Evaluating Attenuation of Vibration Response using Particle Impact Damping for a Range of Equipment Assemblies

Brent Knight [1], David Parsons [2], and Andrew Smith [3]
NASA, Marshall Space Flight Center

Ron Hunt [4]
BRC, Huntsville. AL, 35805, USA

Bruce LaVerde [5]
ERC, Huntsville, AL, 35612, USA

Robert Towner [6], and Ben Craigmyle [7]
Jacobs Engineering Group, Huntsville, AL, 35612, USA

Particle dampers provide a mechanism for diverting energy away from resonant structural vibrations. This experimental study provides data from a series of acoustically excited tests to determine the effectiveness of these dampers for equipment mounted to a curved orthogrid panel for a launch vehicle application. Vibration attenuation trends are examined for variations in particle damper fill level, component mass, and excitation energy. A significant response reduction at the component level was achieved, suggesting that comparatively small, strategically placed, particle damper devices might be advantageously used in launch vehicle design. These test results were compared to baseline acoustic response tests without particle damping devices, over a range of isolation and damping parameters. Instrumentation consisting of accelerometers, microphones, and still photography data will be collected to correlate with the analytical results.

Nomenclature

ESSSA = Engineering and Science Services and Skills Augmentation
MSFC = Marshall Space Flight Center

I. Introduction

Highly energetic structural responses of lightly damped aerospace structures to acoustic fields present significant problems for the survivability of electronic equipment and the structural integrity of structural members. For these structures, even a slight increase in available damping at the right location, could make a critical difference, by reducing the response at resonance. Validating vibration environment estimates for equipment assembled to vehicle panels and refining analytical approaches used to estimate these environments, based on ground or flight tests, is of major importance to new launch vehicle programs. The data acquired from this experimental series should permit critical evaluation of the usefulness of particle dampers and suggest estimation methodology useful to the aerospace community.

---

1 Engineer, Thermal and Mechanical Analysis Branch (ES22), NASA Marshall Space Flight Center, Huntsville, Alabama, 35812
2 Structural Dynamics Analyst, Thermal and Mechanical Analysis Branch (ES22), NASA Marshall Space Flight Center, Huntsville, Alabama, 35812.
3 Vibroacoustics Specialist, Loads and Strength Branch (EV31), NASA Marshall Space Flight Center, Huntsville, Alabama, 35812.
4 Structural Dynamics Analyst, Bevilacqua Research Corporation, Supporting MSFC/ES22, Huntsville, AL.
5 Vibroacoustics Lead Engineer, ERC, Supporting MSFC/EV31, Huntsville, AL.
6 Loads and Dynamics Lead Engineer, Jacobs Engineering, Huntsville, AL, AIAA Member.
7 Structural Analyst, Jacobs Engineering, Huntsville, AL, AIAA Member.

Marshall Space Flight Center (MSFC) completed a series of ground test cases using acoustic noise to excite a flight-like vehicle panel. Bare panel responses were compared to a variety of vibration mitigating configurations, including the addition of mass, cable harnesses, passive wire-rope isolation, and particle damping. This paper will report on the damping trends observed from response measurements for several different test configurations and varying particle damper fill levels. In addition to answering the question of efficacy, the planned test series was designed to characterize the particle damping variation with excitation energy and the ratio of total particle mass to overall test article mass. Since these test configurations and excitation levels were also subjected to other damping/isolation methods, the test results will inform analysts as to the relative merits of each particle damping method.

II. Test Overview

The flight-like test article used in acoustic ground testing at MSFC consists of an aluminum orthogrid rib stiffened panel. It has a curved Outer Mold Line (OML) that approximates a 45^0 section (i.e., $1/8^{th}$ of the cylindrical exterior shell) of a launch vehicle. The panel is clamped into a baffled test fixture, which separates a reverberant chamber from an anechoic room (simulating a flight-like condition, with the exterior panel surface excited by a high-energy acoustic field). The panel is excited by an acoustic noise excitation simulating the liftoff vibroacoustic environment and more roughly approximating the ascent flight events. Note that fixing the baffled panel so that it is excited by source room energies on only one side, approximates the loading in-service on the launch vehicle. Accelerometer, microphone, and strain gage data measure the response of the panel as well as the transmission loss across the panel.

The acoustic field was generated in the MSFC Reverberant Chamber using conditioned/compressed air to drive up to four parallel WAS 3000 Modulators, which in-turn feed sound into the room through a single horn. The acoustic field was monitored using an array of microphones in front of the test article. A standard microphone configuration was used, consisting of an array centered in each of seven sectors, 1.5 inches in front of the test panel. This acoustic power source was utilized to approximate a diffuse acoustic field in the reverberant chamber. A sketch of the test setup, showing the source and receiver rooms, with the approximate location of the microphone array is presented as Figure 1.

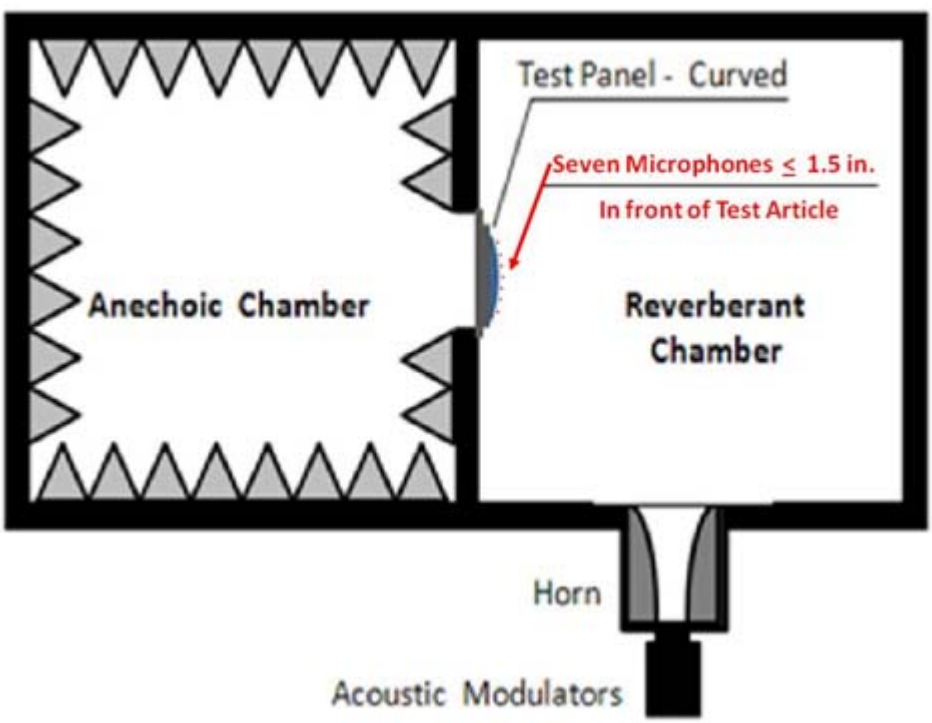


Figure 1. Test Chamber Plan View.

The panel has a smooth outer surface with small orthogrid construction on the interior surface. The material type is an aluminum 2219 alloy. It is approximately 81 inches in height. The outer surface is described by a diameter of 216.5 inches. The arc length is approximately equivalent to one eighth of the full cylinder circumference, which is approximately 85 inches. Pictures of the reverberant chamber (showing the outer surface) and the anechoic chamber (showing the interior surface) are presented in Figure 2 and Figure 3.

Figure 2. Reverb-Side Integration of Test Article.

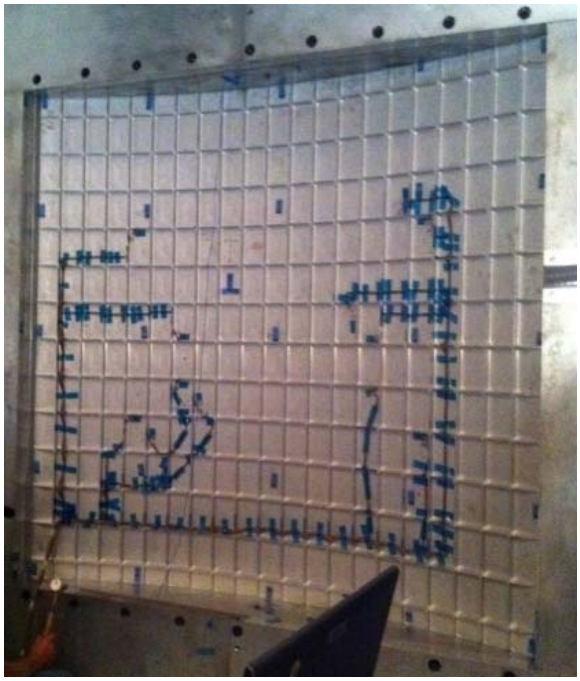


Figure 3. Anechoic-Side Integration of Test Article.

III. Test Configurations

Configurations for the test series include mass simulators that can be added to the orthogrid panel. During the first test series, three primary configurations were used; a bare panel, a panel mass-loaded by a small mass simulator , and a panel mass-loaded by a larger mass simulator (with a footprint of 28” x 36”). The supported mass of the small and large mass simulators allow further variation by bolting “increment plates” to the mass simulators. For the particle damping test series, the test configuration with a larger mass simulator was used. The basic configurations include:

1. Bare panel without particle dampers
2. Panel with 4 small particle dampers
3. Panel with a mass simulator
4. Panel with passive isolation, a mass simulator, and 4 small particle dampers
5. Panel with a mass simulator, one mass increment plate, and 4 small particle dampers
6. Panel with a mass simulator, and 4 large particle dampers

A picture of the large mass simulator configuration is presented in Figures 4. Particle damper installation and assembly details can be seen in Figures 5 and 6.

Within each basic test configuration, the fill level of the particle dampers was set to 0%, 30%, 60%, and 90% full (by volume). Particle fill was achieved by adding or removing steel shot through an opening at the top of the damper housing. During testing, particles were contained within the damper housing by sealing the access hole with a bolt. Additionally, each basic configuration/fill level, was exposed to four excitation levels wherein responses were measured and recorded.

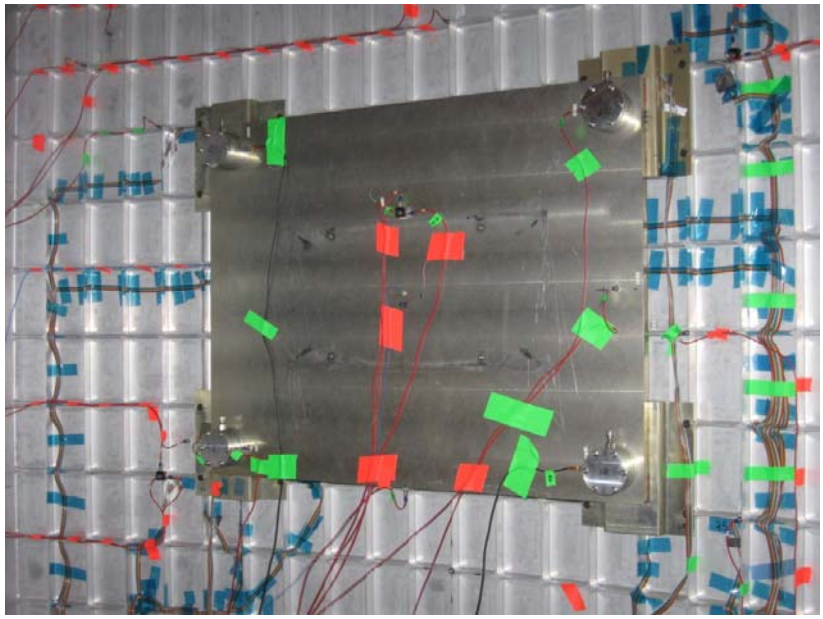


Figure 4. Anechoic-Side Integration of Test Article depicting the Case 3 Mass Simulator configured with 4 Small Particle Dampers.

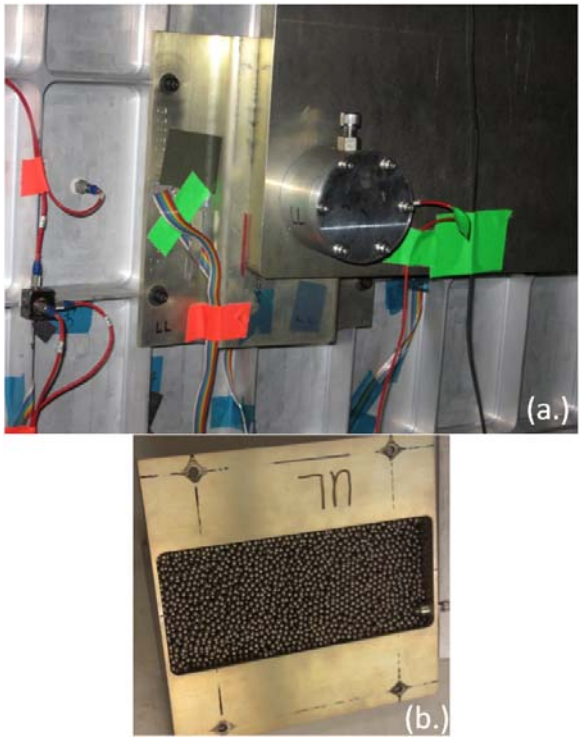
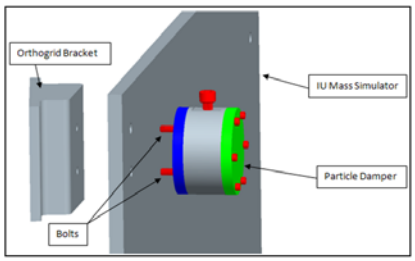


Figure 5. Arrangement of the Small and Large Particle Damper Assemblies with the Mass Simulator. (a.) One of Four Small Cylindrical Particle Damper Packages installed at Lower Corner of the Mass Simulator. (b.) The Large Particle Damper placed BB type particles inside the Bathtub Bracket that mounted the Mass Simulator to the Primary Structure.

Each small particle damper is a cylindrically shaped housing that contains up to 0.75 lb of steel shot (at the 90% fill level). Further details for the small particle damper are provided in Figures 6 and 7. The large particle damper, which consists of a cavity machined into the mounting brackets that attach the mass simulator to the panel, is shown in Figure 8.

- Canister PID:

- PID housing bolted to the corners of the component mass simulator
- Steel shot with fill levels: 0% 30% 60% 90%
- Mass:
  - Housing: 1lb each
  - 90% fill: .75 lb each



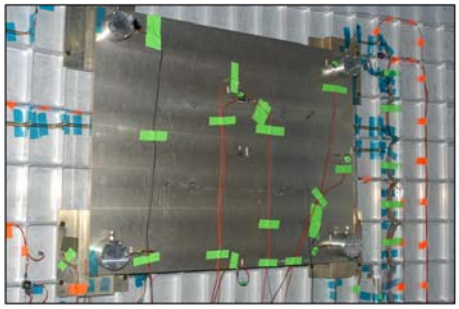
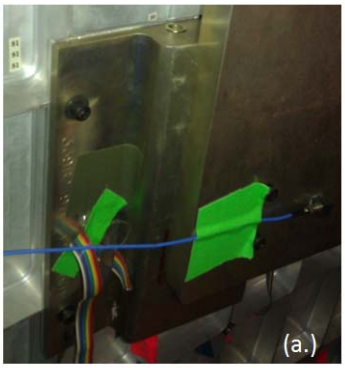


Figure 7. Canister Type Particle Damper Assembly

- Bracket PID:

- PID housing formed by cavity in mounting hardware. (could have used the orthogrid pockets)
- Tungsten shot with fill levels: 0% 50% 90%
- Mass:
  - 50% fill: 5 lb each (20 lb total for 4 locations)
  - 90% fill: 8.75 lb each (35 lb total for 4 locations)



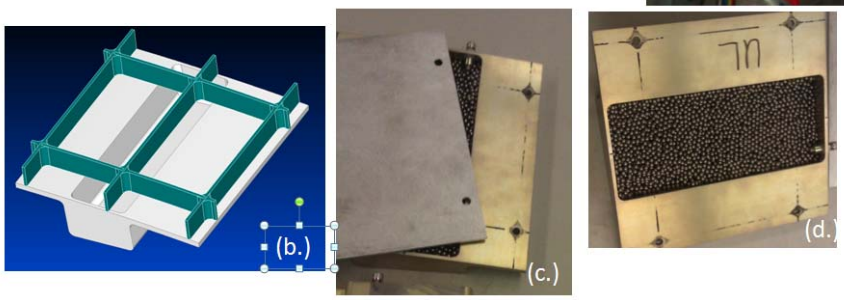


Figure 8. Bracket Type Particle Damper Assembly (a.) Installed Bracket. (b.) Bathtub Cavity in Bracket. (c.)Bracket with Cover. (d.) Bracket filled with BB type Particles.

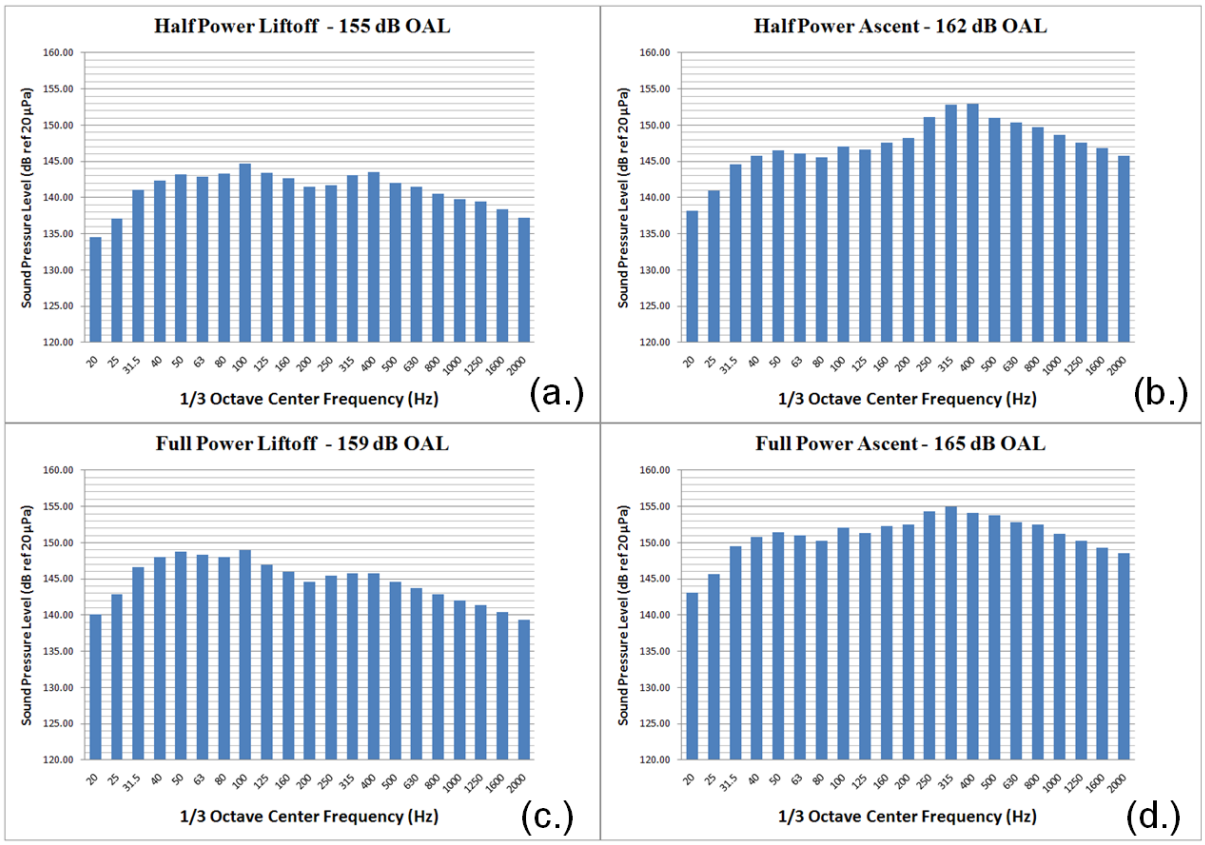


Figure 9. Example Average Liftoff Sound Pressure Level Repeated for Configurations with/without Particle Dampers. (a.) Half Power Liftoff. (b.) Half Power Ascent (c.) Full Power Liftoff. (d.) Full Power Ascent .

IV. Supporting Characterization of Measurements

MSFC has used this test set up to produce significant sound pressure levels that elicit flight like levels of response in the test article system. Figure 9 shows a plot of the average sound pressure spectrum recorded by the six microphones in the reverberant chamber. Figure 10 presents response level for 5 configurations of the test article hardware that were tested without particle dampers. These serve as a baseline response which will help to illustrate the attenuation of response provided when the particle dampers are included during the follow on test series.

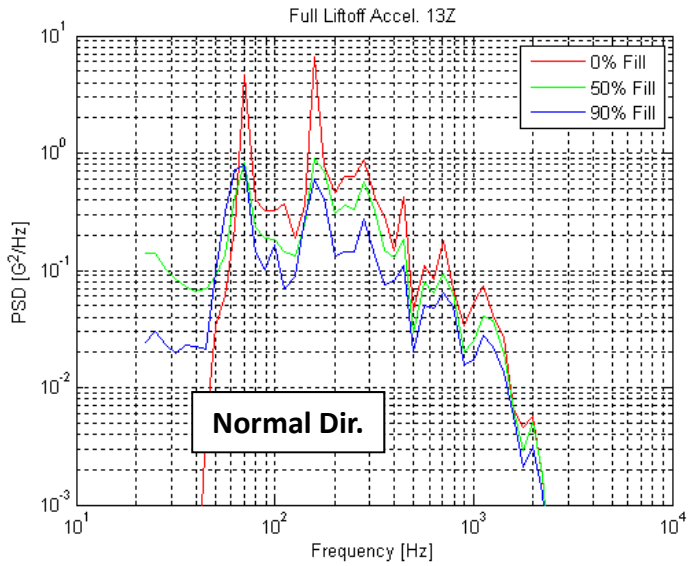


Figure 10. Vibration Levels Prior to and After the Addition of Large Bracket-Type Particle Dampers-Response for Liftoff Acoustic Spectrum

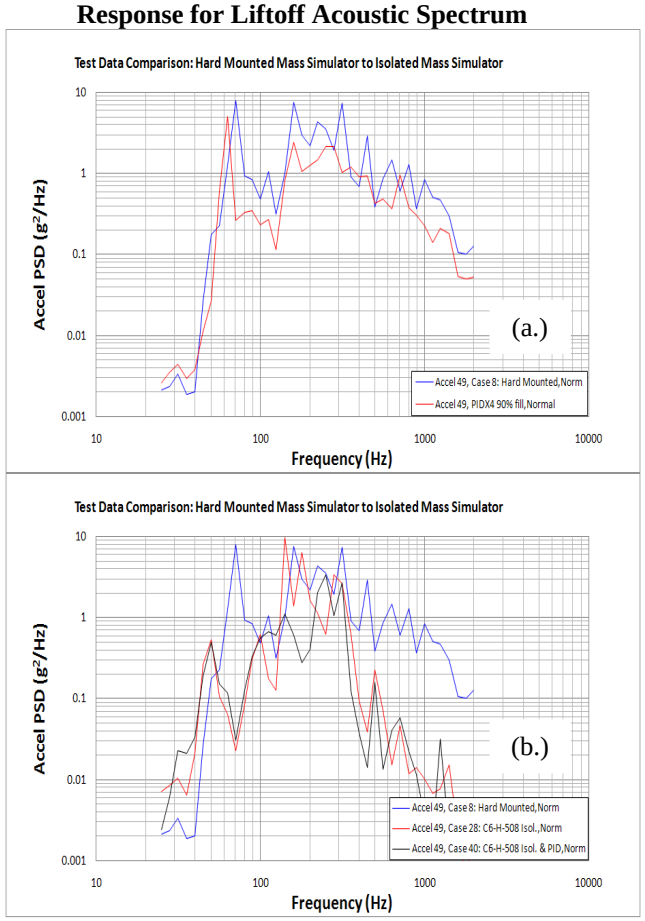


Figure 11. Vibration Levels Prior to and After the Addition of Small Canister-Type Particle Dampers. (a.) Hard-mounted Response for Liftoff Acoustic Spectrum (b.) Response for Ascent Acoustic Spectrum. Particle Dampers Combined with Wire Rope Isolation.

V. Conclusions

The results of this engineering development test will examine the effect of particle damping on the vibro-acoustic response of a launch vehicle exterior panel, exposed to acoustic and aerodynamic forces during launch and ascent. The data measured from this test series will be useful for characterizing the potential to attenuate severe launch vibroacoustic environments using particle damping devices. Additionally, the data will provide useful design information to size and locate particle damping devices to maximize attenuation.

Acknowledgments

The authors would like to acknowledge the fine support provided by the test organization at MSFC. The dedicated and capable staff of the MSFC ET40 department has provided outstanding support to complete an earlier set of ambitious acoustic response tests. They have also been actively developing opportunities to leverage the test article and test setup toward valuable follow on tests. The authors would also like to thank our Test integrator Mr. Anthony Kelley.

References

[1] Rodgers, C., Brewster, S., Smith, A., et al., "Test and Checkout Procedure - ARES 1 Upper Stage - AD01-01 Instrument Unit and Aft Skirt Skin Section - Development Acoustic Test," ARES 1-DEV-10-043, NASA-MSFC, September 2010.

[2] Smith, A., Harrison, P., LaVerde, B., Hunt, R., Teague, D., "AD01 Ground Acoustic Development Test, Initial Assessment Report, - Orthogrid Curved Panel Response To Acoustic Excitation - With/Without Mass Loading" NASA-MSFC-EV31, April, 2011.

[3] Smith, A., Harrison, P., LaVerde, B., Hunt, R., Teague, D., "Preliminary Evaluation of Mass Loaded Vehicle Panel Response Estimates and Approaches Based on Acoustic Ground Test Results," Proceedings of 2011 Aerospace Testing Seminar, March, 2011.

[4] Driskill, T., Rodgers, C., Brewster, S., et.al, "ARES 1 Upper Stage AD01 Instrument Unit and Aft Skirt Skin Section Development Acoustic Test, ARES 1-DEV-10-043A", Memorandum ET40 (ET40-11-006), NASA, MSFC, ET40, February 23, 2011. Kelley, A., Harrison, P., Smith, A., et al., "Test Plan - AD01-01 Instrument Unit (IU) and Aft Skirt (AS) Skin Section Acoustic Response Test," CxP Ares-USO-TE-25142, NASA-MSFC, March 2011

[5] Peck, J., Smith, A., Fulcher, C.., LaVerde B., Hunt, R.., "Development of Component Interface Loads on a Cylindrical Orthogrid Vehicle Section from Test-Correlated Models of a Curved Panel," Proceedings of 2011 Spacecraft and Launch Vehicle Dynamic Environments Workshop, June 2011.