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Acoustic Analysis and Design of the E-STA MSA Simulator

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Abstract

The Orion European Service Module Structural Test Article (E-STA) Acoustic Test was completed in May 2016 to verify that the European Service Module (ESM) can withstand qualification acoustic environments. The test article required an aft closeout to simulate the Multi-Pupose Crew Vehicle (MPCV) Stage Adapter (MSA) cavity, however, the flight MSA design was too cost-prohibitive to build. NASA Glenn Research Center (GRC) had 6 months to design an MSA Simulator that could recreate the qualification prediction MSA cavity sound pressure level to within a reasonable tolerance. This paper summarizes the design and analysis process to arrive at a design for the MSA Simulator, and then compares its performance to the final prediction models created prior to test.

1.0 Introduction

The Orion European Service Module Structural Test Article (E-STA) test campaign will qualify the design of the European Service Module (ESM) in preparation for its first flight in 2018. The ESM is the propulsion subsystem of the Orion Multi-Pupose Crew Vehicle (MPCV), shown in Figure 1 (Ref. 1).

One component of the E-STA qualification test campaign is the acoustic test, which was performed in May 2016 at the Reverberant Acoustic Test Facility (RATF) at the Space Power Facility (SPF), located within NASA's Plum Brook Station (PBS) in Sandusky, Ohio. In order to test as close as possible to the flight configuration, the full Service Module was built and tested to measure response of ESM in-situ. The test article included the ESM, Crew Module Adapter (CMA), fairings (SAJ), and spacecraft adapter (SA). Additionally, a plywood forward closeout representing the crew module (CM) heatshield was included, as well as a CM and Launch Abort System (LAS) mass simulator.

The test article configuration is shown mounted on a vibration table in Figure 2 (Ref. 1).

Although this configuration is representative for vibration testing, there are missing elements for the acoustic test. When testing in a reverberant acoustic chamber, the article should be lifted up off the floor and onto a scaffold-like test stand to prevent standing waves. This, however, leaves the aft end of the test article completely open to the chamber. In flight, the aft end is sealed off by the addition of the launch vehicle adapter, called the MPCV Stage Adapter (MSA), shown in Figure 3.

The MSA completes the boundary of the MSA acoustic cavity, shown by the red outline in Figure 4. The cavity is bounded by the MSA, the SA, and the aft bumper of the ESM. So, in order to test to the flight configuration, an aft closeout representation had to be constructed for the acoustic test to create an enclosed MSA cavity.

The most acoustically accurate option would be to construct the flight design MSA. This would provide the exact geometry of the acoustic cavity at the aft end of the vehicle, and also provide the same panel transmission loss by using the same material properties. However, due to testing budget constraints, this option was not viable. The flight MSA has a dome-shaped closeout that would be very expensive to manufacture. This paper outlines the design process to create an MSA Simulator which generates a sound pressure level (SPL) inside the MSA cavity matching the flight design MSA within a specified tolerance, under the limitations of a tight budget and schedule. The goal of the design is to be within a tolerance of ±3 dB from 100 to 500 Hz, which is the key range of peak acoustic cavity response.

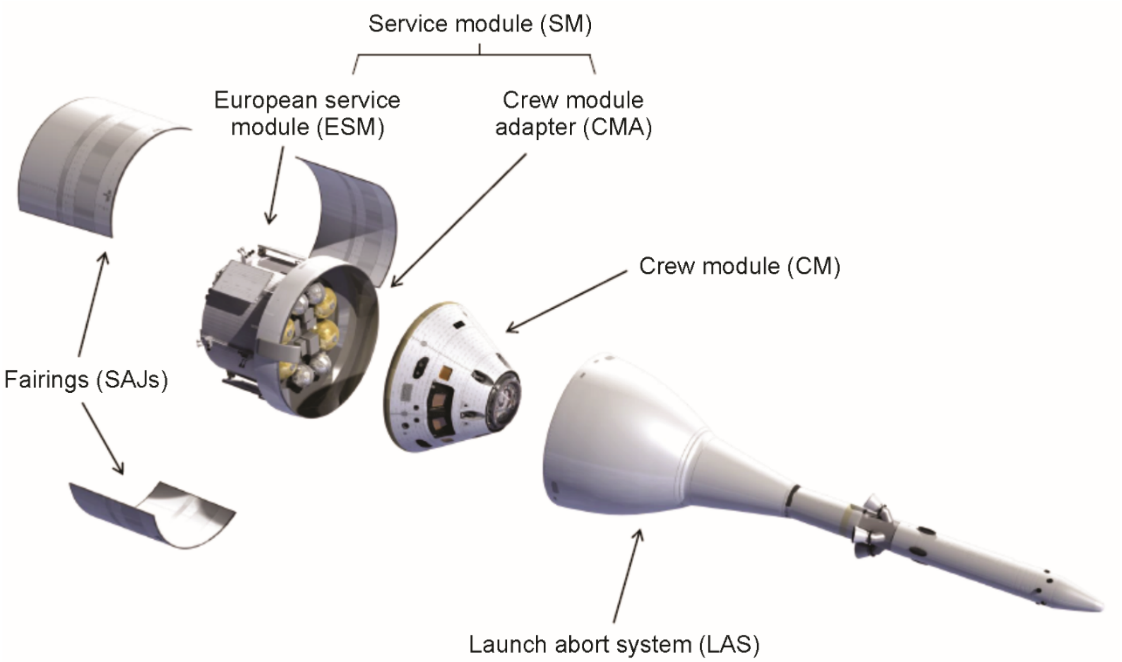


Figure 1.—Orion multipurpose crew vehicle.

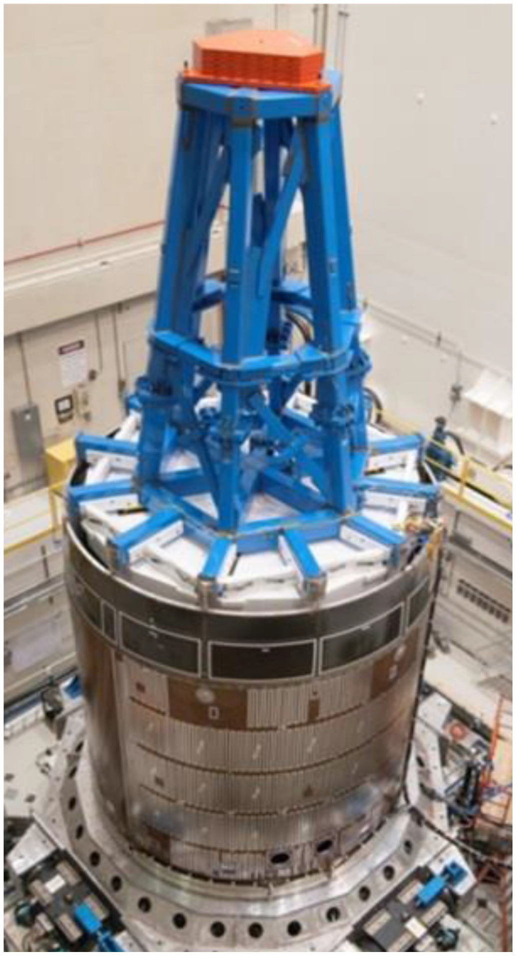


Figure 2.—E-STA on vibration table.

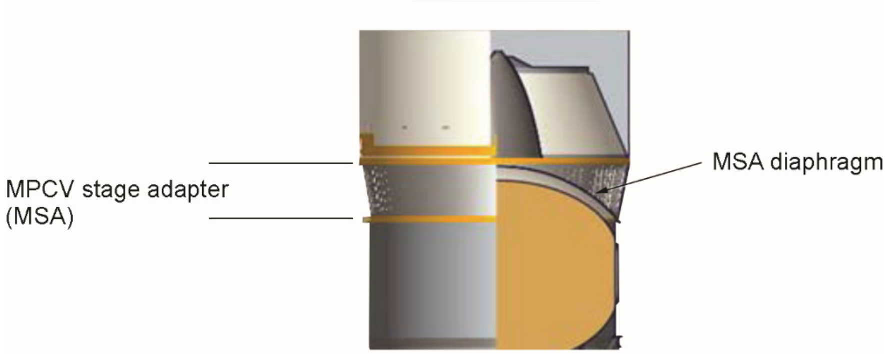


Figure 3.—MPCV stage adapter.

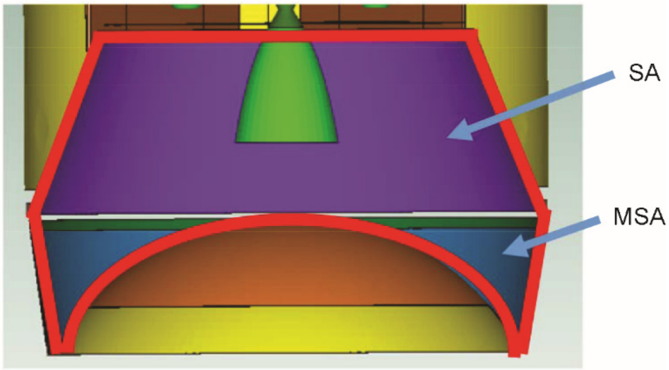


Figure 4.—Flight configuration MSA cavity.

2.0 Acoustic Design Process

The first step in designing the MSA Simulator was the selection of an acoustic modeling method. The MSA Simulator design and analysis process was limited to 6 months in order for manufacturing to be complete in time for the test. Thus, Statistical Energy Analysis (SEA) was an ideal choice. SEA is a good starting point for design problems because geometry creation and property changes are quite simple, and solution times are very quick, allowing trade studies to be completed rapidly. VA One software was used to create the model.

The flight Orion Exploration Mission 1 Version 4 Acoustic (EM1v4a) SEA model was used as the starting point. Although the EM1v4a is not the same configuration as E-STA, it gives a good basis to begin trade studies without investing too much time modeling E-STA explicitly.

SEA is best utilized to predict acoustic enviroments and transmission loss at higher frequencies. The valid analysis frequency range is determined by the criteria of 3 modes in band (MIB). Figure 5 shows that the number of modes in band of the MSA cavity drops below 3 below 80 Hz. Therefore, for the MSA cavity environment, SEA is considered valid at about 80 Hz and above.

2.1 Geometric Options

To design the MSA Simulator, the first step was the downselect of the general geometric shape. As previously mentioned, the ideal geometry would be the flight configuration. However, the dome-shaped closeout was too cost prohibitive to build for this test campaign. Two alternative design choices were evaluated: an MSA with the appropriate cone angle with a flat aft closeout, and a simple flat closeout panel bolted to the aft end of the SA.

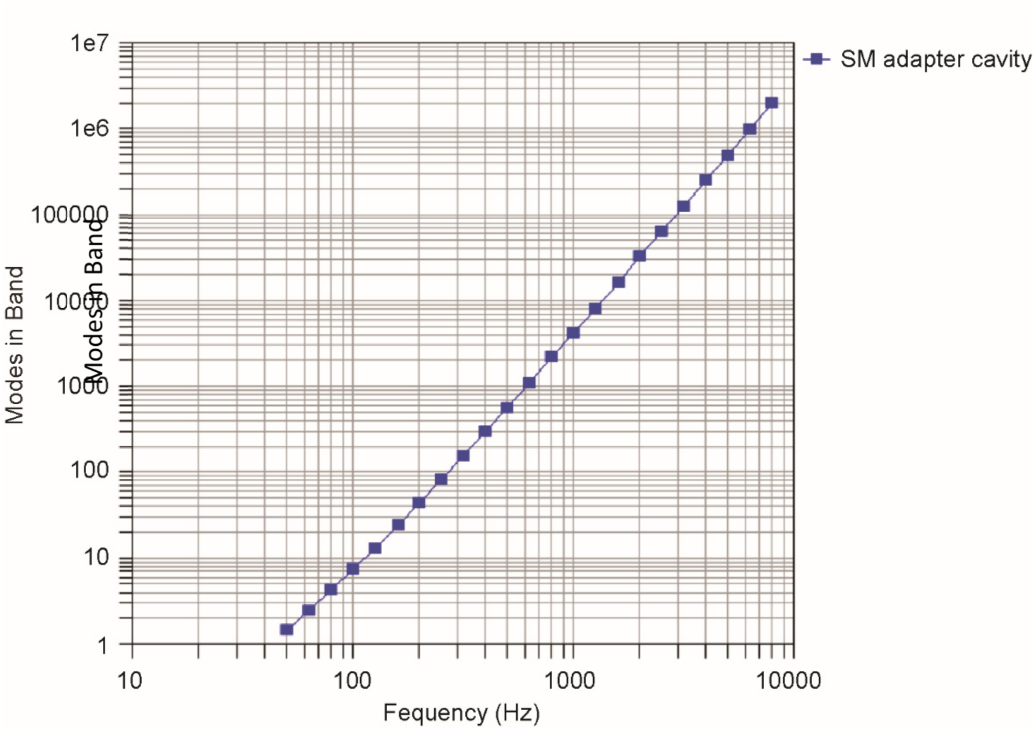
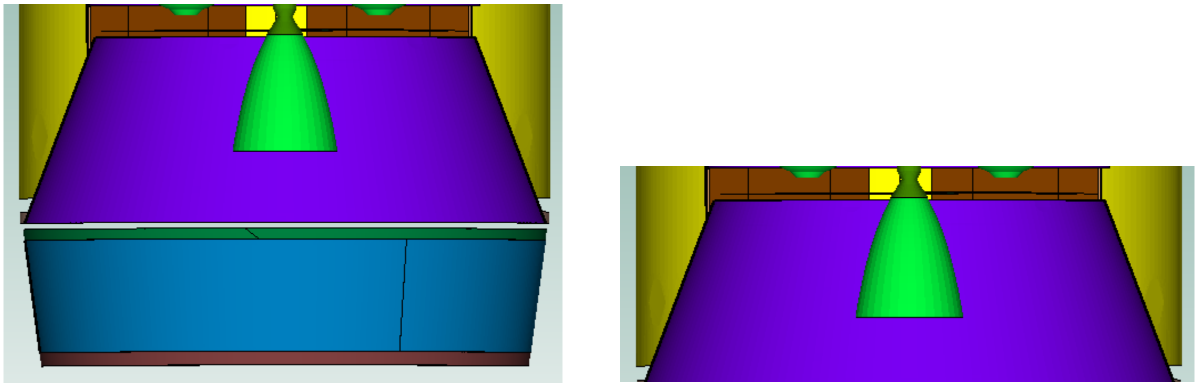


Figure 5.—Flight MSA cavity modes in band.



(a) (b)

Figure 6.—Options 1 and 2. (a) MSA simulator. (b) SA flat closeout.

These options were evaluated for high-frequency acoustics by manipulating the geometry of the EM1v4a SEA model. For the first option, the existing MSA was maintained, but the dome closeout was replaced with flat plates. For the second option, the MSA was removed entirely, and a flat plate was created at the aft end of the SA. The options are shown in Figures 6(a) and (b) (Ref. 2).

Both closeouts were created with the same material properties as the original dome closeout (a composite orthotropic layup). Both models' resultant cavity environment was compared against the flight configuration model, shown in Figure 7. Both cavity geometries achieved the same general shape as the flight dome, however, the SA Flat Closeout design cavity response is lower than the flight configuration in the range of 630 to 2000 Hz. The MSA Simulator achieved a better match throughout more of the range. The difference in performance drove the design to a full MSA Simulator with a flat aft closeout. It should be noted that neither model matches particularly well below 200 Hz or above 5000 Hz. This could be due to the fact that the cavity shape and volume have been changed.

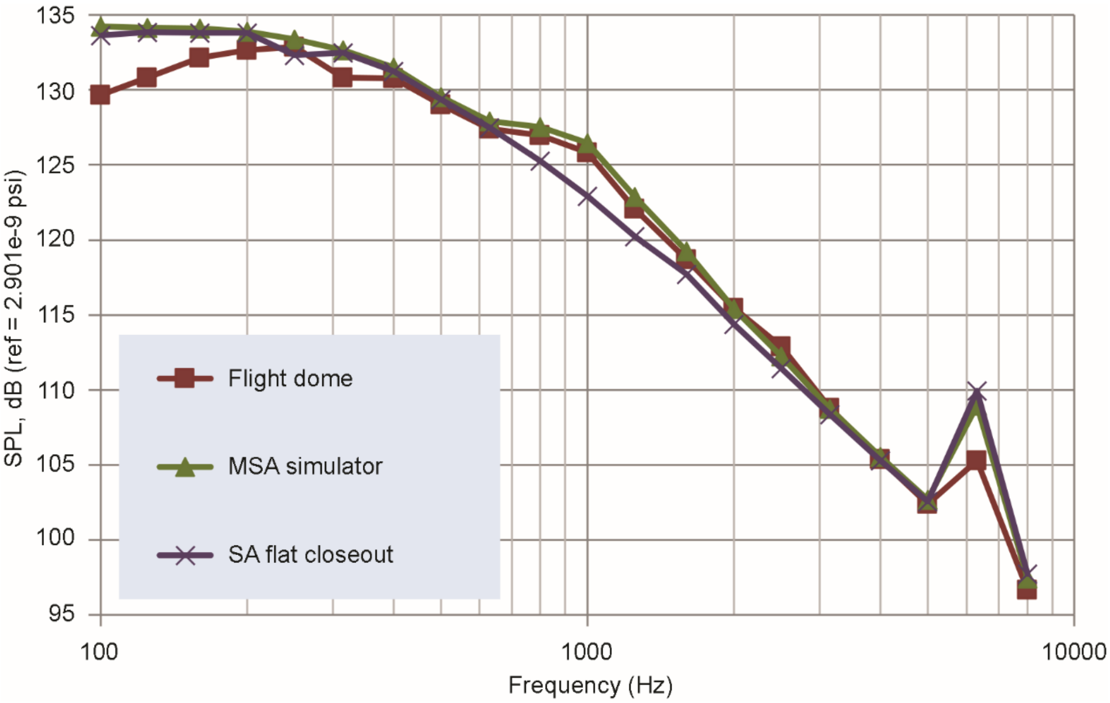


Figure 7.—MSA cavity sound pressure level—comparison of geometry, mass, and stiffness effects.

After the downselect of the geometry, the designer provided a configuration of closeout panels that would allow access throught the aft end as required by the test plan. It is shown in Figure 8 (Ref. 2).

Figure 9 shows the SEA model updated to reflect the MSA Simulator design.

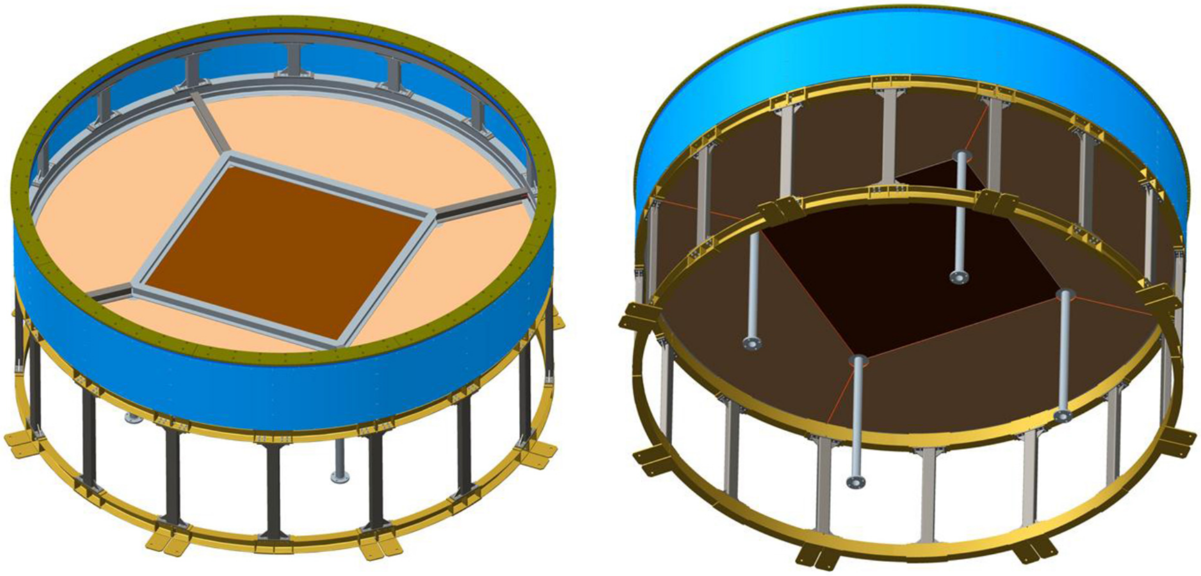
2.2 Material Properties Trade Studies

After the downselect of the MSA Simulator geometry, SEA was again used to choose the material properties. Considering cost limitations, the studies were constrained to aluminum. Nearly 100 panel variations were analyzed to find an ideal match to the dome closeout.

The majority of the panel material property parametric study focused on the flat closeout panels being used to represent the dome. Uniform aluminum panels of varying thickness were analyzed along with aluminum honeycomb panels. Dozens of combinations of facesheet thickness, core thickness, and core density were analyzed. In SEA, both types of panel performed fairly well.

Melamine foam noise control treatment was applied to the closeout panels in varying thicknesses, however, as expected, this dropped the cavity SPL below the target range. Noise control treatments were not used in the final design.

The outer fairing panels (Fig. 8, blue panels) were modified several times, however this did not significantly impact the acoustic environment. Thus, a uniform aluminum panel was selected to save on cost.



(a) (b)

Figure 8.—MSA simulator design 1. (a) Top view. (b) Bottom view.

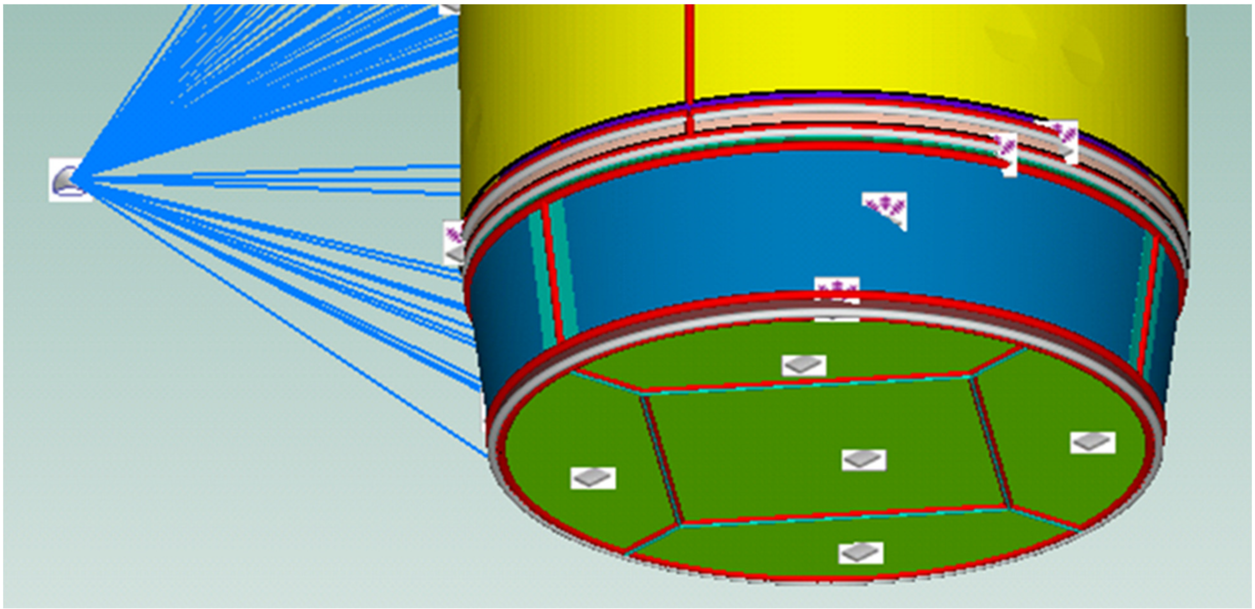


Figure 9.—MSA simulator design 1 SEA model.

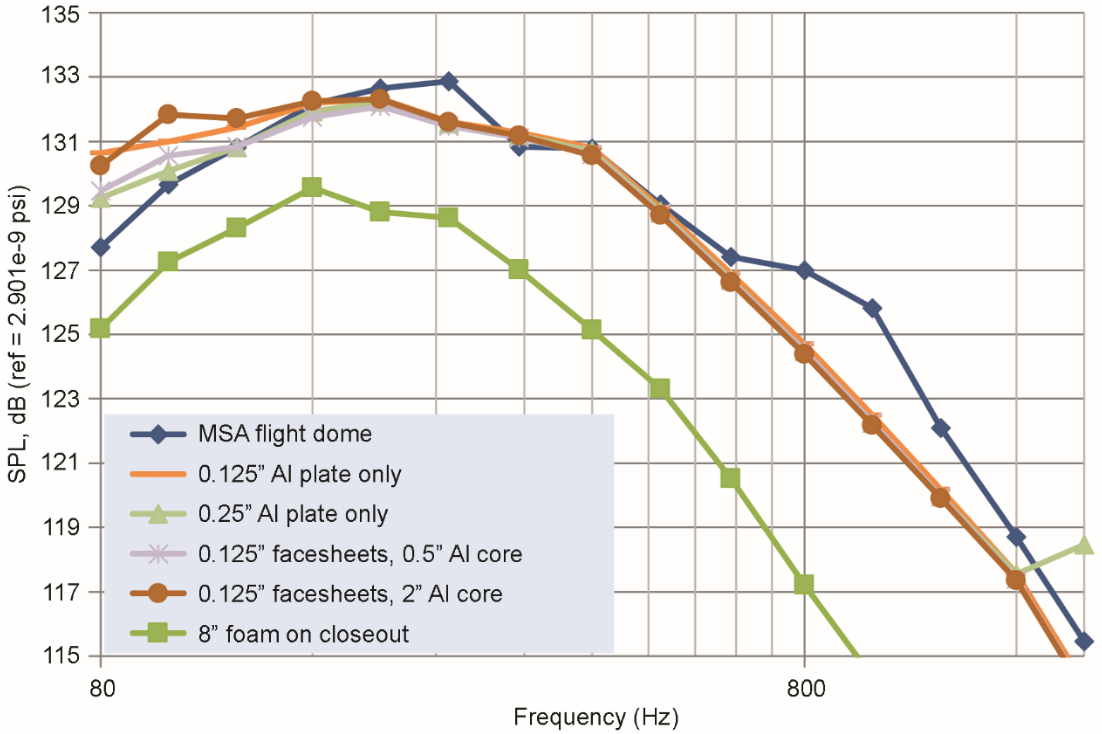


Figure 10.—MSA cavity sound pressure level—material property parametric studies.

A sample of five closeout material property parametric studies are shown in Figure 10. With the exception of the melamine foam, all other panel types are within acceptable limits.

2.3 FE Low-Frequency Analysis

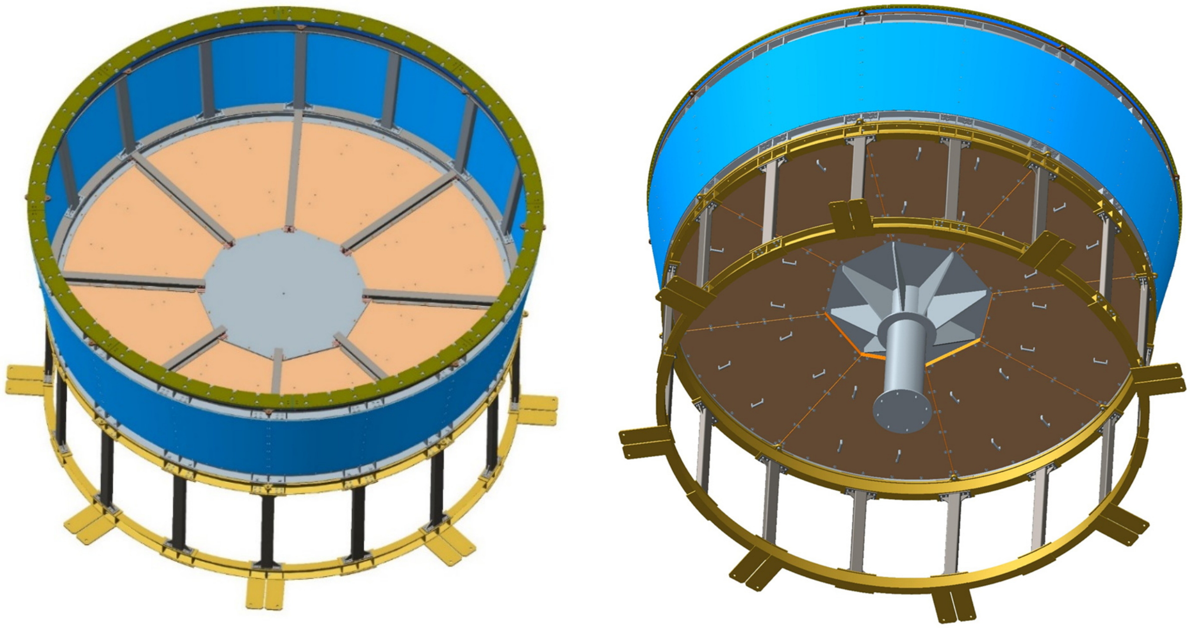
Low-frequency acoustic models were not created due to time constraints. To compensate for this, modal finite element analysis (FEA) of the MSA Simulator closeout panels was performed and compared to the FEA of the flight MSA design. A match on fundamental mode is ideal, but it is very difficult to match the first mode of a dome with a flat closeout. A dome has much higher intrinsic stiffness.

For this process, a fixed-edge boundary condition (BC) was applied to both configurations to represent the in-situ configuration. For the MSA Simulator, four additional constraints were added to represent the four support columns that would exist in the as-built configuration (see Fig. 8). For the existing geometry and constraints, the first mode was far too low to even be considered. Even 2 in. core honeycomb panels could not achieve close to the flight dome’s fundamental frequency.

A completely new closeout design was considered to raise the fundamental frequency, shown in Figure 11 (Ref. 3). The new design consists of 8 ‘petals’ with a large steel central post. The issue of fundamental frequency also drove the panel property selection to be as stiff as possible, so aluminum honeycomb closeout panels were used. Core thickness is key for stiffness, so the custom 2 in. aluminum honeycomb core was selected.

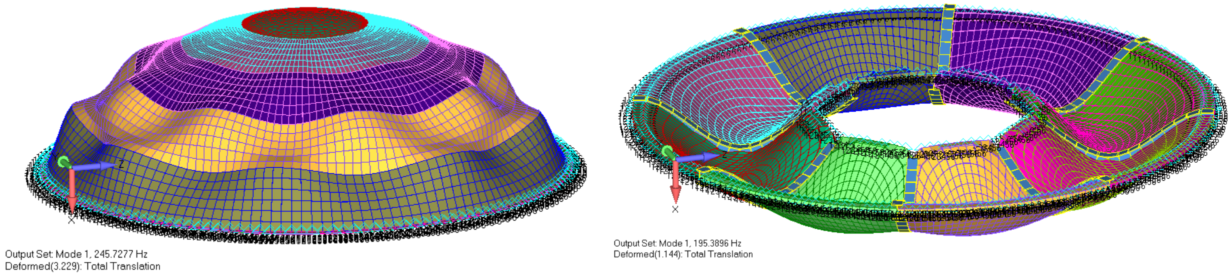
In the FE analysis of the new aft closeout, fixed constraints were placed at the outer and inner diameter of the honeycomb panels to represent the stiff interface of the test stand and central post. The first mode of the flight MSA dome (v6 FEM) is 246 Hz. In the new MSA Simulator design, the first mode came in at 195 Hz. Both mode shapes are shown in Figure 12 (Ref. 3). This was the highest fundamental mode of any of the design concepts. Since the first mode is close to that of the flight MSA dome, the low-frequency acoustic response should be relatively representative of flight.

The SEA model was also updated to reflect the change in panel configuration, as shown in Figure 13 (Ref. 3).



(a) (b)

Figure 11.—MSA simulator design 2. (a) Top view. (b) Bottom view.



(a) (b)

Figure 12.—Fundamental mode shapes. (a) Flight MSA dome 246 Hz. (b) Flight MSA Simulator closeout 195 Hz.

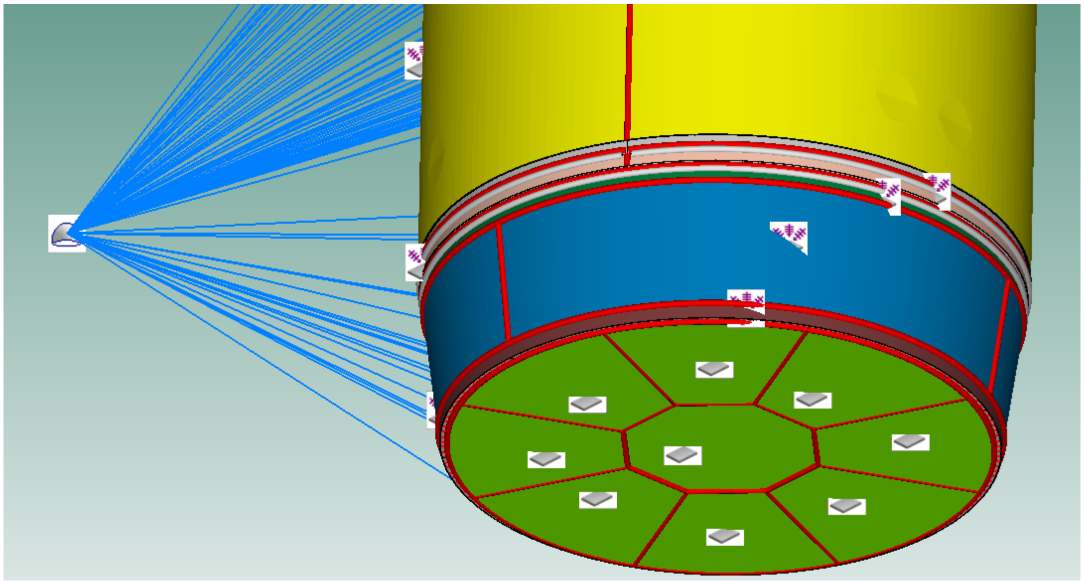


Figure 13.—MSA simulator design 2 SEA model.

2.4 Final Design Specifications

The final MSA Simulator design consists of an aft closeout of 8 “petal” honeycomb panels and 3/16 in. aluminum fairing panels. The closeout panels have 1/8 in. aluminum facesheets and 2 in. aluminum honeycomb core. The closeout is stiffened by I-beams between aft closeout petals. The MSA Simulator is supported by the Acoustic Test Stand around its circumference, and by a large steel center post, which helps tremendously in raising the fundamental frequency of the aft closeout.

The final MSA Simulator design selected best recreates the flight MSA cavity qualification environment SEA prediction and incorporates the fundamental mode, while remaining within a realistic budget. Figure 14 shows the final SEA comparison between models (Ref. 3). In the frequency range of interest (100 to 500 Hz), there are no exceedances of the ±3 dB tolerance, thus meeting the original design metric.

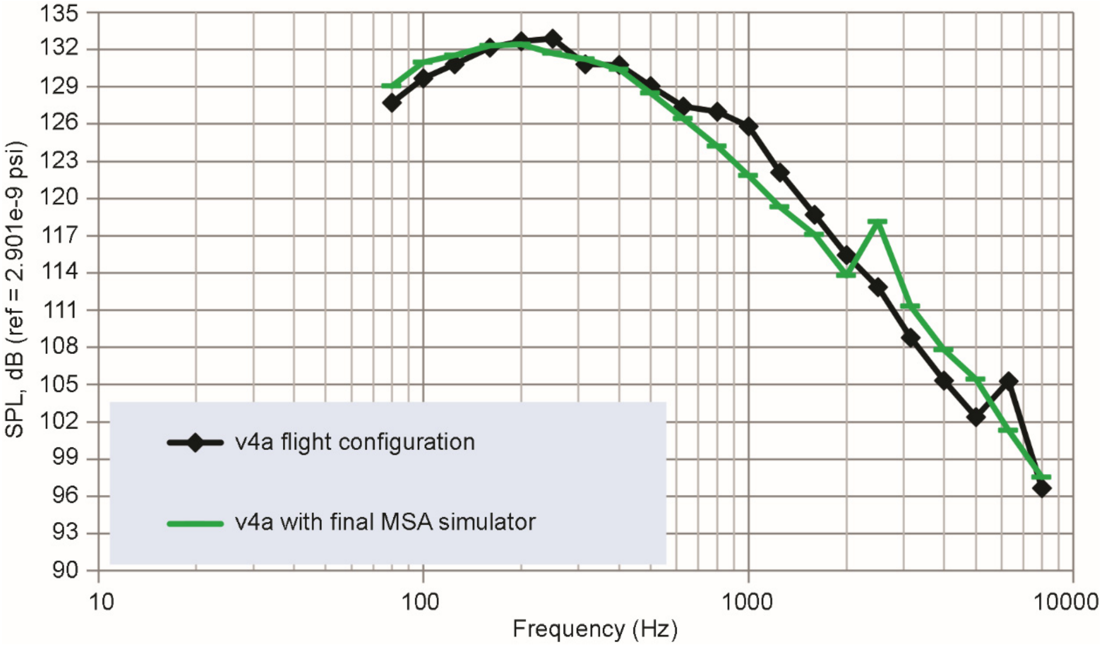


Figure 14.—MSA cavity sound pressure level—final comparison of the MSA simulator design versus flight configuration.

Figure 15 shows the E-STA mounted on top of the as-built MSA Simulator, which is mounted on the test stand (Ref. 1). The photo was taken inside the Plum Brook RATF.

Figure 15.—E-STA with MSA simulator and test stand.

3.0 E-STA Configuration Model Predictions

After initial manufacturing of the MSA Simulator and prior to test, dedicated E-STA configuration vibroacoustic models were constructed to provide accurate pretest predictions leading into the test for not only the MSA cavity, but all other cavities and also structural response. An SEA model was built to predict at 315 Hz and above, and a low-frequency boundary element model (BEM) was also developed to predict from 31.5 to 315 Hz. The E-STA vibroacoustic model development was led by ATA Engineering and supported by NASA GRC. The task took a concentrated 8 month effort to complete. This time period did not include the time creating and integrating the E-STA FEM, which was a necessary input for both models. Had the program waited for the E-STA configuration vibroacoustic models to be assembled and run to select an MSA Simulator design, the MSA Simulator would not have been built in time for the test. The E-STA models were used as the benchmark to evaluate the method outlined in this paper of using SEA on a modified flight configuration model (v4a) to efficiently design the MSA Simulator. The details of the creation of the E-STA models will not be discussed in this paper, but their final prediction for the MSA cavity is shown in Figure 16, as compared to the original predictions.

The E-STA models showed a much lower MSA cavity environment than the original predictions from 315 to 2500 Hz. The difference reaches 10 dB. However, the original models predicted the key peak acoustic cavity response very well, within ±3 dB from 100 to 250 Hz. This is the most important frequency response range of the prediction because it represents the highest sound pressure levels, which can be the most damaging to the components within the MSA cavity, such as the main engine and auxiliary thrusters. The comparison shows that it is best to create dedicated test models, however, the original method of quickly modifying the flight SEA model to design the MSA Simulator gave a relatively accurate cavity SPL estimation, especially in the peak acoustic cavity response frequency range (100 to 250 Hz).

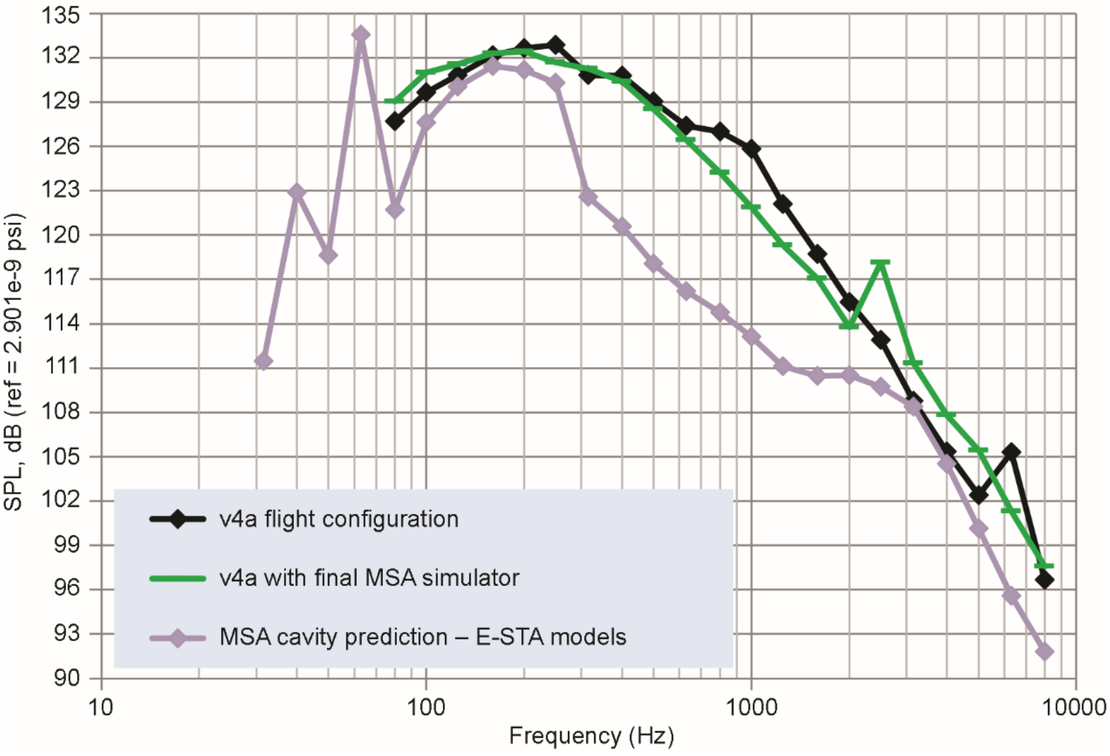


Figure 16.—MSA cavity sound pressure level—comparison of flight, design, and E-STA models.

4.0 Conclusions

The final MSA Simulator design satisfied the MSA acoustic cavity qualification environment objective of a ±3 dB tolerance to the flight model's prediction from 100 to 500 Hz. This is the key range that includes the peak acoustic cavity response. The greater difference seen in the higher-frequency region is not concerning because the levels are not as high as in the 100 to 500 Hz peak acoustic cavity response. The MSA Simulator closeout panels were made flat in order to reduce cost. The closeout panels are constructed from 2 in. aluminum honeycomb core to provide a high fundamental frequency to mimic the flight dome closeout, and 1/8 in. aluminum facesheets for a flight like amount of transmission loss through the panels. The predictions were updated one year later after an extensive modeling effort of the true E-STA configuration using both SEA and BEA. The new predictions showed marked differences at various frequency bands, however, the peak acoustic cavity response frequency range from 100 to 250 Hz still matched the original prediction very well. The comparison verified the value of the initial method of acoustic modeling and design of the MSA Simulator under time and budget constraints.

References

1. "Design, Verification, and Ground Qualification Approach for the Structure of the European Service Module of the Orion Multi-Purpose Crew Vehicle," by V. Denis, G. Di Vita, J. Larko, A. Thirkettle, J. Touzard. Presentation to the 67th International Astronautical Congress 2016, September 26–30, 2016.
2. "Acoustic/Structural Interface Options for E-STA & EM Test Fixtures," Chris Lupo & Quyen Jones. MPCV Control Board Presentation on September 11, 2014.
3. "eSTA MSA Simulator Acoustic Design & Analysis," by Samantha Bittinger. Orion internal project presentation on March 5, 2015.