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Acoustic Test Characterization of Melamine Foam for Usage in NASA's Payload Fairing Acoustic Attenuation Systems

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Abstract

The external acoustic liftoff levels predicted for NASA's future heavy lift launch vehicles are expected to be significantly higher than the environment created by today's commercial launch vehicles. This creates a need to develop an improved acoustic attenuation system for future NASA payload fairings. NASA Glenn Research Center initiated an acoustic test series to characterize the acoustic performance of melamine foam, with and without various acoustic enhancements. This testing was denoted as NEMFAT, which stands for NESC Enhanced Melamine Foam Acoustic Test, and is the subject of this paper. Both absorption and transmission loss testing of numerous foam configurations were performed at the Riverbank Acoustical Laboratory in July 2013. The NEMFAT test data provides an initial acoustic characterization and database of melamine foam for NASA. Because of its acoustic performance and lighter mass relative to fiberglass blankets, melamine foam is being strongly considered for use in the acoustic attenuation systems of NASA's future launch vehicles.

Problem Description and Background

The increased propulsion capability requirements of NASA's future heavy lift launch vehicles will likely result in the payload fairing being exposed to extremely high external acoustic environment during liftoff. Of particular concern are the predicted high acoustic levels occurring at low frequencies internal to the fairing.

Expendable launch vehicle (ELV) fairings typically utilize acoustic treatments (e.g., foam blankets, fiberglass blankets, and passive Helmholtz resonator devices) to reduce the acoustic energy that transmits through the fairing wall and into the payload region. The typical acoustic blanket treatments applied to launch vehicle fairings are effective in reducing the transmission of noise in the 400 Hertz (Hz) and higher frequency range. Something beyond the traditional and current state-of-the-art acoustic reduction methodologies will be required for future vehicle noise reduction, especially at lower frequencies (<400 Hz).

A similar situation occurred in the 1990's for the NASA Cassini mission to Saturn, which required specialized acoustic treatments to address a radioisotope thermoelectric generator (RTG) vibration concern at 200 and 250 Hz. From an extensive and successful acoustic blanket development test series performed for the Titan IV/Cassini Project, NASA accumulated a wealth of knowledge and acoustic characterization data on fiberglass blankets (Hughes and McNelis 1996 and Hughes and McNelis 1997). The Titan IV/Cassini Project evaluated 19 different fiberglass configurations of varying blanket thicknesses, blanket densities, and internal mass barriers with varying placement locations and densities, for a series of flat panel acoustic testing at the Riverbank Acoustical Laboratory (RAL) in March to April 1994. This data was then used to down-select to the two most promising new blanket designs for full-scale acoustic testing at the Lockheed-Martin (Denver) reverberant acoustic chamber in January to February 1995. As a result, a new fiberglass barrier blanket, denoted "V5," was chosen for implementation on the Titan IV/Cassini mission and flew in October 1997. This V5 fiberglass barrier blanket successfully reduced the acoustic environment to the Cassini spacecraft as needed (Hughes, McNelis, and Himelblau 2000).

Given the trend within the aerospace industry today to use melamine (ML) foam for payload fairing acoustic attenuation, it was deemed prudent to try to assemble a database of acoustic performance test data for ML foam, similar (albeit smaller) to what was achieved for the fiberglass blankets for the Titan IV/Cassini Project. The initial step for obtaining this database was the NASA Engineering and Safety Center (NESC) Enhanced Melamine Foam Acoustic Test (NEMFAT) series of acoustic tests.

The technical objective of this NESC-funded NEMFAT task was to obtain relevant acoustic test data characterizing the acoustic performance of ML foam, both normal and enhanced. This data could then be used as a starting point for future acoustic testing and to help baseline predictions for potential use of these systems.

NEMFAT Approach and Overview

Because the NEMFAT testing was limited to a small budget, consideration had to be given to balancing the cost of the foam materials with the cost of testing. Additional thought was given to balancing the simplicity of the foam configurations and interpretation of the test data versus testing a realistic flight-like acoustic attenuation system configuration.

It was ultimately decided to purchase seven sheets of ML foam from the Soundcoat Company. Each sheet was 4 ft × 8 ft × 2 in. in dimension. Five sheets were the "standard" density (0.562 lb/ft^3) gray ML foam. One sheet was the yellow ML "ultralight" (ML UL) foam, which has a lighter density (0.375 lb/ft^3) than the standard ML foam. One sheet was the "standard" density gray ML foam with an internal Sonic 5666 mass barrier (60 oz/yd^2) placed midway in the foam thickness. A representative fiber-reinforced foam (FRF) panel was utilized as the mounting base panel during transmission loss testing.

Enhancements were also made to two of the gray ML foam sheets. Voids and mass inclusions were investigated with these enhancements. These enhancement ideas were based in part on previous work (Gardner, et al. 2002, and Kidner, et al. 2005) within the aerospace industry.

Acoustic testing was conducted at the RAL, located in Geneva, Illinois. RAL performed three absorption tests per the American Society for Testing and Materials (ASTM) C423 standard (ASTM 2009) and six transmission loss (TL) tests per ASTM E90 standard (ASTM 2009) for NEMFAT. The NEMFAT testing at RAL was performed on July 9 to 10, 2013.

The results of these tests are summarized in the Data Analysis section of this paper. Every individual ML foam sheet was 2 in. thick. The thicker 4-in. and 8-in. test configurations were assembled by layering the appropriate number and type of 2-in.-thick ML foam and ML UL foam sheets.

The absorption coefficient for both the 2-in. and the 4-in. thicknesses of ML foam were measured; that data showed that ML foam has a higher absorption over a broader and higher frequency range relative to previously tested 3-in.-thick fiberglass blankets. However, it should be noted that unlike the fiberglass blanket the ML foam test article did not include a cover sheet material, which could affect these absorption results. These results also showed that the absorption at low frequencies is improved by increasing the thickness of the ML foam.

The TLs of the 4-in. ML foam, the 4-in. ML foam with a mass barrier, and the 8-in. ML UL foam and ML foam combination with a mass barrier were measured. It was found that ML foam augmented the TL of the baseline panel above 200 Hz. The addition of the mass barrier provided additional TL performance, again above 200 Hz. The 8-in.-thick combination of ML UL foam and ML foam with a mass barrier provided the greatest TL performance of the six NEMFAT test configurations.

Limited testing was also performed by enhancing the ML foam using voids (for both the absorption and TL tests) and mass inclusions (for the TL tests only). The acoustic performances of the enhanced ML foam and the normal ML foam were similar for the three enhanced configurations that were tested.

TABLE 1.—WEIGHT SUMMARY OF TEST CONFIGURATIONS

RAL test report no.	Test configuration description	Panel weight, lb	Treatment weight, lb	Total weight, lb	Overall dimensions, in. (W × H × T)
Absorption test					
A13-173	2-in. ML foam	No panel	6.0	6.0	96 × 96 × 2
A13-174	2-in. ML foam with voids	No panel	6.0	6.0	96 × 96 × 2
A13-175	4-in. ML foam	No panel	12.0	12.00	96 × 96 × 4
TL Test					
TL13-139	FRF panel	39.5	No treatment	39.5	47.75 × 95.75 × 1.08
TL13-140	FRF panel with 4-in. ML foam	39.5	6.0	45.5	47.75 × 95.75 × 5.08
TL13-141	FRF panel with 4-in. ML foam with voids	39.5	6.0	45.5	47.75 × 95.75 × 5.08
TL13-142	FRF panel with 4-in. ML foam with mass inclusions (in voids)	39.5	7.8 with mass inclusions	47.3	47.75 × 95.75 × 5.08
TL13-143	FRF panel with 4-in. ML foam with mass barrier	39.5	20.0 with mass barrier	59.5	47.75 × 95.75 × 5.08
TL13-144	FRF panel with 8-in. ML UL foam and ML foam combination with mass barrier	39.5	24.8 with mass barrier	64.3	47.75 × 95.75 × 8.08

Data Analysis

The NEMFAT test series consisted of three absorption tests and six TL tests performed at RAL on July 9 to 10, 2013. The Vibro-Acoustics (VA One) analysis software, sold by the ESI Group, was used by the NASA Glenn Research Center engineers to make pretest TL predictions. A summary of the weights and dimensions of the various test configurations as measured at RAL is given in Table 1.

RAL is accredited to perform sound absorption coefficient measurements and sound TL measurements for the one-third octave bands in the frequency range of 100 to 5,000 Hz. Additional unofficial representative test data was requested and provided at several extra one-third octave band frequencies, both at lower (40 to 80 Hz) and higher (6,300 to 10,000 Hz) frequencies than the ASTM standard frequencies.

The following sections describe the testing and data analysis performed for NEMFAT.

Absorption Testing

The choices for the absorption test configurations were based on the test concepts stated in the original proposal to NESC, as well as material limitations. For absorption testing, ATSM C423 recommends that the area of the test specimen be at least 60 ft^2 and recommends 72 ft^2. Since the foam sheets were each 4 × 8 ft (32 ft^2), an area of 64 ft^2 was achievable by placing two foam sheets next to each other. However, lack of sufficient physical materials prevented this from being possible in all cases; for example, a total of only 32 ft^2 was available for the ML UL foam, the ML foam with a mass barrier, and for the FRF base panel. Therefore, no absorption testing could be performed for these three items. What was achievable and actually tested were the following three foam configurations, as illustrated in Figure 1.

- A13-173—2-in. ML foam
- A13-174—2-in. ML foam with voids
- A13-175—4-in. ML foam

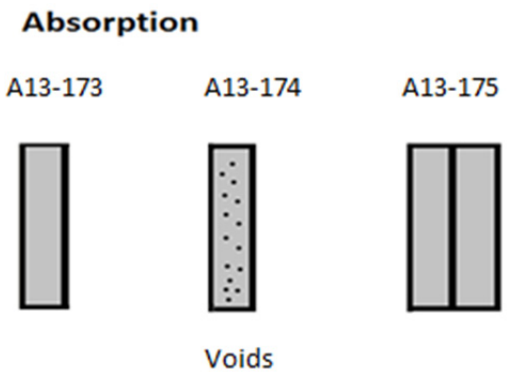


Figure 1.—Cross-sectional views of NEMFAT absorption test configurations.



Figure 2.—RAL's absorption test setup (4-in.-thick ML foam, ASTM-C423 reverberation room method).

This testing allowed an analysis of the effect of thickness on absorption (i.e., a comparison of 2-in. versus 4-in.-thick ML foam), and also allowed a comparison of ML foam with and without the voids. A typical absorption test setup at RAL is shown in Figure 2.

In Figure 3, a plot of the measured absorption coefficient (Sabine absorption) is shown versus frequency for the three configurations tested. The thicker foam (4 in.; A13-175) is a much more effective absorber at lower frequencies compared with the thinner foam (2 in.; A13-173). This trend is expected from theory and also agrees with previous test data obtained from the Cassini fiberglass blanket testing. Note that the Sabine absorption coefficient can exceed a value of 1.0 due to edge diffraction effects and to the Sabine formulation itself (Cox and D'Antonio 2004).

An enhancement was made to two of the gray ML foam sheets. The enhancement was to introduce 18 voids (or holes), each with a 0.25-in. diameter, through the foam thickness direction, in a random pattern for each sheet. It can also be seen in Figure 3 that the presence of the voids in the ML foam (A13-174) had no significant effect on the absorption of the ML foam compared with the unaltered ML foam (A13-173) of the same thickness. Further study is needed to reach any firm conclusion since only one enhanced void variation was tested.

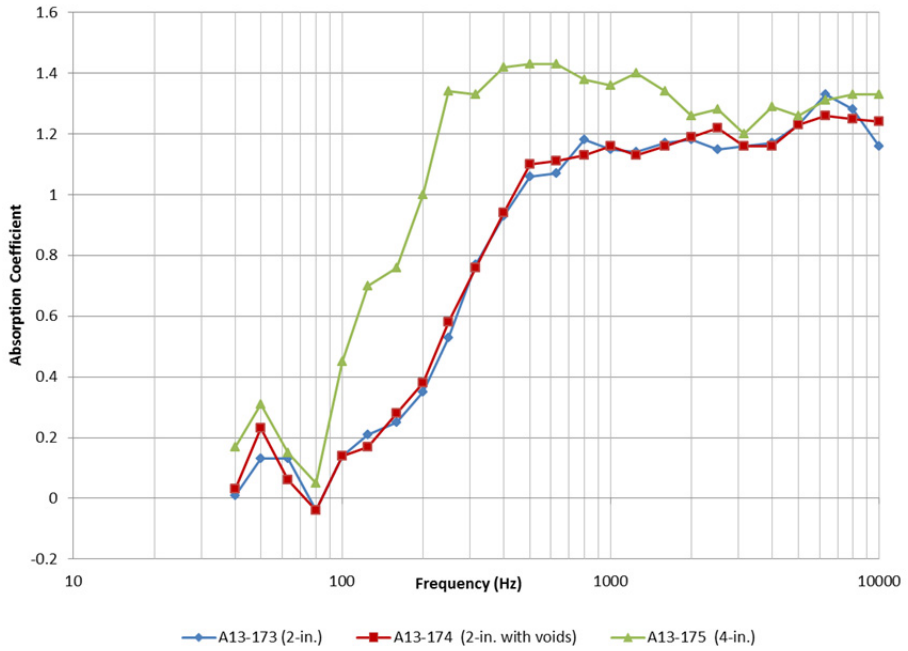


Figure 3.—NEMFAT absorption test results.

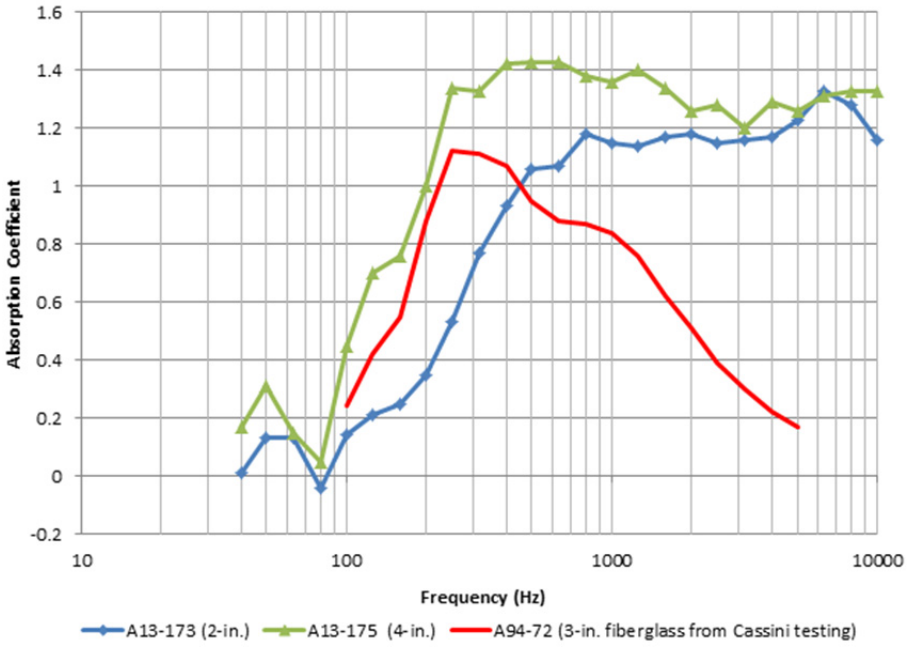


Figure 4.—Comparison of absorption coefficients for melamine foam versus fiberglass (Note: the tested ML foam treatments did not have cover sheets).

The 2-in. (A13-173) and 4-in. (A13-175) thick ML foam absorption data are compared in Figure 4 with the absorption data from the 3-in.-thick fiberglass "baseline" blanket (from the 1994 Titan IV/ Cassini testing; A94-72). From this comparison, it appears that the ML foam has a higher peak magnitude of absorption relative to the fiberglass blanket and that the ML foam has a much greater frequency range of effectiveness relative to the fiberglass. However, note that the ML foam tests had no cover sheet material for the NEMFAT testing, whereas the Cassini fiberglass blanket was encapsulated in a Teflon coated fibrous cover, which may be the cause of the decline in absorption after reaching the peak absorption value. Further testing of ML foam with a cover sheet is required to determine those effects.

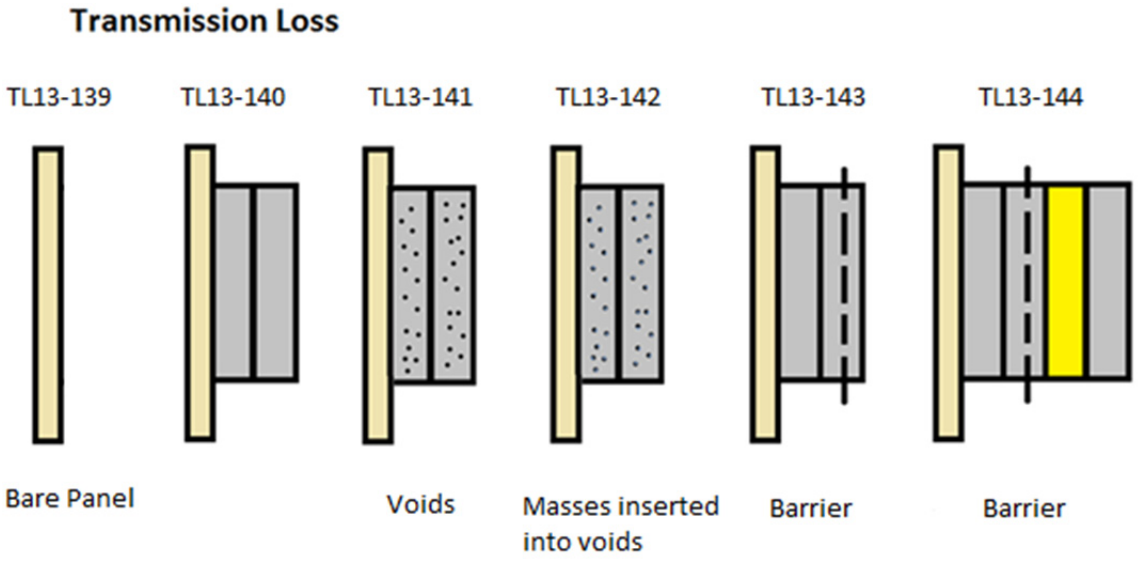


Figure 5.—Cross-sectional views of NEMFAT TL test configurations.

Transmission Loss Testing

The choice for the TL test configurations was based first on the test concepts stated in the original proposal to NESC and secondly on obtaining additional relevant knowledge. Since the RAL test specimen window between the source and receiver rooms was 8 × 4 ft, only one foam sheet of that size was needed for testing. This allowed TL testing of both the ML foam with the mass barrier, and a complex, thicker buildup of materials combining the ML UL foam, the ML foam, and the ML foam with the barrier. The six TL tests performed, as shown in Figure 5, were as follows:

- TL13-139—FRF panel
- TL13-140—FRF panel with 4-in. ML foam
- TL13-141—FRF panel with 4-in. ML foam with voids
- TL13-142—FRF panel with 4-in. ML foam with mass inclusions (in voids)
- TL13-143—FRF panel with 4-in. ML foam with a mass barrier
- TL13-144—FRF panel with 8-in. total foam thickness: ML UL foam (2 in.) and ML foam (6 in.) combination with a mass barrier

These test configurations allowed for multiple acoustic TL performance comparisons, including (a) bare panel versus treated panel, (b) normal ML foam versus enhanced (i.e., voids and mass inclusions) ML foam, (c) the effect of the Sonic 5666 mass barrier (<0.06 in. thickness), and (d) the effect of complex buildup of materials.

A typical TL test setup at RAL is shown in Figure 6.



Left, Transmission Loss Receiver Room (4-in. ML foam with mass inclusions shown in test window)

Right, Transmission Loss Source Room (FRF panel shown in test window)



Figure 6.—RAL's TL test setup for TL13-142 (ASTM E-90 airborne sound TL for building partitions and elements method).

The TL plots for the six NEMFAT test configurations are shown in Figure 7. The bare untreated FRF panel (TL13-139), with a weight of 39.5 lb, provides a nominal TL reduction, reaching a peak of 28 decibels (dB) at 4,000 Hz (and at 3,150 Hz). The addition of 4 in. of ML foam (by using two 2-in. ML foam sheets) to the FRF panel (a total weight of 45.5 lb for panel and treatment) substantially increases the TL (TL13-140), reaching 51 dB, respectively, at 4,000 Hz. This 23-dB improvement in TL at 4,000 Hz is significantly greater than the 1 to 2 dB that could be attributed to the TL increase due only to the mass law.

Enhancements were made to two of the gray ML foam sheets. The enhancement was to introduce 18 voids (or holes), each with a 0.25-in. diameter, through the foam thickness direction, in a random pattern for each sheet. The second enhancement was to later fill these voids with serrated hex flange bolts representing mass inclusions. The added weight of the 36 bolts was 1.8 lb.

There was no measured improvement (or worsening) in the TL due to the voids and the mass inclusion enhancements. This is shown by the overlapping of the TL data measurements for the tests of the 4-in. ML foam (TL13-140), the 4-in. ML foam with voids (TL13-141), and the 4-in. ML foam with mass inclusions (TL13-142) configurations. This observation was disappointing in that both the literature (Gardner, et al. 2002, and Kidner, et al. 2005) and the pretest VA One TL analysis with voids enhancement predicted an observable increase in TL for the enhanced ML foam. Further efforts are necessary to understand the controlling parameters to physically realize this possible improvement. The NEMFAT task funding did not allow for testing of multiple enhancements with varying parameters, such as void size and number of voids.

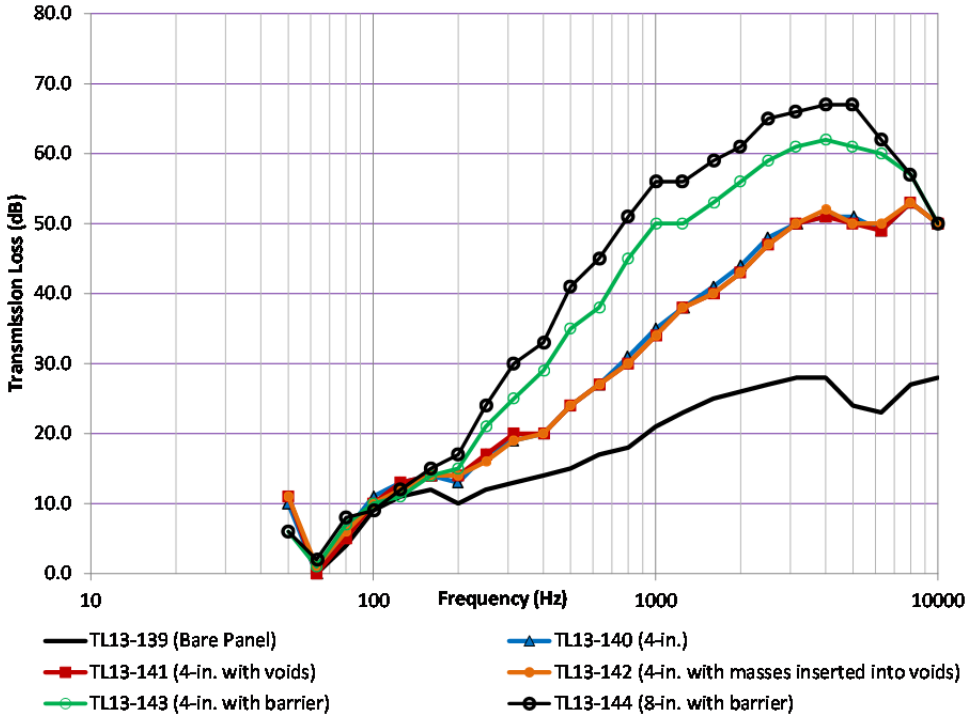


Figure 7.—NEMFAT TL test results.

The next TL test (TL13-143) added a mass barrier to 4 in. of ML foam (total weight of 59.5 lb, including both panel and treatment). This configuration was a 2-in. ML foam sheet layered with another 2-in. ML foam sheet with the mass barrier in its center, as shown in Figure 8. Compared with the normal 4-in. ML foam (TL13-140), the foam/mass barrier configuration was significantly better in resisting sound transmission. For example, at 4,000 Hz the TL was 61 dB, a 10-dB improvement over the same ML foam thickness without the mass barrier, and an improvement of 33 dB over the bare FRF panel.

With one remaining TL test to be performed, it was decided to test a complex foam treatment configuration (TL13-144). This configuration started with the previously described 4-in. ML foam sheet with mass barrier configuration and then added a 2-in.-thick sheet of ML UL foam and a 2-in.-thick sheet of ML foam. This resulted in an 8-in.-thick treatment (with a total weight of 64.3 lb for both the panel and the treatment), as shown in Figure 9. Not surprisingly, this treatment provided the best TL of the NEMFAT treatment configurations tested. At 4,000 Hz, the TL was 67 dB, a 6-dB improvement over the 4-in. with the mass barrier treatment (TL13-143) and a 39-dB improvement over the bare FRF panel (TL13-139).

As can be seen in Figure 7, the improvements in TL for each of the foam treatments are most evident above 200 Hz. Below 100 Hz, the measured TL test data seemed to converge for all configurations tested.

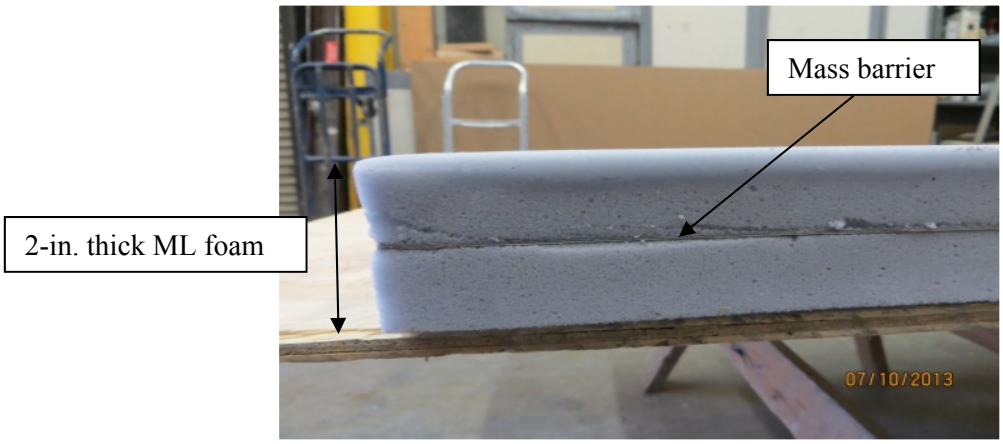


Figure 8.—The 2-in.-thick ML foam sheet with mass barrier at its center.



Figure 9.—The 8-in.-thick combination foam treatment (TL13-144) (top to bottom layers: FRF panel, 2-in. ML foam, 2-in. ML foam with center mass barrier, 2-in. ML UL foam, 2-in. ML foam).

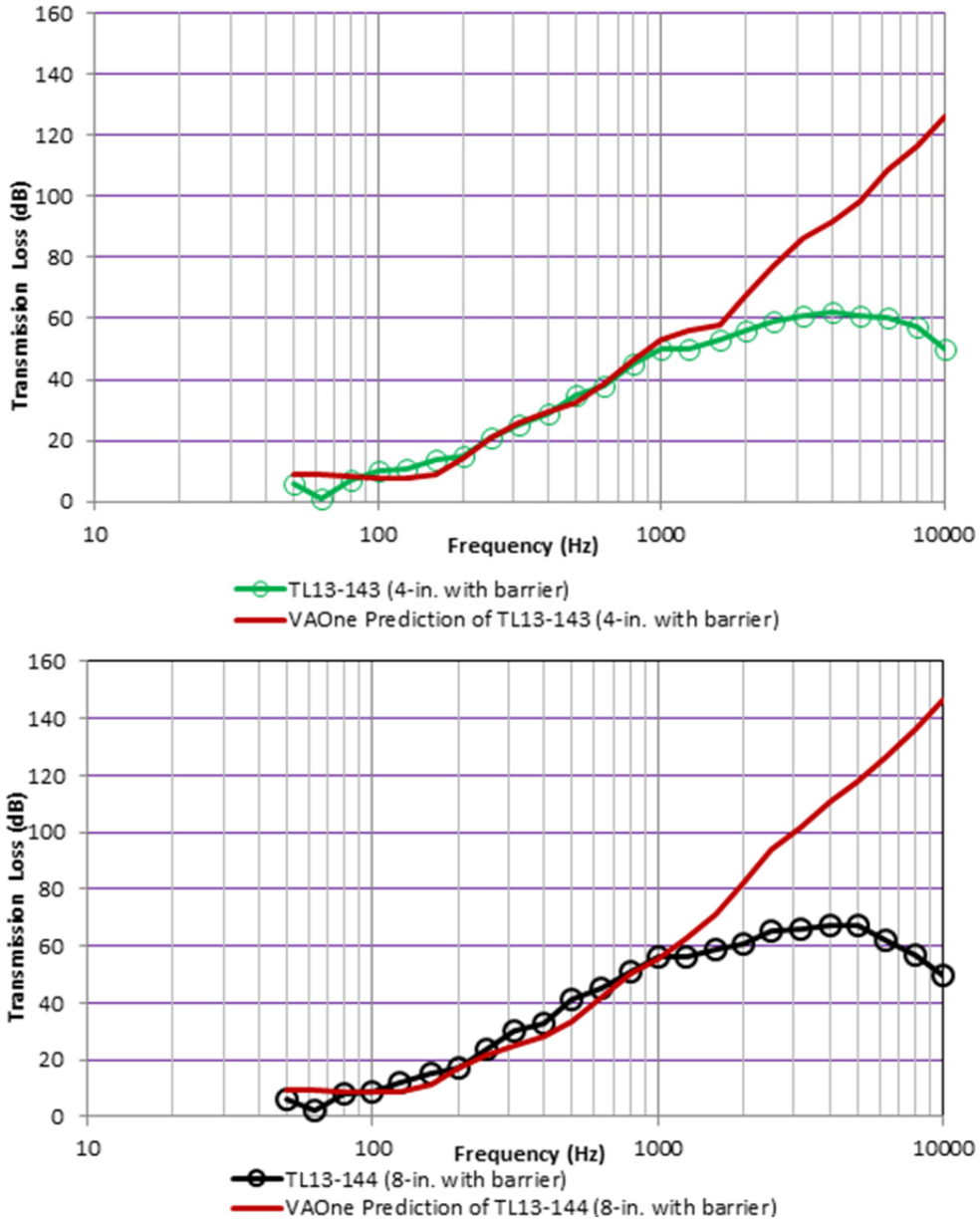


Figure 10.—TL comparison of RAL test data and VA one pretest predictions (top: 4-in. ML foam with mass barrier (TL13-143); bottom: 8-in. combination foam treatment (TL13-144)).

In Figure 10, a comparison is shown of pretest analytical predictions of TL for (a) 4-in. ML foam with mass barrier and (b) the 8-in. complex foam treatment with the associated RAL TL test data (TL13-143 and TL13-144, respectively). For both cases, the VA One prediction is quite good up to 1,000 Hz. Above this frequency, the predicted TL continues to increase, whereas the measured TL data tend to plateau. Understanding why the analysis does not predict better and improving the comparison above 1,000 Hz will be areas of further study.

Summary

The NEMFAT testing was successful in that it established an initial database of acoustic properties of ML foam for NASA. This database is being used as the baseline for future, more comprehensive, testing of ML foam by the NASA Glenn Research Center. Because of ML foam's improved acoustic performance and lighter mass relative to fiberglass blankets, the use of ML foam is being strongly considered for future acoustic attenuation systems for future NASA payload fairings. Additional information on the NEMFAT data and results may be found in the official NESC report (Hughes, A. McNelis and M. McNelis 2013) and the associated NASA TM (McNelis A., Hughes and M. McNelis 2014).

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
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