rd Avenue  
Vancouver, BC, Canada  
V6P 6G5

Prepared by:  
THE UNIVERSITY OF ALBERTA  
MECHANICAL ENGINEERING ACOUSTICS AND NOISE UNIT  
Corjan Buma, M.Sc., P. Eng.

JOB NUMBER: **07-12**

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## EXECUTIVE SUMMARY

Sound absorption measurements were conducted at the request of Monoglass Inc. of Vancouver, BC, in the small reverberation chamber (227 m<sup>3</sup>) at the Mechanical Engineering Acoustics and Noise Unit (the "MEANU") of the University of Alberta in Edmonton, Alberta, Canada. These measurements were conducted in accordance with ASTM C423-99a "Standard Test Method for Sound Absorption And Sound Absorption Coefficients By The Reverberation Room Method".

The specimens were comprised of a series of ½-inch plywood panels to which the spray-on fibreglas had been applied. When assembled together the overall dimensions of the specimen were 2.7 meters (9-feet) by 2.4 meters (8-feet). The outer perimeter of the specimen had been equipped with edging (made of MDF) of a height matching the depth of the spray-on treatment. In order to counteract the effect of warping of the plywood panels (resulting from curing of the treatment), a 5/8-inch plywood backing was attached to the back of the specimen panels using a (nominal) 200-mm spacing of 25-mm drywall screws. When laid in position on the reverberation chamber floor ready for testing the outer perimeter of the specimen was sealed to the floor with a continuous run of common duct tape.

The three configurations tested included (a) a treatment of 0.8 inch (20 mm) depth, (b) a treatment of 1.7 inch (42 mm) depth and (c) the same 1.7 inch treatment equipped with a layer of Insulseal hardener. (A more detailed description of the specimens and the test configuration is given in the body of this Report.)

For the three configurations tested the **Noise Reduction Coefficients** were determined to be :

0.8-inch (nom.) thick Sonoglass, not coated :	<b>0.75</b>
1.7-inch (nom.) thick Sonoglass, not coated :	<b>1.00</b>
1.7-inch (nom.) thick Sonoglass, with Insulseal coating :	<b>1.00</b>

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# LABORATORY MEASUREMENT OF SOUND ABSORPTION OF SONOGLASS SPRAY-ON TREATMENT IN THREE CONFIGURATIONS

## 1.0 INTRODUCTION

The acoustical conditions in a room are determined in large part by the sound absorbing capabilities of both surface treatments and any objects contained within the room. This report summarizes the equipment and procedures used and test results obtained in quantifying the sound absorption of a spray-on glass-fibre surface treatment according to the requirements of ASTM C-423.

The Mechanical Engineering Acoustics and Noise Unit of the University of Alberta in Edmonton was retained by **Monoglass Inc.** of Vancouver, BC, to conduct the tests summarized in this Report. Authorization for this study was received 7-Nov-2007, by means of Monoglass PO # 5030. Testing was conducted at the MEANU on various dates between November 2007 and March 2008 by Corjan Buma, M.Sc., P.Eng.

## 2.0 DESCRIPTION OF TEST FACILITIES

The Mechanical Engineering Acoustics and Noise Unit (the "MEANU") is owned and operated by the University of Alberta as an integral component of the Department of Mechanical Engineering. This allows for educational and research uses as well as for standardized commercial testing. The MEANU is equipped to conduct laboratory measurements according to various standards including some American National Standards ("ANSI"), some American Society for Testing and Materials ("ASTM") standard test procedures and some International Organization for Standardization (ISO) procedures. Projects such as standard acoustical tests, research contracts and fundamental research can be developed and completed.

A partial layout of the facility is shown in Figure 1 (page 7). The two inter-connecting reverberation chambers in which most acoustical tests are conducted are arranged as essentially separate buildings on independent foundations; a cross-section through the test Chamber walls is shown in Figure 2 (page 7). A test opening, nominally 2.4 meters high by 2.7 meters wide, is provided for the installation of wall test specimens. The test opening spans the two chamber walls, the walls being physically connected through lead sheet flashing only. Normally, when testing specimens for their sound-absorbing capabilities, as in this study, only one chamber is used and a specially-constructed plug wall is installed in the test opening to acoustically decouple the two chambers.

In order to satisfy the requirements for adequate sound diffusion, for each chamber its shape, volume and the arrangement of its sound diffusing panels contained within were designed to meet or exceed all applicable testing standards and guidelines. The diffusers can be set into motion (in a slow undulating pattern), however for the tests in this study the diffusers were kept stationary.

### 3.0 THEORY

The sound absorption of a surface or object is a property of the material(s) comprising the surface or object. It is ideally defined as the fraction of the randomly incident sound power absorbed by the surface. In ASTM test method C423 [1] the absorption of sound in a room is operationally defined by the Sabine equation:

$$A = 0.921 Vd/c \quad \text{Eqn 1}$$

where:

A = room absorption, metric sabins or sabins,

V = volume of room, m<sup>3</sup> or ft<sup>3</sup>,

d = rate of decay of sound pressure level in the room, dB per second,

c = speed of sound in the medium, m/s or ft/sec.

The speed of sound is a function of temperature and can be found with:

$$c = 20.047 \sqrt{(273.15+T)} \quad \text{Eqn 2}$$

where:

c = speed of sound, m/s,

T° = room temperature, C°.

If an object positioned within a room away from any enclosing surfaces contributes to the sound absorption within the room, it is termed a “space absorber”. To quantify the sound absorption contributed by the object, this is determined from the difference in room absorption “A” (Eqn. 1) within a test Chamber with the object present vs. absent. When this difference is divided by the area of the object (as is particularly appropriate for surface treatments) one obtains the “sound absorption coefficient”,

$$\alpha = [(A_2 - A_1) / S] \quad \text{Eqn 3}$$

where:

$\alpha$  = absorption coefficient of specimen (dimensionless)

A<sub>1</sub> = absorption of the empty reverberation room, metric sabins or sabins,

A<sub>2</sub> = absorption of the room after the specimen has been brought in,

S = area of test specimen, m<sup>2</sup> or ft<sup>2</sup>.

For materials used as a surface treatment, diffraction effects usually cause the area of a specimen to be effectively greater than its geometrical area, thereby increasing the measured coefficient. This phenomenon may cause the derived values of sound absorption coefficient to exceed one (which is a theoretical impossibility). Since the effects of diffraction are less when specimen area is greater, a specimen size of at least 6.69 m<sup>2</sup> (72 ft<sup>2</sup>) is recommended. Since diffraction effects are not yet completely understood, the standard recommends that no adjustments be made and the coefficients simply reported as derived.

Sound absorption coefficients are normally reported in a series of 18 contiguous 1/3-octave band center frequencies ranging from 100 to 5000 Hertz (the standard audible range for good speech intelligibility for humans with average hearing capability). It is common in published data to find only the 6 required standard octave-band center frequencies of 125, 250, 500, 1000, 2000 and 4000 Hertz. Note that these 6 frequency bands are 1/3-octave band data and NOT an average of the three 1/3-octave band center frequencies that comprise a full octave band of that same frequency.

When requested, additional 1/3-octave band sound absorption coefficients may be measured and reported outside the 100-to-5000 Hz frequency range. However, these do not form part of the test procedure according to ASTM C423, and thus are not considered “valid” but only approximate. Often, they provide a useful indication of sound absorption trends outside the “valid” range.

Sound absorption coefficients normally range from a numerical value of zero to one and are defined, ideally, as the fraction of randomly-incident sound power absorbed by the specimen. Sometimes values are reported outside this coefficient range. Coefficients just below a value of zero may occur because of the uncertainty of the measurement. Coefficients exceeding a value of 1 may occur for the same reason or due to the diffraction effects discussed earlier.

The **Noise Reduction Coefficient (NRC)**, a single number rating, is calculated by determining the arithmetic mean (to the nearest 0.05) of the absorption coefficients in the 250, 500, 1000 and 2000 Hertz 1/3-octave frequency bands.

#### **4.0 DESCRIPTION OF SPECIMEN AND TEST LAYOUT**

The specimens consisted of two sets of panels that had been equipped with spray-applied fibre-glass known as “Sonoglass Acoustic Insulation”. One set of panels had been equipped with a treatment on average 0.8 inches (20 mm) thick and the other set of panels equipped with a treatment on average 1.7 inches (42.5 mm) thick. Spray-on thickness had been determined by Monoglass Inc. based on averaging of 187 depth measurements for the 1.7 inch specimen and 163 depth measurements for the 0.8 inch specimen. For further particulars on the fibre-glass used, the Reader is referred to MonoGlass Inc.

For both sets of panels the treatment had been applied to ½-inch (12.7 mm) thick plywood substrate, with component panels being four of 4-feet by 4-feet and two 4-feet by 1-foot; this allowed placement in the A-mounting (per ASTM E-795 [2]) with an overall specimen size of 9-feet by 8-feet (nominally 2.7 meters by 2.4 meters).

As the panels had undergone approximately 4 weeks of curing prior to being delivered to the MEANU, some warping of the wood backing had occurred. To counteract this warping and obtain a specimen lying essentially flat on the reverberation chamber floor, additional 5/8-inch (16 mm) plywood sheeting was attached to the back of the component panels; the plywood sheeting was attached using common drywall screws on a nominal 200 mm spacing; where needed additional screws were installed to ensure that there were no voids between the plywood layers.

When each completed specimen was in turn laid on the reverberation chamber floor prior to testing, it was confirmed that the warping did not result in unwanted cavities between the specimen and the chamber floor.

The entire perimeter of each specimen had been equipped with edging boards made of 5/8-inch thick MDF (no edging boards between component panels of each specimen). For the 0.8-inch specimen these boards extended above the plywood substrate by approximately 0.8 inches (20mm) and for the 1.7-inch specimen by 1.7 inches (42.5 mm). Thus the face exposed upward to the reverberation chamber was the only surface providing sound absorption.

Once the complete specimen had been laid in position on the reverberation chamber floor (see Figure 3 for a schematic drawing of the positioning), the bottom edge of the outer perimeter was sealed to the chamber floor with a continuous run of common duct-tape.

One sound absorption test was completed for each specimen. For the 1.7-inch specimen a second test was conducted after application of “Insulseal” protective coating.

## **5.0 METHODOLOGY**

### **5.1 Equipment**

A list of the equipment used in this study is given in the Appendix to this Report.

### **5.2 Signal Excitation and Measurement**

Normally, sound absorption is frequency-dependent and therefore measurements are made in a series of frequency bands. Random noise (“pink”) is used as a test signal in the range of 110 dBA and allowed to stabilize for typically 3-to-4 seconds before the noise is abruptly stopped and the decay initiated. When the excitation signal is turned off, the sound pressure level decreases and the rate of decay is determined from measurement of the average time needed for the sound pressure level in a specific frequency band to decay through a certain range. The 1/3-octave band sound pressure levels are measured without any weighting (“linear”).

Reverberation time measurements were made by generating 2 channels of random, uncorrelated broadband noise simultaneously through 2 independent loudspeaker systems located in opposite corners of the test chamber. The resulting decays were measured at each of 8 microphone locations within a well-defined, allowable region within the test chamber. This procedure was done both with the specimen present and with the specimen absent. Any difference detected in the average decay rate of the sound was attributed to the presence of the specimen, accounting for any change in sound absorption by the air in the test chamber due to temperature, relative humidity and barometric pressure variations.

As reverberation data was being measured, environmental conditions were also being monitored. A mercury column barometer was used to record barometric pressure changes. A lithium chloride sensor suspended approximately in the center of the test chamber was used to verify that changes in the air absorption of sound due to temperature and relative humidity were accounted for.

Acquisition of acoustic and environmental data was accomplished with custom computer software, with individual-run data being stored temporarily on hard-disk (note that only overall averaged results of reverberation times were retained for long-term storage). Data analysis was then completed using the custom software to derive averages of the decays referred to in Equation 1 at the various microphone positions.

The precision of the average RT60 at each microphone position at each frequency was attained by collecting sufficient decays (typically, about 40) until the precision requirements of ASTM C423 were satisfied. At frequencies of 250 Hz and higher, the absorption of the test chamber, either empty or with-specimen, must be measured with an uncertainty of less than 2% with 95% confidence and at frequencies below 250 Hz, the uncertainty must be less than 4% (with 95% confidence). The precision of sound absorption values was derived from the spatial variation of the average RT60 at each microphone position for each room condition (i.e. with or without specimen) and combining their uncertainties to calculate the uncertainty for absorption coefficient at the 95% confidence level.

## 6.0 RESULTS

The data-sheets obtained for each of the three sound absorption tests are given in Figures 4 – 6 (pages 10 – 12). The Noise Reduction Coefficients (“NRC”) derived for the three specimen configurations tested were :

Test 07-12A, 0.8-inch (nom.) spray-on Sonoglass, no coating : **NRC = 0.75**

Test 07-12B, 1.7-inch (nom.) spray-on Sonoglass, no coating : **NRC = 1.00**

Test 07-12C, 1.7-inch (nom.) spray-on Sonoglass, with InsulSeal coating : **NRC = 1.00**

## 7.0 DECLARATION OF COMPLIANCE

Every effort has been made to conduct and report the measurements and derived results in accordance with the requirements of ASTM Standard Test Method C423-99a, along with ASTM Standard Mounting Practices E795 except where noted. While test procedure C423-99a requires only one microphone position and the measurement of only a limited number of reverberation decays, the procedure as applied for this study meets or exceeds the minimum requirements.



## **8.0 DISCLAIMER**

The MECHANICAL ENGINEERING ACOUSTICS AND NOISE UNIT (MEANU) has absolutely no financial or managerial interests vested in the Client named in this report nor does the Client so-mentioned have any vested interests in the MEANU.

Although every effort has been made to comply with all aspects of the standards referred to in this report, as of this writing the MEANU has no recognized certification.

## **9.0 REFERENCES**

- [1] ASTM C423 – 99a: “Standard Test Method for SOUND ABSORPTION AND SOUND ABSORPTION COEFFICIENTS BY THE REVERBERATION ROOM METHOD”; American Society for Testing and Materials, Volume 04.06, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959
- [2] ASTM E795 – 93: “Standard Practices for MOUNTING TEST SPECIMENS DURING SOUND ABSORPTION TESTS”; American Society for Testing and Materials, Volume 04.06, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959
- [3] ANSI S1.26, “Method for the Calculation of the Absorption of Sound by the Atmosphere”, American National Standards Institute, 1430 Broadway, New York, NY, USA 10018.

## **FIGURES**

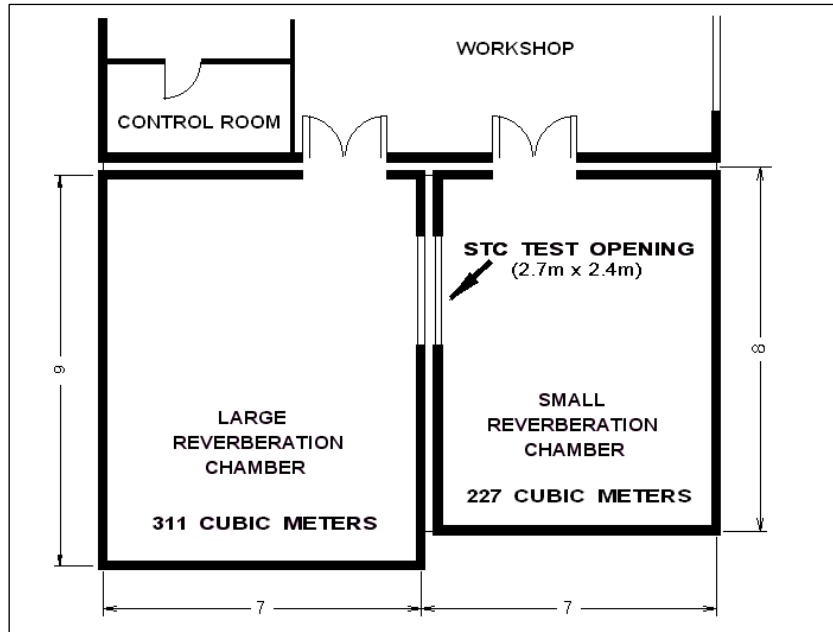


Figure 1 – MEANU Floor Plan (partial)

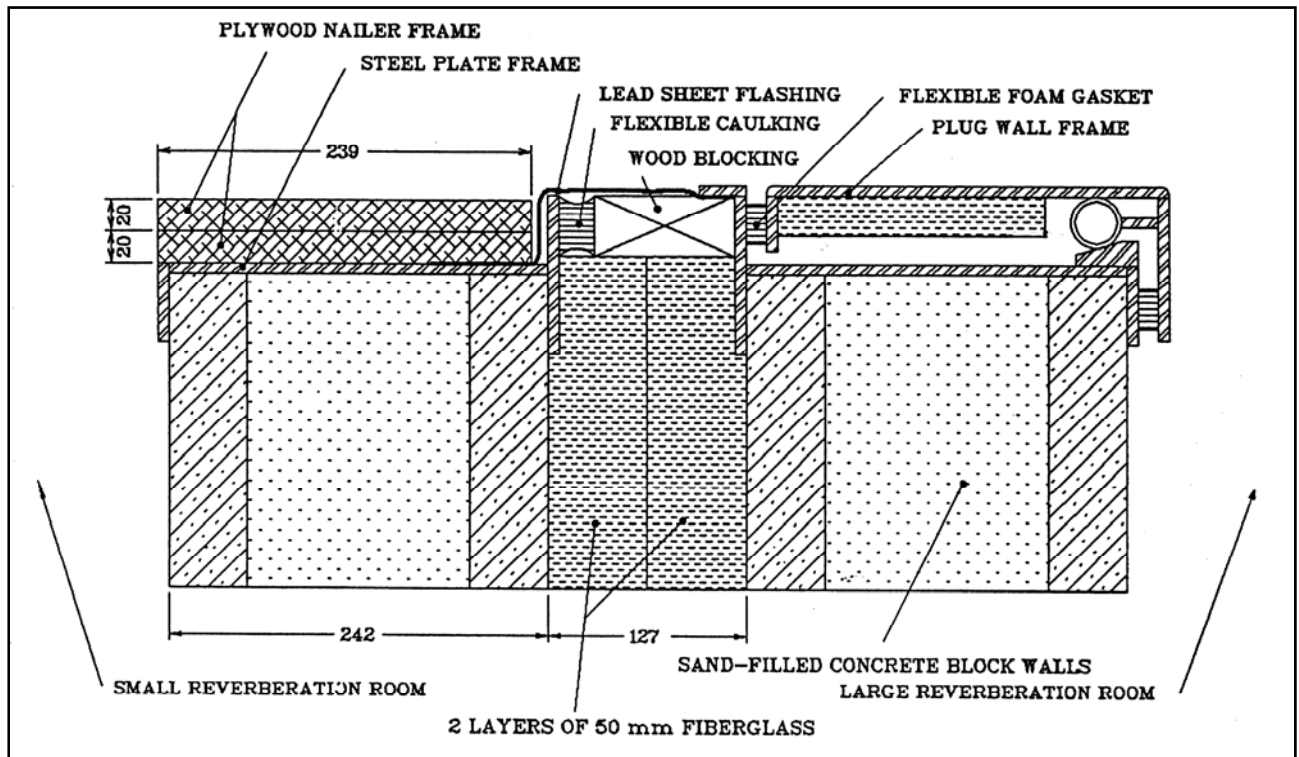
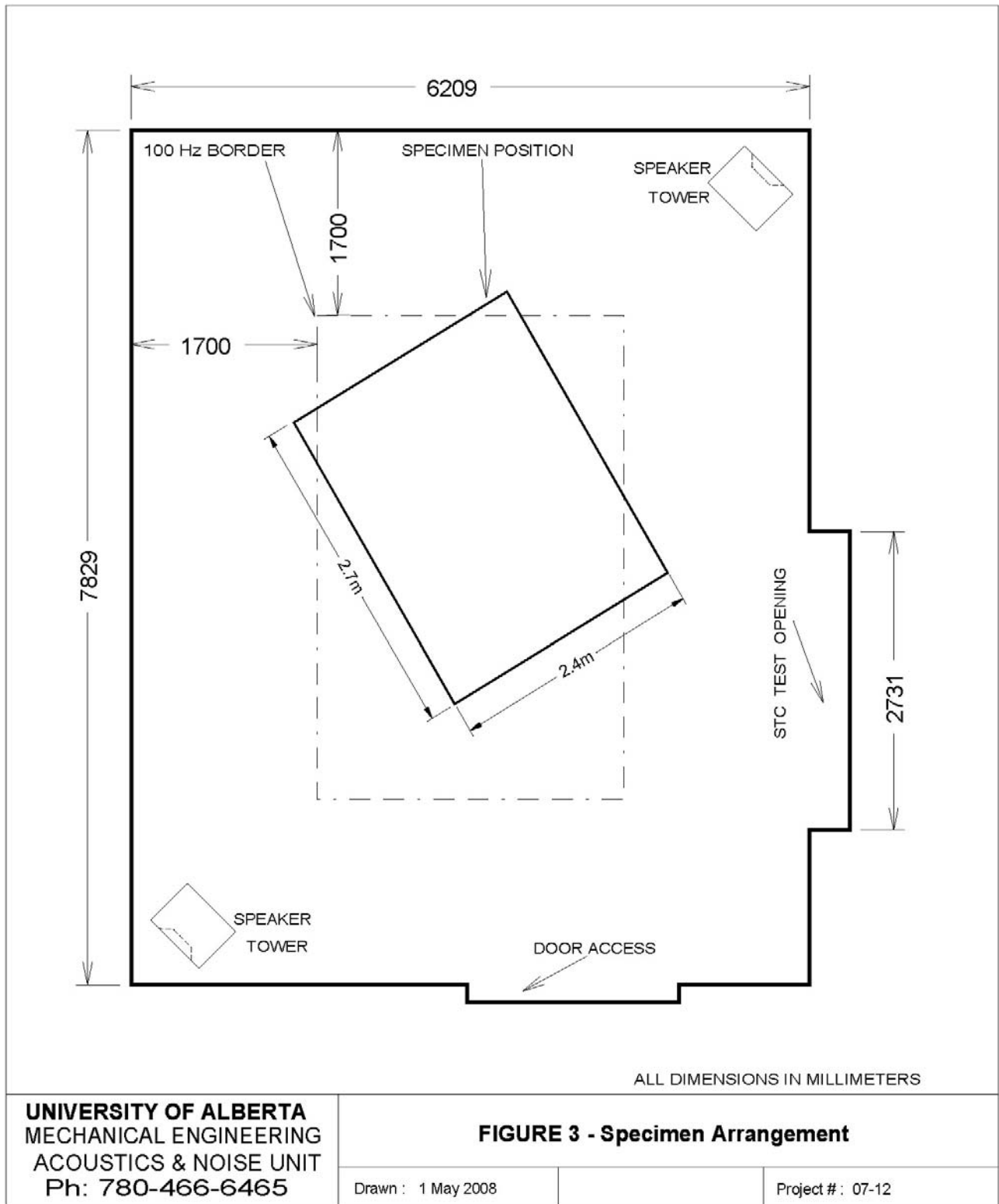


Figure 2 – Cross-Section through MEANU Chamber Walls



**Figure 3 – Test Configuration of Specimen Within Small Reverberation Chamber**

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MECHANICAL ENGINEERING ACOUSTICS AND NOISE UNIT  
EDMONTON, ALBERTA, CANADA

DETERMINATION OF NOISE REDUCTION COEFFICIENT (NRC)  
ACCORDING TO ASTM STANDARD: C423

DATE: 2007 Nov 30, Fri  
CLIENT: Monoglass Inc.

TEST NO: 1  
TEST PERFORMED BY:  
CJ Buma, M.Sc., P.Eng.

REVERB ROOM VOLUME: 228.3621 Cubic Meters  
MICROPHONE PLACED AT 8 FIXED POSITIONS

ENVIRONMENT:	TIME	DATE	TEMP(C)	RH(%)	ATMOSPHERIC PRESSURE (KPa)
# 1 EMPTY ROOM:	21:00	11-30-07	13.25	22.88	93.96 (706.4 mm Hg @ 19.0 C)
# 8 EMPTY ROOM:	21:53	11-30-07	10.03	27.91	93.96 (706.4 mm Hg @ 19.0 C)
# 1 SAMPLE ROOM:	19:35	11-30-07	16.31	18.08	93.95 (706.4 mm Hg @ 19.4 C)
# 8 SAMPLE ROOM:	20:38	11-30-07	10.50	27.60	93.95 (706.4 mm Hg @ 19.4 C)

TEST SAMPLE SURFACE AREA : 6.687 Sq m [ 2.743 m wide by 2.438 m high]  
MOUNTING CONFIGURATION : 'A'

TEST SAMPLE DESCRIPTION :

Specimen = 0.8in thick spray-on Sonoglass; specimen comprised of series of trays (four @ 4'x4' + two @ 1'x4'), prepared off-site and allowed to cure (>28 days); trays attached to 5/8in plywood back-plate with drywall screws (to keep overall specimen uniformly flat); outer perimeter of specimen equipped with 5/8in thick by 1in high MDF edging; lower backplate sealed to Chamber floor with common duct tape along full perimeter.

FREQ (Hz)	EMPTY RT60 (sec)	SAMPLE RT60 (sec)	TOTAL METRIC SABINE	ABSORB COEFF	COEFF UNCERTAINTY (+/-)
100	3.58	3.49	0.26	0.04	0.13
125	3.82	3.62	0.54	0.08	0.13
160	4.64	4.06	1.14	0.17	0.10
200	5.32	4.63	1.03	0.15	0.04
250	5.49	4.22	2.03	0.30	0.03
315	5.60	3.86	2.99	0.46	0.05
400	5.38	3.52	3.62	0.54	0.05
500	5.11	3.13	4.81	0.69	0.04
630	4.73	2.77	5.54	0.83	0.05
800	4.44	2.64	5.68	0.85	0.06
1000	3.85	2.32	6.35	0.95	0.06
1250	3.39	2.10	6.75	1.01	0.07
1600	2.96	1.91	6.83	1.02	0.06
2000	2.56	1.73	6.86	1.03	0.04
2500	2.15	1.52	6.99	1.05	0.08
3150	1.71	1.30	6.73	1.01	0.12
4000	1.35	1.08	6.62	0.99	0.14
5000	1.08	0.89	6.60	0.99	0.16

NRC = 0.75

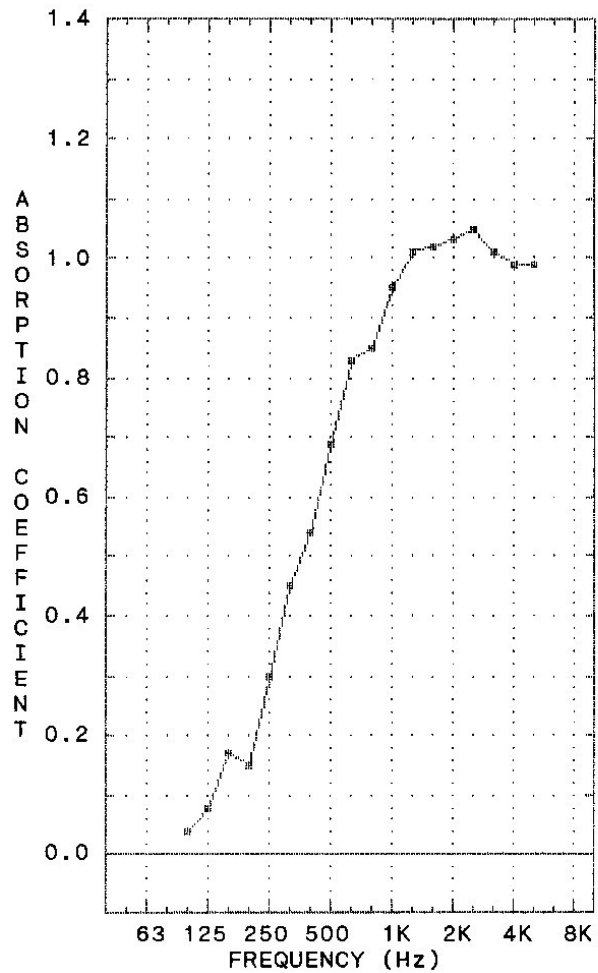


Figure 4 – Sound Absorption of 0.8-inch (nom.) Sonoglass (no coating)

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MECHANICAL ENGINEERING ACOUSTICS AND NOISE UNIT  
EDMONTON, ALBERTA, CANADA

DETERMINATION OF NOISE REDUCTION COEFFICIENT (NRC)  
ACCORDING TO ASTM STANDARD: C423

DATE: 2007 Dec 04, Tues  
CLIENT: Monoglass Inc.

TEST NO: 2  
TEST PERFORMED BY:  
CJ Buma, M.Sc., P.Eng.

REVERB ROOM VOLUME: 228.3621 Cubic Meters  
MICROPHONE PLACED AT 8 FIXED POSITIONS

ENVIRONMENT:	TIME	DATE	TEMP(C)	RH(%)	ATMOSPHERIC PRESSURE (KPa)
# 1 EMPTY ROOM:	18:50	12-04-07	19.18	14.81	94.15 (708.2 mm Hg @ 21.8 C)
# 8 EMPTY ROOM:	19:51	12-04-07	15.92	18.17	94.15 (708.2 mm Hg @ 21.8 C)
# 1 SAMPLE ROOM:	17:05	12-04-07	20.13	13.06	94.18 (708.2 mm Hg @ 20.2 C)
# 8 SAMPLE ROOM:	18:19	12-04-07	16.23	18.58	94.18 (708.2 mm Hg @ 20.2 C)

TEST SAMPLE SURFACE AREA : 6.687 Sq m [ 2.743 m wide by 2.438 m high]  
MOUNTING CONFIGURATION : 'A'

TEST SAMPLE DESCRIPTION :

Specimen = 1.7in thick spray-on Sonoglass; prepared and installed as for 0.8in specimen; full perimeter of backplate sealed to Chamber floor with common duct tape.

FREQ (Hz)	EMPTY RT60 (sec)	SAMPLE RT60 (sec)	TOTAL METRIC SABINE	ABSORB COEFF	COEFF UNCERTAINTY (+/-)
100	3.53	3.23	1.01	0.15	0.16
125	3.85	3.29	1.63	0.24	0.11
160	4.55	3.25	3.30	0.49	0.13
200	5.27	3.45	3.72	0.56	0.07
250	5.38	3.12	5.00	0.75	0.06
315	5.42	2.88	6.02	0.90	0.07
400	5.21	2.73	6.44	0.96	0.06
500	4.98	2.57	6.94	1.04	0.04
630	4.63	2.43	7.22	1.08	0.04
800	4.30	2.38	6.96	1.04	0.06
1000	3.73	2.17	7.14	1.07	0.07
1250	3.24	2.01	6.98	1.04	0.05
1600	2.83	1.84	7.04	1.05	0.06
2000	2.42	1.66	7.09	1.06	0.09
2500	2.00	1.47	6.79	1.01	0.07
3150	1.61	1.24	6.94	1.04	0.11
4000	1.26	1.02	6.94	1.04	0.18
5000	1.00	0.84	6.96	1.04	0.15

NRC = 1.00

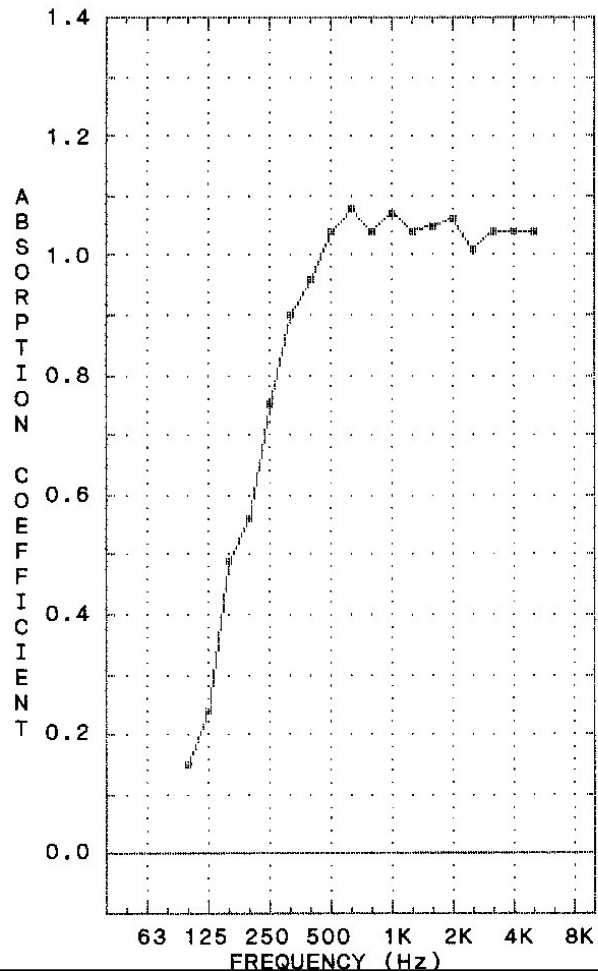


Figure 5 – Sound Absorption of 1.7-inch (nom.) Sonoglass (no coating)

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MECHANICAL ENGINEERING ACOUSTICS AND NOISE UNIT  
EDMONTON, ALBERTA, CANADA

DETERMINATION OF NOISE REDUCTION COEFFICIENT (NRC)  
ACCORDING TO ASTM STANDARD: C423

DATE: 2008 March 20, Thurs  
CLIENT: Monoglass Inc.

TEST NO: 3  
TEST PERFORMED BY:  
CJ Buma, M.Sc., P.Eng.

REVERB ROOM VOLUME: 228.3621 Cubic Meters  
MICROPHONE PLACED AT 8 FIXED POSITIONS

ENVIRONMENT:	TIME	DATE	TEMP(C)	RH(%)	ATMOSPHERIC PRESSURE (KPa)
# 1 EMPTY ROOM:	05:42	03-20-08	15.84	36.26	93.30 (701.8 mm Hg @ 21.7 C)
# 8 EMPTY ROOM:	05:33	03-20-08	16.02	35.75	93.30 (701.8 mm Hg @ 21.7 C)
# 1 SAMPLE ROOM:	03:16	03-20-08	20.30	24.83	93.30 (701.8 mm Hg @ 21.8 C)
# 8 SAMPLE ROOM:	03:24	03-20-08	19.13	26.97	93.30 (701.8 mm Hg @ 21.8 C)

TEST SAMPLE SURFACE AREA : 6.687 Sq m [ 2.743 m wide by 2.438 m high]  
MOUNTING CONFIGURATION : 'A'

TEST SAMPLE DESCRIPTION :  
Specimen = 1.7in thick spray-on Sonoglass; coated with Insulseal Hardener;  
installed as for "without hardener" test; perimeter of specimen fully sealed to  
Chamber floor with common duct tape.

FREQ (Hz)	EMPTY RT60 (sec)	SAMPLE RT60 (sec)	TOTAL METRIC SABINE	ABSORB COEFF	COEFF UNCERTAINTY (+/-)
100	3.64	3.23	1.29	0.19	0.11
125	3.91	3.31	1.66	0.25	0.13
160	4.64	3.44	2.86	0.43	0.15
200	5.35	3.51	3.64	0.54	0.08
250	5.39	3.08	5.11	0.76	0.05
315	5.46	2.88	6.07	0.91	0.05
400	5.30	2.72	6.61	0.99	0.07
500	5.10	2.56	7.19	1.08	0.03
630	4.78	2.45	7.33	1.10	0.05
800	4.57	2.42	7.18	1.07	0.06
1000	4.05	2.22	7.45	1.11	0.04
1250	3.58	2.12	7.02	1.05	0.05
1600	3.24	1.99	7.07	1.06	0.04
2000	2.92	1.86	7.10	1.06	0.05
2500	2.57	1.71	6.92	1.04	0.05
3150	2.13	1.50	6.89	1.03	0.06
4000	1.70	1.26	7.16	1.07	0.07
5000	1.32	1.04	6.68	1.00	0.10

NRC = 1.00

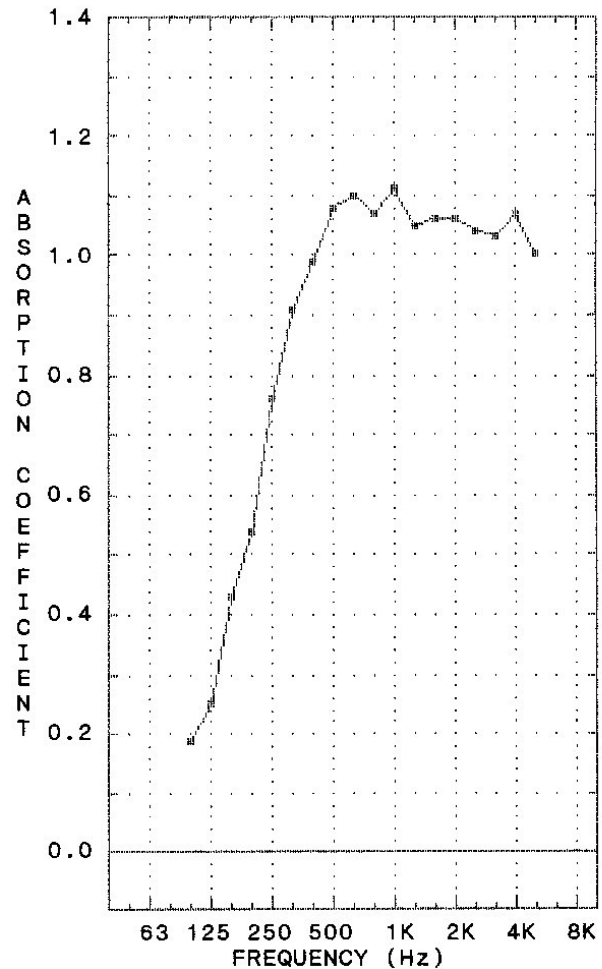


Figure 6 – Sound Absorption of 1.7-inch (nom.) Sonoglass (with coating)

## APPENDIX

### EQUIPMENT LIST

The following equipment was used to make the various acoustical measurements:

#### EXCITATION and CONDITIONING:

Custom-built Dual Channel Pink/White noise Generator  
Crest FA-800 Stereo Power Amplifiers (2; "LOW" & "MID")  
Crest 7001 Stereo Power Amplifier ("HIGH")  
Furman VU-40 Power Monitors (3)  
Urei 525 3-Way Stereo Crossover (18 dB/octave)  
White 4650 One-Third Octave Band Equalizers (2)

#### 3-Way Loudspeaker Systems (2):

##### SMALL REVERBERATION CHAMBER:

- EV SH1810L-ER 18" sub-woofer cabinets
- JBL 2220H 15" woofers in custom mid-range cabinets
- JBL 2446J 2" horns in 2385A radial flares

#### MEASUREMENT:

Pentium II/350 PC compatible computer running custom data-acquisition software  
Bruel and Kjaer 4231 Sound Level Calibrator  
Bruel and Kjaer 4134 Microphone  
Larson-Davis 900B Microphone Preamplifier  
Larson-Davis Model 3200 Precision Sound Level Analyzer  
Small (227 m<sup>3</sup>) Reverberation Chamber

#### ATMOSPHERIC

Princo Model 453 Mercury column barometer  
Hygrodyamics L15-3087 Hygrometer