Examination of the Measurement of Absorption Using the Reverberant Room Method for Highly Absorptive Acoustic Foam

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William O. Hughes, Anne M. McNelis
NASA Glenn Research Center (GRC)

Chris Nottoli, Eric Wolfram
Riverbank Acoustical Laboratories (RAL)

Overview

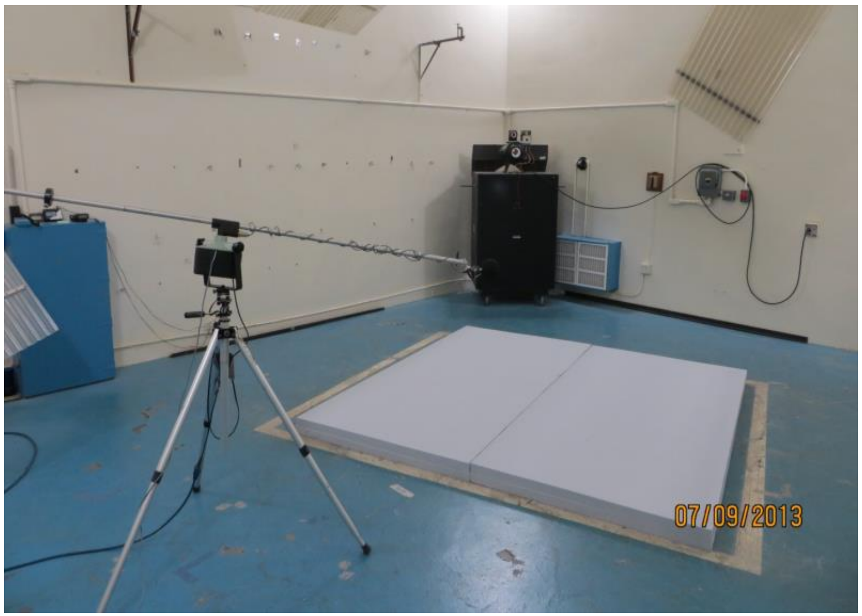
- **Challenge:**
  - Aerospace industry is moving to foam for acoustic attenuation systems.
  - Absorption characteristics of foam are needed.
    - Results computed from ASTM C423, *"Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberant Room Method."*
      - This test method is based on Sabin's Formula.
  - Interpretation of these measured Sabine absorption coefficients.
    - How can these Sabine absorption coefficients > 1.0 ?
- **Actions:**
  - Investigative test series planned and implemented.
  - Review of literature.
- **Results:**
  - Increased understanding of ASTM C423 method, assumptions, and results.
  - New acoustic absorption database for a highly absorptive acoustic foam.
    - Supporting five different test objectives.
  - Realization that Sabine absorption coefficient is not the same as the Energy absorption coefficient.

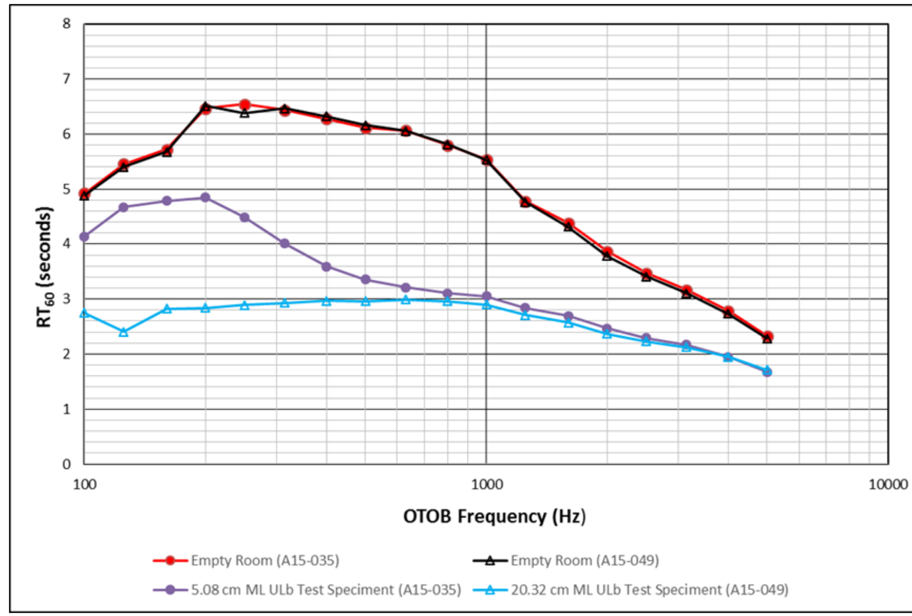
ASTM C423 Sound Absorption Tests

"Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberant Room Method"

Measure room's decay time, RT_{60}, with and without the test specimen, to obtain the **total absorption**, A, of the test specimen.

$$\boldsymbol{RT_{60}} = \frac{0.161\,\boldsymbol{V}}{\boldsymbol{A_{room}}}$$

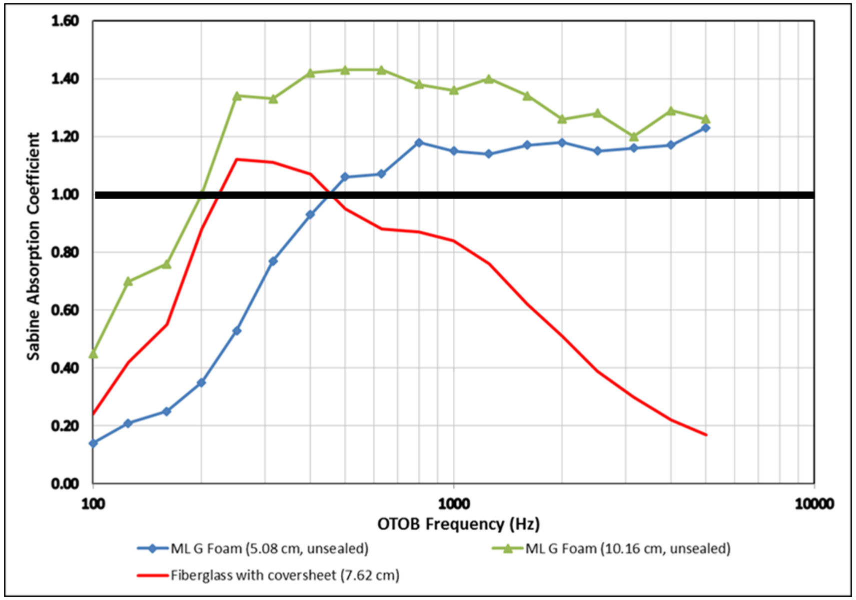




Sabine Absorption Coefficient, $\boldsymbol{\alpha}$, is computed by taking the total absorption of the test specimen, $\boldsymbol{A}$, and dividing it by its top surface area, $\boldsymbol{S}$.

$$\boldsymbol{\alpha} = \frac{\boldsymbol{A}}{\boldsymbol{S}}$$

Sabine Absorption Coefficients can be > 1.0, why?



- Sabine absorption coefficients, $\boldsymbol{\alpha}$, are a calculation from the Reverberant Room Method and its underlying assumptions.
- Additionally, high Sabine absorption coefficients may be a result of:
  - Highly absorptive materials
  - Diffraction Edge Effects
  - Surface Area Effects

- Sabine coefficients, $\boldsymbol{\alpha}$, are NOT the same as the Energy absorption coefficients, $\boldsymbol{\varepsilon}$. Here $\boldsymbol{E_i}$ is incident energy on test specimen, $\boldsymbol{E_a}$ is energy absorbed, and $\boldsymbol{E_r}$ is reflected energy.

$$\boldsymbol{\alpha = \frac{A}{S}} \qquad \boldsymbol{\varepsilon = \frac{E_a}{E_i} = \frac{E_i - E_r}{E_i} = 1 - \frac{E_r}{E_i}}$$

Test Program

- The donation of foam test materials by Soundcoat Company Inc., and test services by Riverbank Acoustical Laboratories (RAL), allowed an investigative test program to study the factors affecting the ASTM C423 method for highly absorptive acoustic foam, Soundfoam® Melamine Ultralight foam (ML ULb).
- The objectives for this test program, relative to measuring the foam test specimen's absorption, are:
  - **Objective # 1:** Evaluate the effect on absorption of varying the test specimen's surface area size for a constant 5.08 cm (2 in) thick test specimen.
  - Objective # 2*: Evaluate the effect on absorption of varying an airspace gap between the test specimen and the floor.
  - **Objective # 3:** Evaluate the effect on absorption of changing the test specimen's thickness for a constant surface area of 6.69 m^2 (64 $ft.^2$).
  - Objective # 4*: Evaluate the effect on absorption of separating the test specimen into several pieces with air gaps between these pieces.
  - **Objective # 5:** Evaluate the effect on absorption of keeping the overall (both top and side edges) surface area constant for two different shape test specimens.

Note: * to be discussed in a future follow-on paper

Test Matrix (metric units)

Test Objective #	Test Config. #	RAL Test #	Length (m)	Width (m)	Size (m^2)	Thickness (cm)	E795 Mount	Airspace (mm)	Perimeter Seal	Spaced Object Gap (cm)	Note
1	1	A15-029	3.35	3.05	10.22	5.08	A	0	Yes	0	ISO 354 Size
	2	A15-030	2.74	2.44	6.69	5.08	A	0	Yes	0	RAL and ASTM C423 Standard Size
	3	A15-031	2.74	2.44	6.69	5.08	A	0	No	0	Edges unsealed; RAL and ASTM C423 Standard Size
	4	A15-033	2.44	2.44	5.95	5.08	A	0	Yes	0	RAL and ASTM C423 Minimum Size
	5	A15-034	2.44	2.13	5.21	5.08	A	0	Yes	0	Undersized per ASTM C423
	6	A15-036	2.13	1.83	3.90	5.08	A	0	Yes	0	Undersized per ASTM C423
	7	A15-037	2.13	1.83	3.90	5.08	A	0	No	0	Edges unsealed; Undersized per ASTM C423
2*	8	A15-048	2.74	2.44	6.69	2.54	E-400	375	Yes	0	
	9		2.74	2.44	6.69	2.54	A	0	Yes	0	
	10		2.74	2.44	6.69	2.54	F	10	Yes	0	
	11		2.74	2.44	6.69	2.54	F	20	Yes	0	
	12		2.74	2.44	6.69	2.54	F	30	Yes	0	
	13		2.74	2.44	6.69	2.54	F	40	Yes	0	
	14		2.74	2.44	6.69	2.54	F	50	Yes	0	
	15		2.74	2.44	6.69	2.54	F	100	Yes	0	
3	16	A15-038a	2.74	2.44	6.69	1.27	A	0	Yes	0	
	17	A15-039	2.74	2.44	6.69	2.54	A	0	Yes	0	
	18	A15-040b	2.74	2.44	6.69	3.81	A	0	Yes	0	
	19	A15-035	2.74	2.44	6.69	5.08	A	0	Yes	0	
	20	A15-041	2.74	2.44	6.69	7.62	A	0	Yes	0	
	21	A15-043	2.74	2.44	6.69	10.16	A	0	Yes	0	
	22	A15-042	2.74	2.44	6.69	10.16	A	0	No	0	Edges unsealed
	23	A15-044	2.74	2.44	6.69	12.70	A	0	Yes	0	
	24	A15-045	2.74	2.44	6.69	15.24	A	0	Yes	0	
	25	A15-046	2.74	2.44	6.69	17.78	A	0	Yes	0	
	26	A15-049	2.74	2.44	6.69	20.32	A	0	Yes	0	
	27	A15-050	2.74	2.44	6.69	20.32	A	0	No	0	Edges unsealed
	28	A15-051	2.74	2.44	6.69	25.40	A	0	Yes	0	
	29	A15-052	2.74	2.44	6.69	30.48	A	0	Yes	0	
4*	30	A15-097	2.44	2.44	5.95	5.08	A	0	No	0	
	31	A15-098	2.53	2.53	6.41	5.08	J	0	No	2.54	16 0.61 m x 0.61 m Panels (Overal area used in calc)
	32	A15-099	2.44	2.44	5.95	5.08	J	0	No	2.54	16 0.61 m x 0.61 m Panels
	33	A15-100	2.44	2.44	5.95	5.08	J	0	No	5.08	16 0.61 m x 0.61 m Panels
	34	A15-101	2.76	2.76	7.60	5.08	J	0	No	10.16	16 0.61 m x 0.61 m Panels (Overal area used in calc)
	35	A15-102	2.44	2.44	5.95	5.08	J	0	No	10.16	16 0.61 m x 0.61 m Panels
	36	A15-103	2.44	2.44	5.95	5.08	J	0	No	15.24	16 0.61 m x 0.61 m Panels
	37	A15-104	2.44	2.44	5.95	5.08	J	0	No	20.32	16 0.61 m x 0.61 m Panels; Panels <1m from wall
	38	A15-105	3.08	3.07	9.46	5.08	J	0	No	20.32	16 0.61 m x 0.61 m Panels; Panels <1m from wall (Overall Area used in calc)
	39	A51-106	2.44	2.44	5.95	5.08	J	0	No	30.48	16 0.61 m x 0.61 m Panels; Panels <1m from wall
	40	A51-107	2.44	2.44	5.95	5.08	J	0	No	60.96	16 0.61 m x 0.61 m Panels; Panels <1m from wall
	41	A51-108	2.44	2.44	5.95	5.08	J	0	No	91.44	16 0.61 m x 0.61 m Panels; Panels <1m from wall
5	42	A15-053	1.22	2.44	2.97	81.28	A	0	No	0	
	43	A15-054	2.44	2.44	5.95	30.48	A	0	No	0	

Test Objective #	1	2	3	4	5

Unsealed Edges	

Note: * to be discussed in a future follow-on paper

Test Matrix (English units)

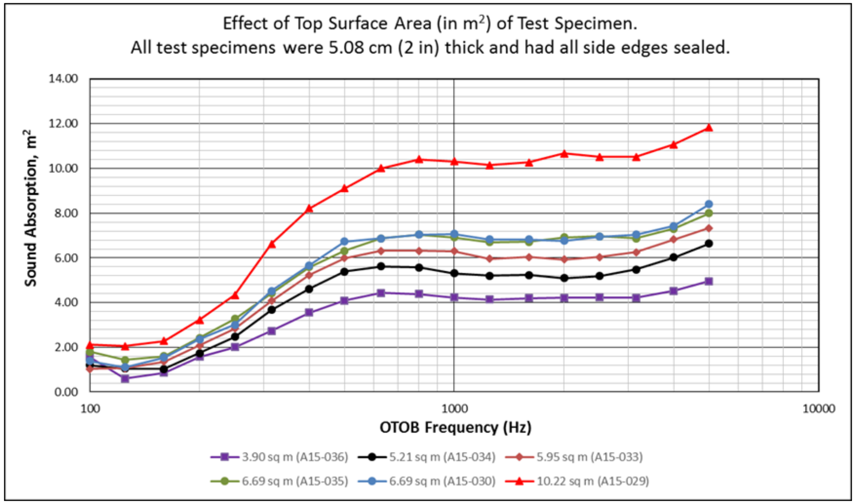
Test Objective #	Test	RAL	Length	Width	Size	Thickness	E795	Airspace	Perimeter	aced Object	
	Config. #	Test #	(ft.)	(ft.)	(ft^2)	(in.)	Mount	(in.)	Seal	Gap (in.)	Note
	1	A15-029	11.0	10.0	110.0	2.0	A	0	Yes	0	ISO 354 Size
	2	A15-030	9.0	8.0	72.0	2.0	A	0	Yes	0	RAL and ASTM C423 Standard Size
	3	A15-031	9.0	8.0	72.0	2.0	A	0	No	0	Edges unsealed; RAL and ASTM C423 Standard Size
1	4	A15-033	8.0	8.0	64.0	2.0	A	0	Yes	0	RAL and ASTM C423 Minimum Size
	5	A15-034	8.0	7.0	56.0	2.0	A	0	Yes	0	Undersized per ASTM C423
	6	A15-036	7.0	6.0	42.0	2.0	A	0	Yes	0	Undersized per ASTM C423
	7	A15-037	7.0	6.0	42.0	2.0	A	0	No	0	Edges unsealed; Undersized per ASTM C423
	8	A15-048	9.0	8.0	72.0	1.0	E-400	14.75	Yes	0	
	9		9.0	8.0	72.0	1.0	A	0	Yes	0	
	10		9.0	8.0	72.0	1.0	F	0.39	Yes	0	
2*	11		9.0	8.0	72.0	1.0	F	0.79	Yes	0	
	12		9.0	8.0	72.0	1.0	F	1.18	Yes	0	
	13		9.0	8.0	72.0	1.0	F	1.57	Yes	0	
	14		9.0	8.0	72.0	1.0	F	1.97	Yes	0	
	15		9.0	8.0	72.0	1.0	F	3.94	Yes	0	
	16	A15-038a	9.0	8.0	72.0	0.5	A	0	Yes	0	
	17	A15-039	9.0	8.0	72.0	1.0	A	0	Yes	0	
	18	A15-040b	9.0	8.0	72.0	1.5	A	0	Yes	0	
	19	A15-035	9.0	8.0	72.0	2.0	A	0	Yes	0	
	20	A15-041	9.0	8.0	72.0	3.0	A	0	Yes	0	
	21	A15-043	9.0	8.0	72.0	4.0	A	0	Yes	0	
3	22	A15-042	9.0	8.0	72.0	4.0	A	0	No	0	Edges unsealed
	23	A15-044	9.0	8.0	72.0	5.0	A	0	Yes	0	
	24	A15-045	9.0	8.0	72.0	6.0	A	0	Yes	0	
	25	A15-046	9.0	8.0	72.0	7.0	A	0	Yes	0	
	26	A15-049	9.0	8.0	72.0	8.0	A	0	Yes	0	
	27	A15-050	9.0	8.0	72.0	8.0	A	0	No	0	Edges unsealed
	28	A15-051	9.0	8.0	72.0	10.0	A	0	Yes	0	
	29	A15-052	9.0	8.0	72.0	12.0	A	0	Yes	0	
	30	A15-097	8.0	8.0	64.0	2.0	A	0	No	0	
	31	A15-098	8.3	8.3	68.9	2.0	J	0	No	1	16 2'x2' Panels (Overal area used in calc)
	32	A15-099	8.0	8.0	64.0	2.0	J	0	No	1	16 2'x2' Panels
	33	A15-100	8.0	8.0	64.0	2.0	J	0	No	2	16 2'x2' Panels
	34	A15-101	9.0	9.0	81.7	2.0	J	0	No	4	16 2'x2' Panels (Overal area used in calc)
	35	A15-102	8.0	8.0	64.0	2.0	J	0	No	4	16 2'x2' Panels
4*	36	A15-103	8.0	8.0	64.0	2.0	J	0	No	6	16 2'x2' Panels
	37	A15-104	8.0	8.0	64.0	2.0	J	0	No	8	16 2'x2' Panels; Panels < 39.37 in from wall
	38	A15-105	10.1	10.1	101.8	2.0	J	0	No	8	16 2'x2' Panels; Panels < 39.37 in from wall; Overall Area used in calc
	39	A51-106	8.0	8.0	64.0	2.0	J	0	No	12	16 2'x2' Panels; Panels < 39.37 in from wall
	40	A51-107	8.0	8.0	64.0	2.0	J	0	No	24	16 2'x2' Panels; Panels < 39.37 in from wall
	41	A51-108	8.0	8.0	64.0	2.0	J	0	No	36	16 2'x2' Panels; Panels < 39.37 in from wall
	42	A15-053	4.0	8.0	32.0	32.0	A	0	No	0	
5	43	A15-054	8.0	8.0	64.0	12.0	A	0	No	0	

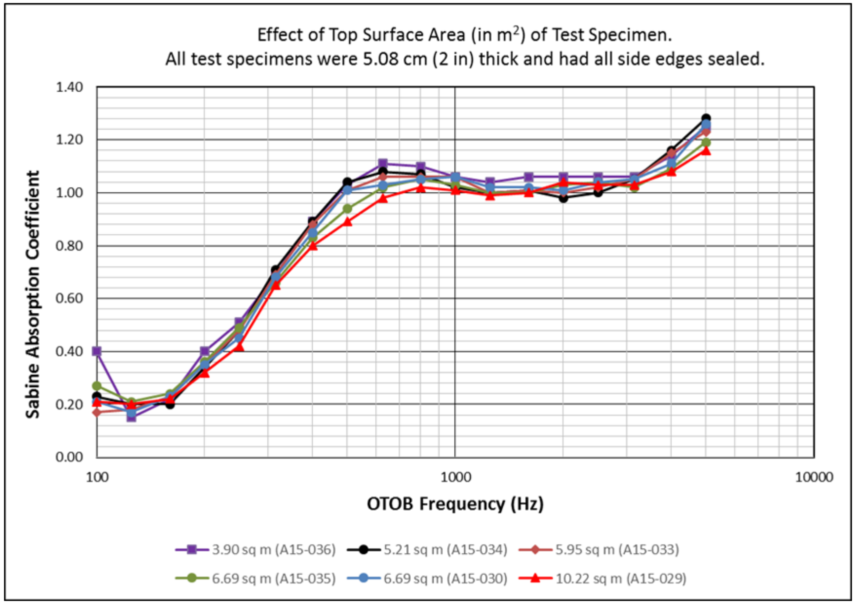
Test Objective #	1	2	3	4	5

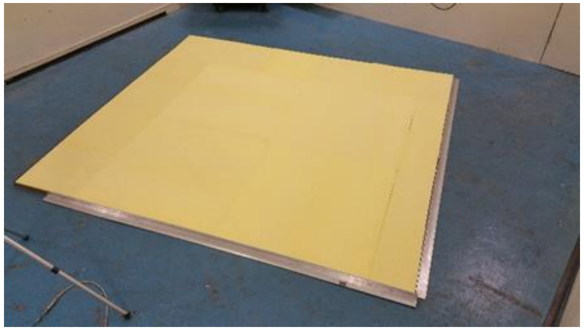
Unsealed Edges

Note: * to be discussed in a future follow-on paper

Test Objective #1
Varying Surface Area, S







S = 10.22 m^2 (110 ft^2)

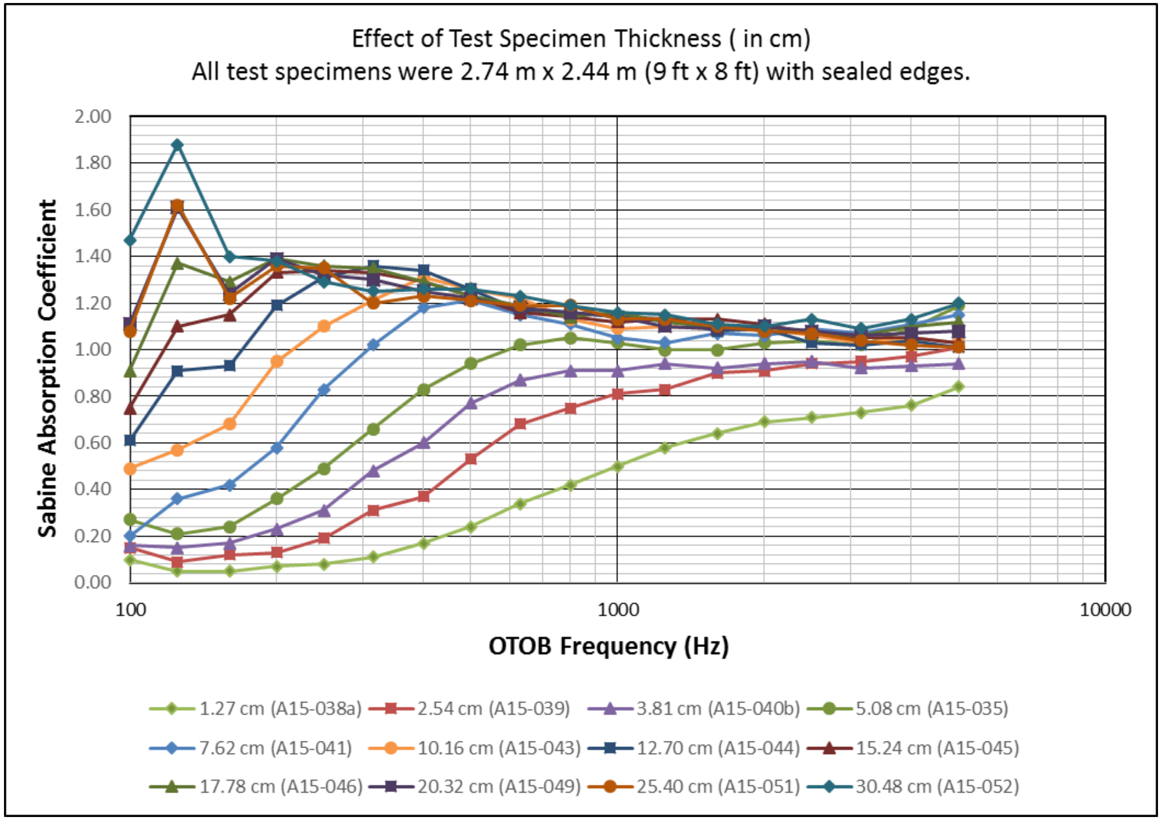
S = 3.90 m^2 (42 ft^2)

- Sabine absorption coefficients are larger for smaller surface areas.
- This ATS paper demonstrates a method for calculating "true" Sabine absorption coefficient (infinite size surface), $\boldsymbol{\alpha_0}$.

$$\boldsymbol{\alpha = \alpha_0 + \beta E}$$

Where, E is ratio of perimeter to surface area.

Test Objective #3
Varying Thickness, h

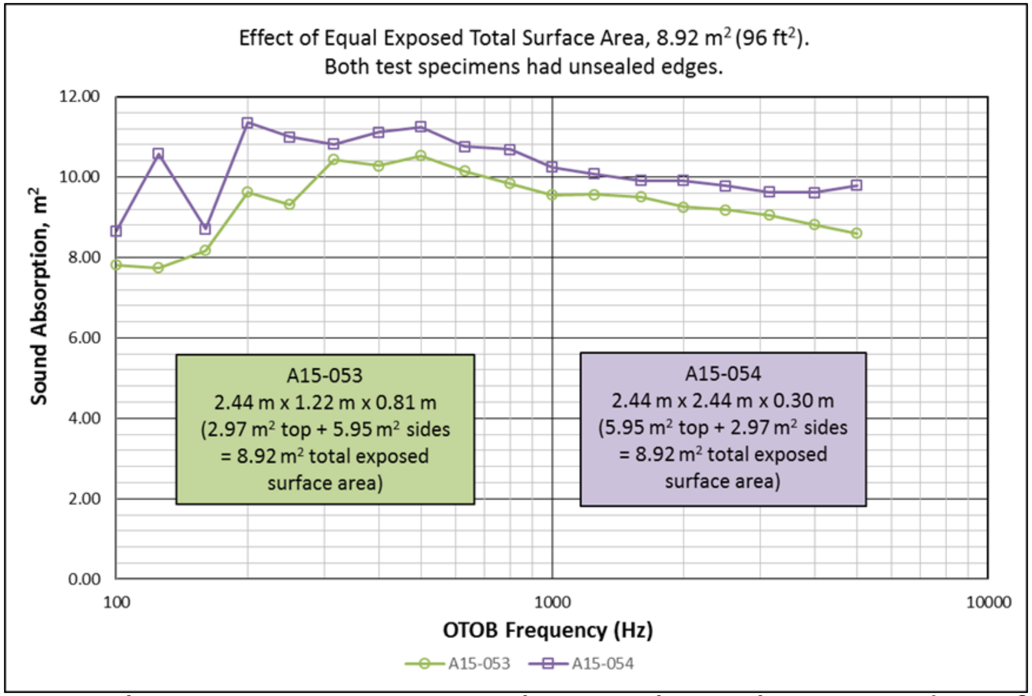


h=1.27 cm (0.5 in)

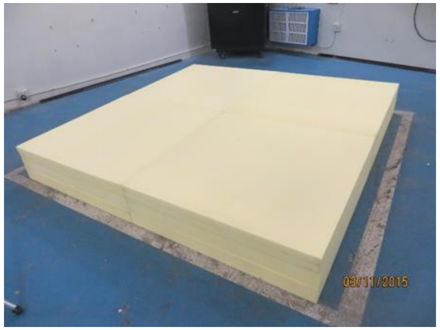
h= 30.48 cm (12 in)

- Increasing the thickness, lowers the frequency of peak absorption and increases the magnitude of the Sabine absorption coefficients.
- Diffraction Edge Effect appears to increase at the lower frequencies.
- It is difficult to separate and quantify the diffraction edge effect from the benefit obtained due to thicker test specimens.

Test Objective #5
Equal Total Exposed Surface Area



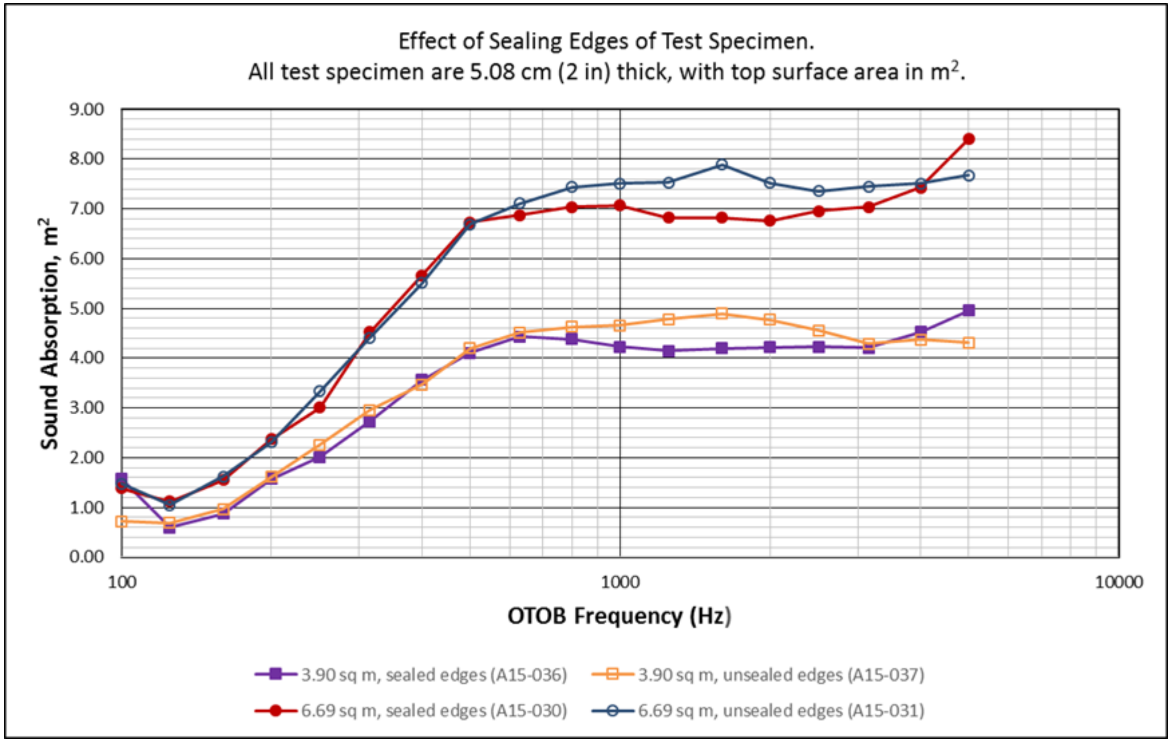
A15-053



A15-054

- Two atypical test specimens, with equal total exposed surface areas, but violating the underlying assumptions of reverberant room method were tested.
- The measured total absorption is close (~ 10% on average), but not the same, for these two test specimens.
  - Field may no longer be diffuse.
  - Test specimen may be blocking sound.
- The test specimen with the larger top surface area (A15-054) has the higher total absorption; perhaps this is due to higher % of exposed surface being more “visible.”

Sealing Edges



Sealed Edges

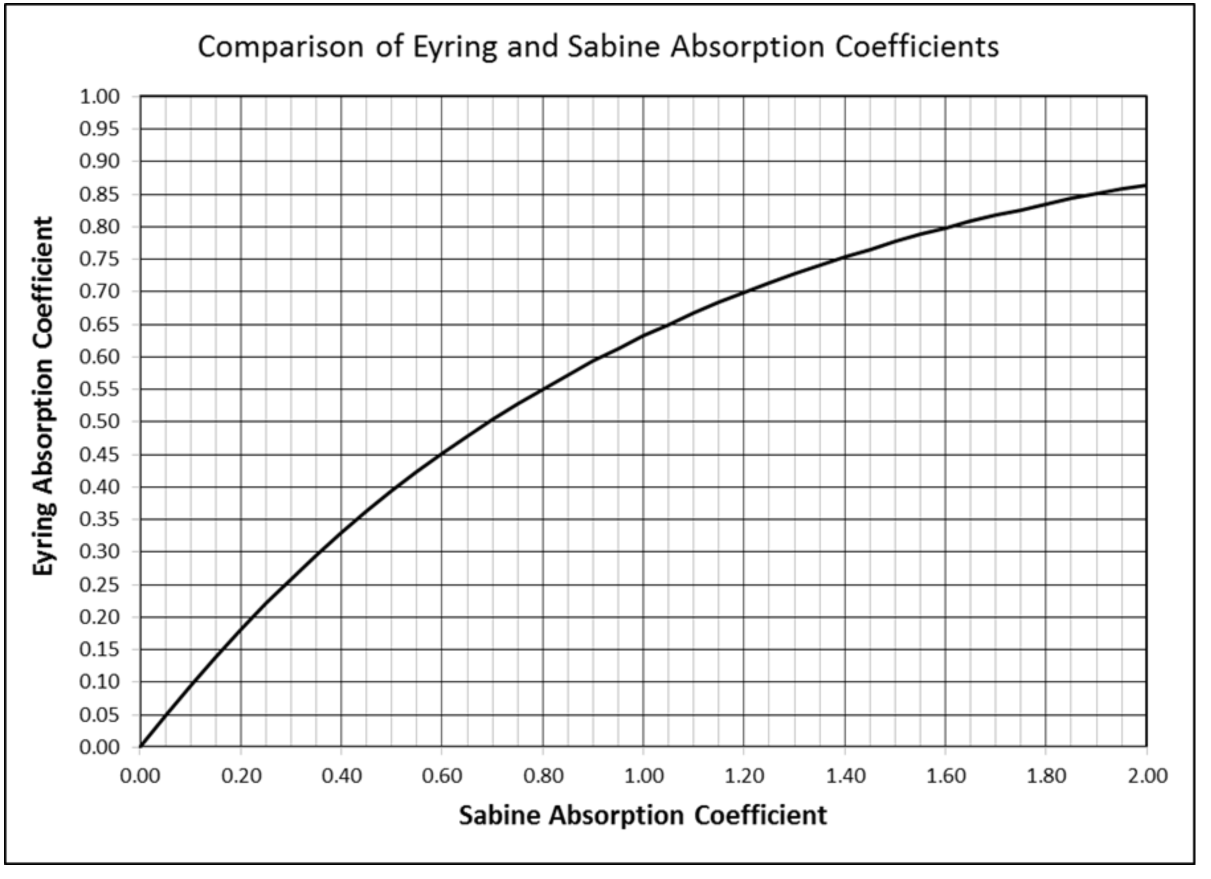
Unsealed edges

- ASTM C423 testing is typically performed with the side edges of a test specimen "sealed" to remove unwanted side absorptive surface areas.
- The sealing condition did not significantly affect the absorption at lower frequencies.
- At higher frequencies, the unsealed edge test configurations result in higher total absorption and higher Sabine absorption coefficients for otherwise identical test configurations.
  - This effect appears to peak at a frequency corresponding to a wavelength of 4x the test specimen's thickness (e.g. ~ 1700 Hz for 2 in thickness).

Sabine and Eyring Absorptions

- Sabine absorption coefficients, α, can > 1.0
- Eyring absorption coefficients cannot exceed 1.0
- Eyring absorption coefficients are the Energy absorption coefficients, ε.
- The Eyring and Sabine absorption coefficients are related by:

$$\boldsymbol{\varepsilon = 1 - e^{-\alpha}}$$



Summary

- Recommend that the absorption coefficients produced by the reverberant room method (ASTM C423) should be reported as **Sabine absorption coefficients**, and continue to be used by the noise control industry due to past acoustic design success.
  - Realize that the Sabine absorption coefficients can exceed 1.0.
- The acoustic **Energy absorption coefficients** (or **Eyring absorption coefficients**) should be recognized as the ratio of the energy absorbed to the energy incident.
  - Realize that the Sabine absorption coefficient is <u>not</u> the same as the Energy absorption coefficient.
- The diffraction edge effect and the surface area size effect, as well as the edge sealing conditions, will affect the absorption measurements.
  - The test data provided in this paper provides insight into these effects.
  - A follow-on paper will address additional absorption topics of interest that were tested.

Acknowledgements

The authors would like to thank:

- The Soundcoat Company Inc., and especially Mr. Tom Pellegrino, Soundcoat's Representative for the Aerospace industry, for their generous donation of the melamine foam (*Soundfoam*® ML ULb) products used in this test program.
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Questions?