Standardized Test Procedures for Small Reverberation Rooms

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Small reverberation rooms are used in common practice for determining random-incidence sound absorption properties of flat materials and finished parts. Based on current usage of small reverberation rooms in the automotive industry, there is a need for standardization that would bring about an appropriate level of consistency and repeatability. A round-robin study of these test facilities has been underway for more than three years and was completed in 2005. The data from the study are presented along with statistical analyses and recommendations.

The automotive industry's use of small reverberation rooms for testing, development, and for specification requirements has risen dramatically in the past 10 years. Most small reverberation rooms used today were designed and fabricated by a single manufacturer. There are a growing number of these and other small- and medium-size reverberation rooms in practice. Many of these rooms, that are not designed and fabricated by the same manufacturer, utilize significantly different geometries, test methods and analysis techniques. While large reverberation rooms (>200 m^3) also differ in many ways, there are accepted standards for large reverberation room absorption tests that provide consistency among laboratories. Therefore, a test method that attempts to bring consistency and conformance to the use of small reverberation rooms in the automotive industry is timely and appropriate.

Developing Small-Room Test Methods

The need to develop a method for absorption testing in small reverberation rooms has risen out of established industry practice.[1] The method has been developed in four phases:

1. Developing the logistics of a test matrix, procuring samples, and routing the samples to various testing laboratories.
2. Data gathering (round-robin testing and polling various test methods and equipment already in use).
3. Data analysis (statistical comparisons of the data and assigning causes for variation).
4. Constructing standardized methods from lessons learned through data analysis.

Reference 1 provides a detailed explanation of the test matrix, and provides some preliminary findings of tests conducted between large and small reverberation rooms. This article discusses some of the limitations of the round-robin testing based on how the logistics are set, reviews the data analysis from tests conducted at various laboratories and concludes with a list of items that need to be completed.

Round-robin test programs can be effective tools in gathering pertinent data regarding development of test methods. However, there are issues that should be avoided to ensure the timely success of the process.

Roving Samples vs. Parallel-Path Testing

Roving samples, or test parts that make the trip from laboratory to laboratory, can offer significant consistency benefits over parallel-path testing, where each laboratory is given its own set of samples. The consistency of the same samples being tested at each laboratory also offers the ability to acquire data over a large range of material types and performance levels. However, the extended time periods required for roving samples to be tested at each laboratory may not be worth the added benefit of consistency. This round-robin was started over three years ago, yet only 15 facilities have completed testing and provided data. Two facilities have completed testing but have not yet reported data. An additional seven facilities are still waiting to get their turn at the test samples. The original timeline for this round-robin study was one year. The current schedule shows that the testing will be complete after a total of four years.

A recent ASTM C423 round-robin study was successful in acquiring data from multiple laboratories within a few months rather than years.[2] Test panels of identical materials were manufactured for each laboratory that participated in the study. All of the materials were first tested at a base laboratory to ensure consistency and reduce variation. Strict due dates were set and communicated to participating laboratories. In addition, each laboratory was given the samples to keep as a reference standard. Therefore, when conducting a round-robin test program, both approaches and their benefits should be considered carefully.

Round-Robin Test Protocol

There is a temptation in the construction of a round-robin protocol to include too many factors. While this offers a large data set for analysis, it also can overcomplicate the test plan. The original charter of this subcommittee was to prove feasibility of developing a test method for small reverberation room absorption testing and to correlate small-room testing to large reverberation room testing. Additional goals such as testing multiple materials, testing multiple thicknesses of materials, testing materials, and shaped automotive parts, measuring multiple parts in multiple room locations, investigating the effect of sample area on measurement and investigating the diffusion of each laboratory's reverberation room were added to the test protocol. While these are valid and pertinent investigations, they multiplied the timetable and made the protocol too large for many laboratories to implement. A round-robin test program will have a better chance for timely success if focus can be placed on a smaller set of specific goals.

The protocol for this small reverberation room round robin

Table 1. Reverberation room description.

Lab #	Description	Volume, m^3
L2	Large Room	–
L3	Small Room*	6.40
L4	Large Room	200.00
L5	Small Room*	6.40
L7	Large Room	230.00
L8	Small Room*	6.40
L9	Small Room*	6.40
L10	Small Room*	6.40
L11	Small Room	9.68
L13	Large Room	212.00
L14	Small Room*	6.40

*Alpha Cabin

Based on Paper #2005-01-2284, "Development of a Small Size Reverberation Room Standardized Test Procedure for Random Incidence Sound Absorption Testing," ©2005 SAE International, presented at the Noise & Vibration Conference, May 16-19, Traverse City, MI 2005.

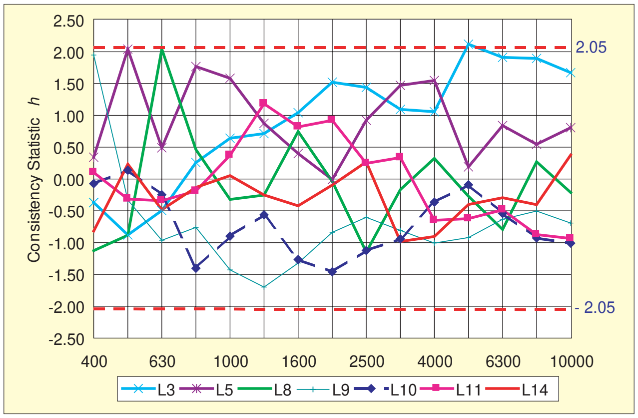

Figure 1. Small reverberation room between-laboratory consistency h-statistic for 25-mm fiberglass.

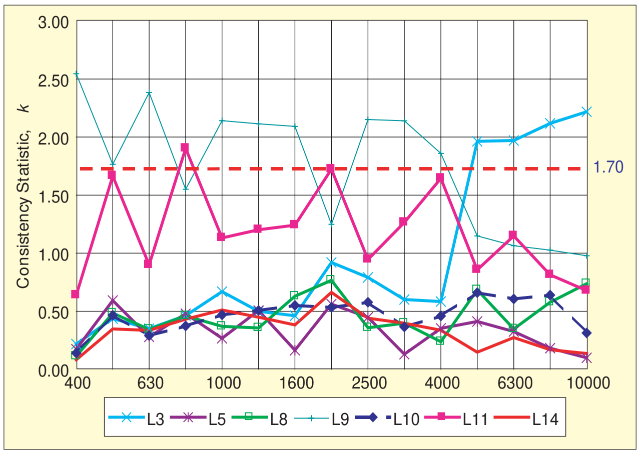

Figure 2. Small reverberation room within-laboratory consistency k-statistic for 25-mm fiberglass.

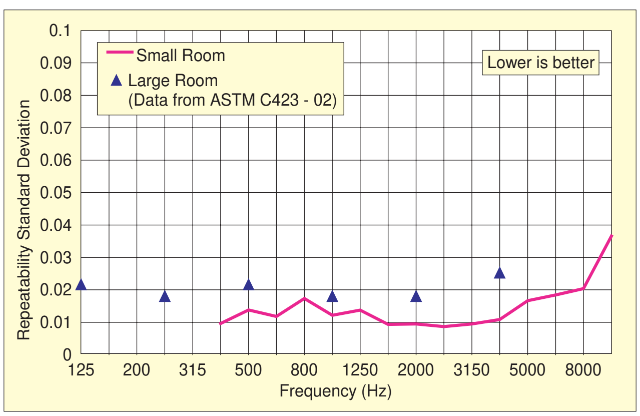

Figure 3. Small- and large-room repeatability comparison for 25-mm fiberglass.

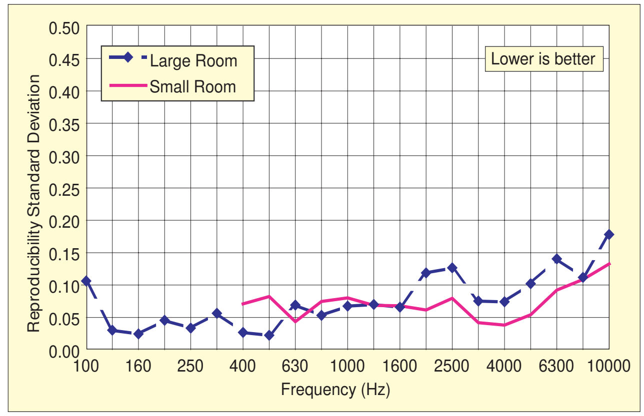

Figure 4. Small- and large-room reproducibility comparison for 25-mm fiberglass.

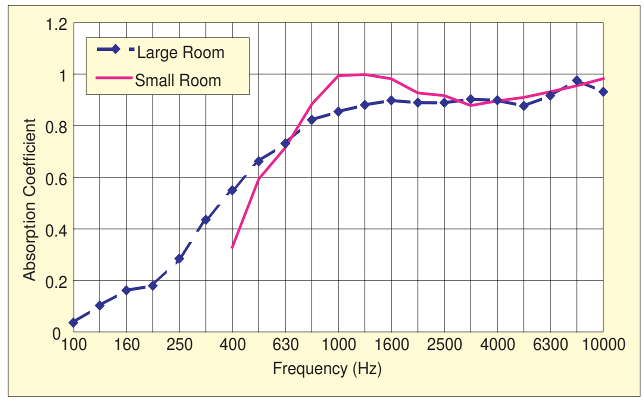

Figure 5. Small- and large-room absorption coefficient comparison for 25-mm fiberglass.

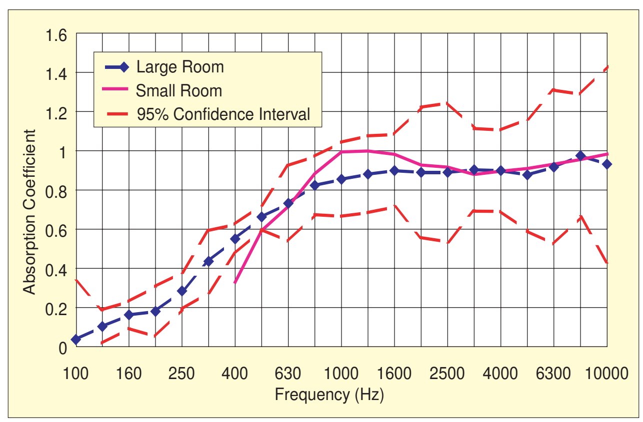

Figure 6. Small- and large-room absorption coefficient comparison for 25-mm fiberglass with 95% confidence interval.

required 45 separate tests per chamber size at each lab facility and statistically valid diffusion testing for each microphone and speaker. This may have been too large of a test plan for laboratories to complete in a timely manner. Many of the laboratories only completed about 25 of the 45 tests and skipped the rest. A recommended appropriate number of tests in a protocol would be 15 or less.

Data Analysis

Variability between test results in a round-robin test program can be expressed in terms of two statistical concepts: repeatability and reproducibility according to ASTM E 691.[3,4] Repeatability refers to measurement variations within the same laboratory with the same operator, measurement equipment and a reasonably constant environment (temperature, humidity, etc.). Reproducibility is a measure of the lab-to-lab variation, while operator, equipment and test environment may differ and contribute appreciably to the variability of the test results.

Repeatability and reproducibility are the basis for determining the precision of a test method in the round-robin test program. However, the validity of the analysis can be undermined by the presence of severe outliers. It is necessary to first examine the consistency of the interlaboratory test results. Two statistical parameters, between-laboratory consistency (statistic h) and within-laboratory consistency (statistic k) are calculated in the data analyses per ASTM E691 to identify inconsistent data sets.[4]

The h-statistic indicates how the deviation of the average data of an individual laboratory from the overall average compares to the range of deviations for all laboratories. The k-statistic is a ratio of within-lab variation of an individual laboratory to the overall level of variations of all laboratories.

In this section, absorption data from 11 of the participating laboratories, four large rooms, seven small rooms (six of them

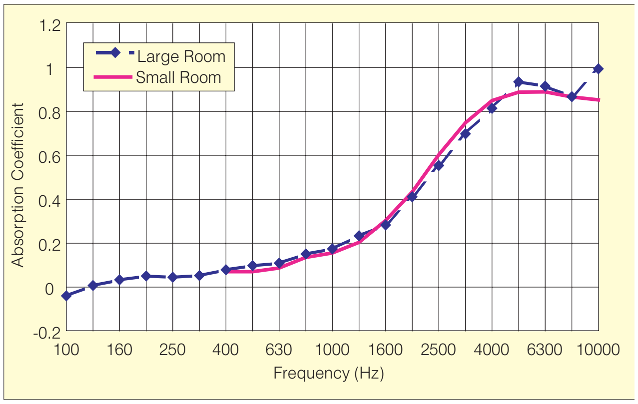

Figure 7. Small and large-room absorption coefficient comparison for 6-mm foam.

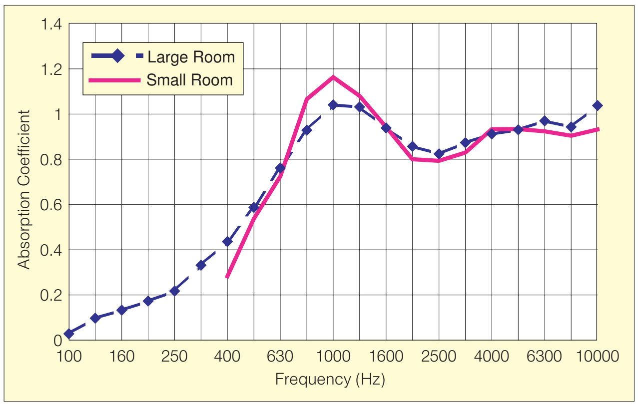

Figure 8. Small- and large-room absorption coefficient comparison for 25-mm foam.

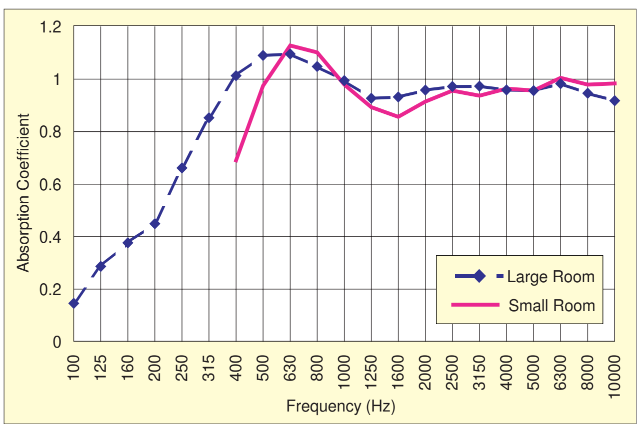

Figure 9. Small- and large-room absorption coefficient comparison for 50-mm foam.

are Alpha Cabins) are processed according to ASTM E691 to determine the precision of a method for small reverberation room sound absorption tests. Participating laboratory code number and room size are given in Table 1.

Figure 1 shows the small room *h*-statistic for the 25-mm fiberglass test specimen. Note that the *h*-values for all laboratories are within the range defined by critical values, except that the *h*-value for L3 exceeds the critical value of 2.05 at 5000 Hz. The critical value for *h* is used to identify laboratories that have significant deviation from the overall average at the 0.5% significance level.

The small reverberation room *k*-statistic for 25-mm fiberglass is given in Figure 2. The critical value for *k* can be used to identify laboratories that have significant repeatability problems at the 0.5% significance level. The *k*-values for L3 exceed the critical value of 1.70 at high frequencies, and the *k*-values for L9 exceed 1.70 at low frequencies. Further investigation of L3 indicates that humidity was not controlled during the measurement and possibly contributed to the large discrepancy at high frequencies. The cause for a large *k*-statistic for L9 is still unknown at this time. It may be necessary to examine the operating procedures in L9 to find out the exact cause. L11 also has high *k*-values, and its cause is under investigation.

Figure 3 shows the small-room repeatability standard deviation for 25-mm fiberglass. We do not have large-room repeatability data in this test program. For comparison purposes, large-room repeatability data published in ASTM C423-02 is plotted in Figure 3. As shown in Figure 3, small-room repeatability is comparable to or even better than large-room repeatability.

Small- and large-room reproducibility values for 25-mm fiberglass are shown in Figure 4. Again, small-room reproducibility is comparable to or better than large-room reproducibility at most frequencies.

Figures 5 compares average absorption coefficients measured in large and small reverberation rooms for 25-mm fiberglass, and Figure 6 includes a 95% confidence interval for large reverberation room measurements. The average absorption coefficient measured in the small reverberation room is within the 95% confidence interval of the average large-room measurements, except for the 400-Hz one-third octave band, where the density of the acoustic modes approaches the recommended lower limit.

Figures 7-9 show comparisons of average absorption coefficients measured in large and small reverberation rooms for 6-mm foam, 25-mm foam, and 50-mm foam.

The data collected to date have been effective in proving that small reverberation room tests can produce consistent, repeatable results in measuring the absorptive properties of materials. The data analysis also highlights the fact that small reverberation room testing can produce very similar results to those from large rooms for random incidence absorption testing. Significant differences between the results for the small and the large rooms at 400 Hz only occur for samples having thicknesses that are at the upper limit of those normally found in automotive acoustic applications.

Development of the Test Method

The process of evaluating the data analyses to date and drafting of a test method will now be initiated. Final data collection and analysis will be completed in parallel with the first draft of the test method. The causes for data variation in the round-robin study will be addressed within the test method to ensure validity of the procedure.

Conclusion

Round-robin studies can be used to generate data sets for developing test methods. However, it is advised that pitfalls be avoided to accomplish the activity within a reasonable amount of time. The data set for the round-robin study on a small reverberation room test method suggests that the precision (repeatability and reproducibility) for small reverberation room absorption tests is comparable to or better than large-room measurements. But, within-laboratory variation can exceed limits in certain laboratories. An expanded comparison of large reverberation room measurements and small reverberation room measurements suggests a stronger correlation than previously reported in 2003.[1]

References

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5. Halliwell, R. E., "Inter-laboratory Variability of Sound Absorption Measurement," *JASA* 73 (3), March 1983.

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