Overview of the Acoustic Testing of the European Service Module Structural Test Article (E-STA)

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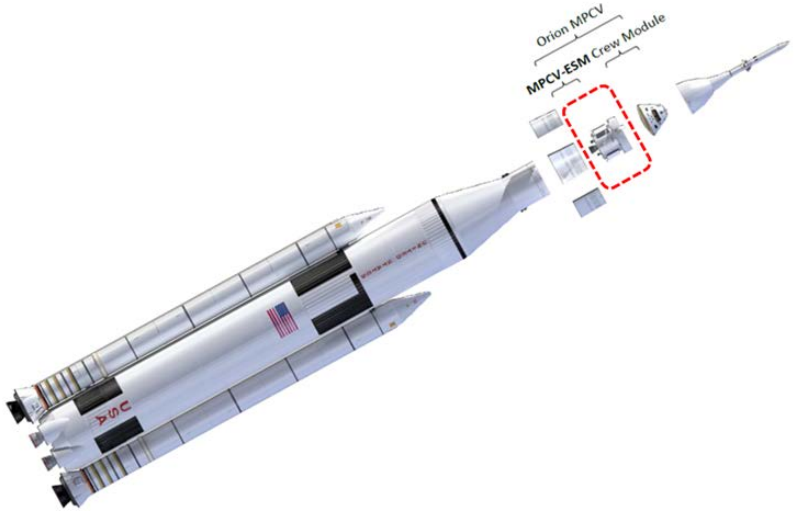
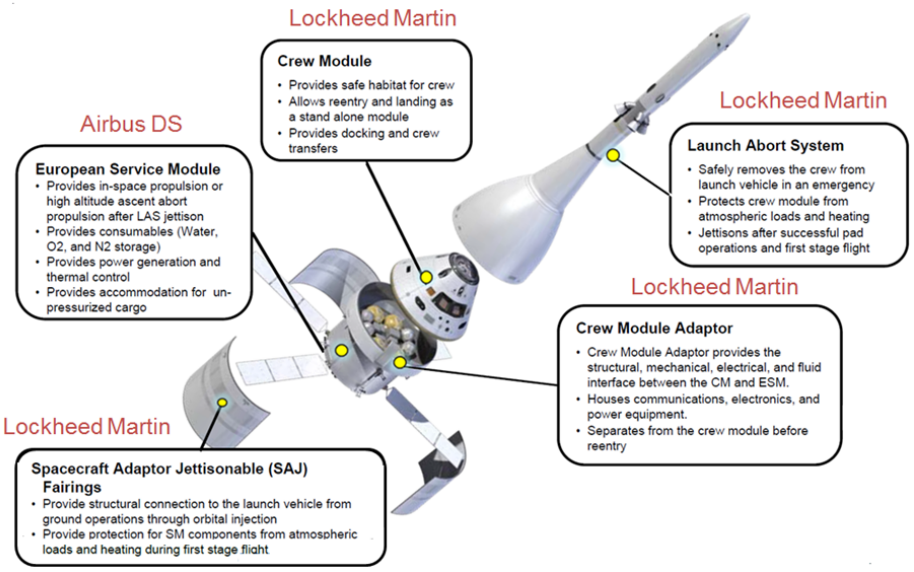
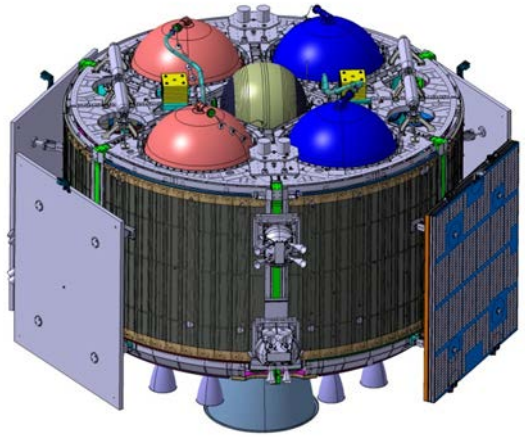
Orion MPCV

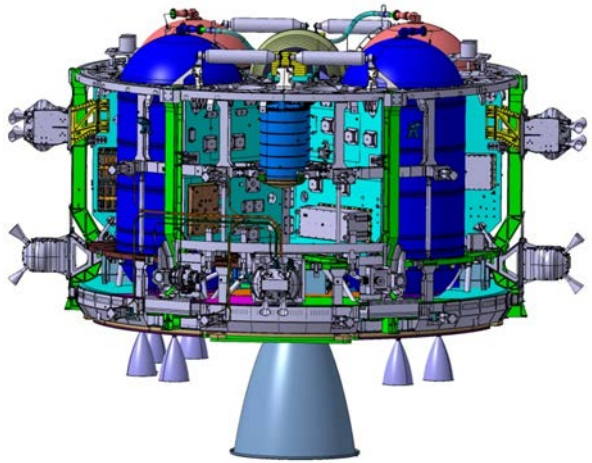




- NASA's Orion Multi-Purpose Crew Vehicle (MPCV) will launch on the Space Launch System (SLS).
  - The first launch of the un-crewed Exploration Mission (EM-1) is in 2018.
- The **European Service Module (ESM)** is being developed by the European Space Agency (ESA), with Airbus as their prime contractor.
  - The ESM will provide propulsion, power, and consumables for the MPCV.
- Lockheed Martin is developing the rest of the MPCV for NASA, including the Crew Module, Launch Abort System, and the Spacecraft Adaptor Jettisonable (SAJ) Fairings.

European Service Module Structural Test Article (E-STA)





- The ESM Structural Test Article or **E-STA** is the mechanical mock-up of the ESM used for mechanical testing.
- In 2016, the E-STA experienced several dynamic environmental tests at the NASA Glenn Research Center's Plum Brook testing facility, including:
  - Solar Array Wing deployment test – pre-environmental (baseline) test check-out,
  - **Acoustic tests in reverberant acoustic chamber**,
  - Random and sine vibration tests on a large shaker system,
  - Separation shock tests – both SAJ fairing separation shock, and Spacecraft Adaptor separation shock,
  - Solar Array Wing deployment test – post-environment tests check-out,
  - Final inspections.

NASA's Reverberant Acoustic Test Facility (RATF)

- RATF is located in Sandusky, OH, USA.
- Facility is capable of achieving empty chamber acoustic level of 163 dB OASPL.
- Chamber volume is > 100,000 ft^3.
- Uses 36 horns and 36 acoustic modulators.
- Facility Data Acquisition System has 1,024 channels.

E-STA Acoustic Test Objectives

- **Verify the mechanical resistance of the ESM under acoustic qualification loads**. The goal here was to gain confidence by a direct demonstration of the ESM ability to withstand the predicted flight acoustic qualification environment and by checking the absence of unexpected behavior at high levels.

- **Validate the dynamic models of the ESM** modal behavior of the equipped ESM in the acoustic frequency range by comparing the simulated ESM acoustic response to test results. These models will be used during the verification cycle to confirm the structural margins, and to confirm the mechanical environment specified to the ESM components, ensuring the qualification of the ESM as flight-ready.

- **Measure responses at the ESM's equipment** mounting points under qualification loads **and validate the mechanical environment specifications of the various ESM equipment items** in relevant acoustic frequency range. Measure induced stresses on some specific structural equipment items (radiators and SAW), and confirm the acoustic stresses requirements specified to these equipment items.

- **Directly qualify the Solar Array Wing (SAW) subsystem, by exposing the flight-like SAW Qualification Model (SAW QM) to its acoustic environment.**

- Prepare for the pre-flight acoustic test planned for the Orion EM-1 spacecraft by performing a high-level acoustic test in an **empty propellant tank configuration (dry tank)**, which is the configuration planned for the future EM-1 ground tests.

Acoustic Test Matrix

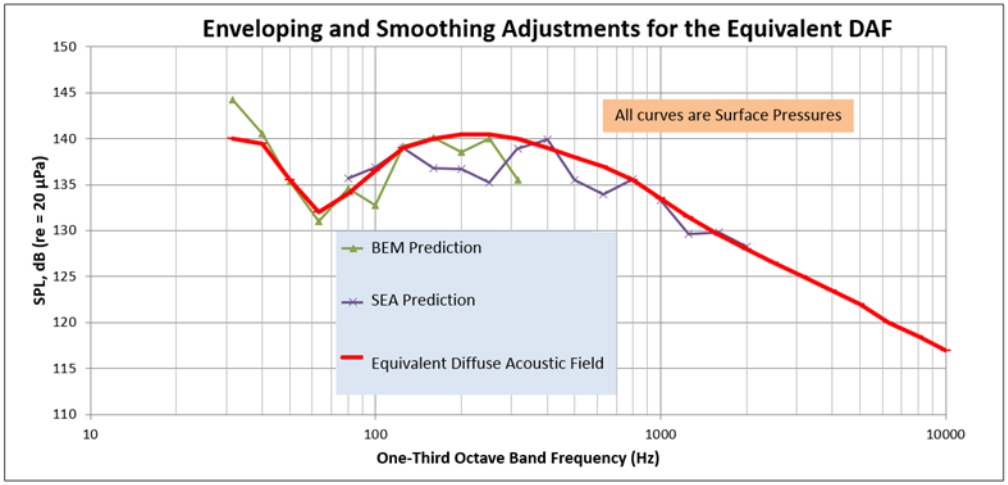
- **10 Acoustic tests were performed: 5 with dry (empty) propellant tanks, and 5 with wet (filled) propellant tanks; 2 full level Qualification tests.**

Name	Number	Level [dB]	Duration [seconds]
First Low Level Dry	AC0240	-12dB	30
Second Low Level Dry	AC0241	-12dB	30
Pre -6dB Level Dry	AC0242	-6dB	45
Full Level Dry	AC0243	0dB	60
Post -6dB Level Dry	AC0244	-6dB	45
Low Level Wet	AC0245	-12dB	45
Pre -6dB Level Wet	AC0246	-6dB	45
-3dB Level Wet	AC0247	-3dB	45
Full Level Wet	AC0248	-0dB	180
Post -6dB Level Wet	AC0249	-6dB	45

- **A total of 746 instrumentation channels installed on E-STA.**
- **Test excitation levels chosen to target a flight-based response (targeted SM Outer Cavity SPL's from analysis predictions)**

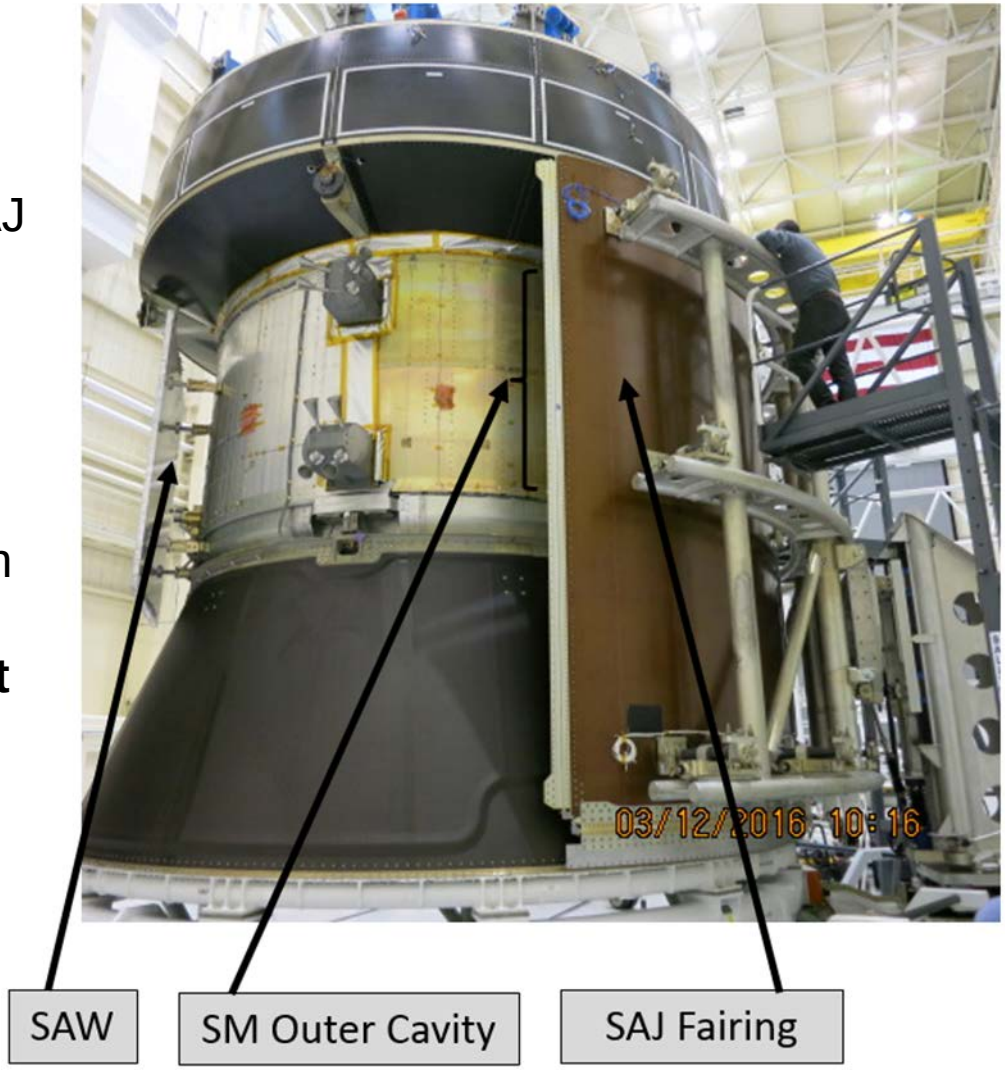
Derivation of External Test Excitation Levels

- SLS subscale model acoustic testing has indicated that the external acoustic environment that is produced is a mixture of diffuse and propagating waves; this produces a test environment formulation challenge.
- A flight-based response approach was developed by NASA to determine the E-STA acoustic test excitation levels.
  - Chose test excitation levels to replicate a targeted flight response* of a structure or cavity based on analytical flight model predictions using both diffuse and propagating waves excitation.
  - Find equivalent diffuse acoustic field (DAF) that produces the same targeted response on the test model using just diffuse excitation.
  - * Response of the SM Outer Cavity was chosen for the E-STA tests.



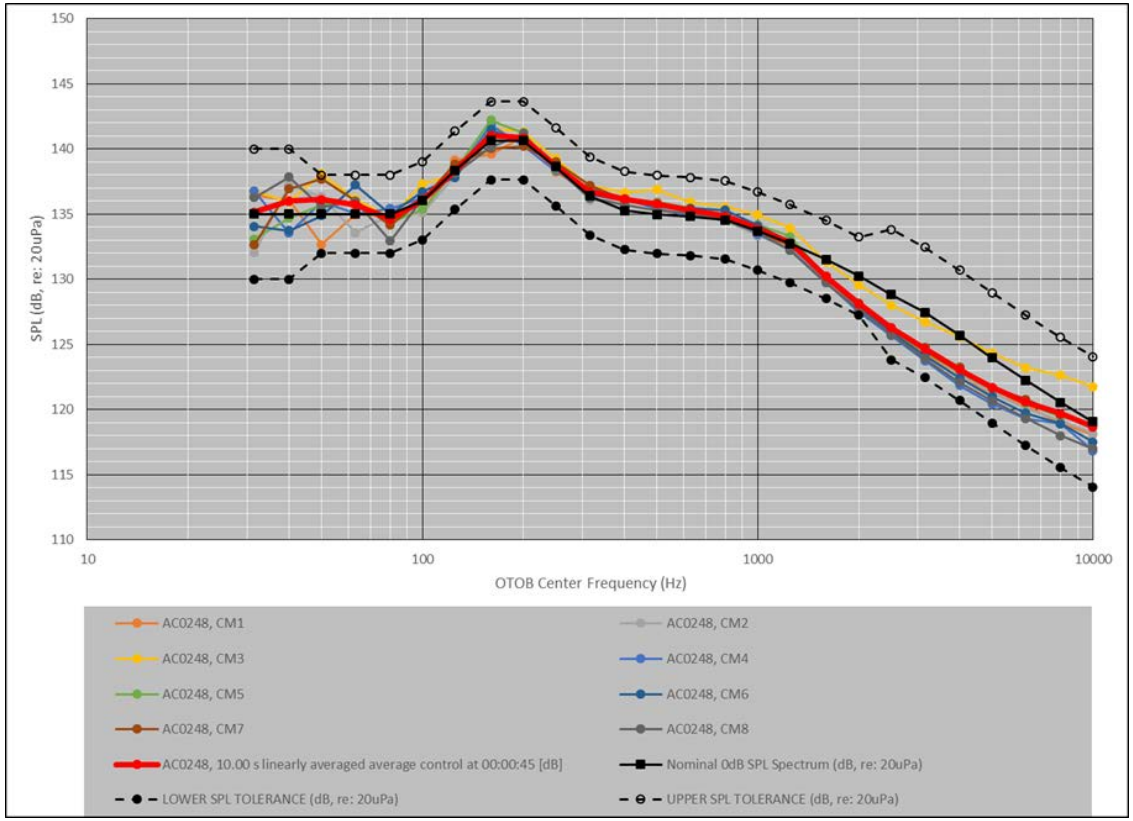
SM Outer Cavity

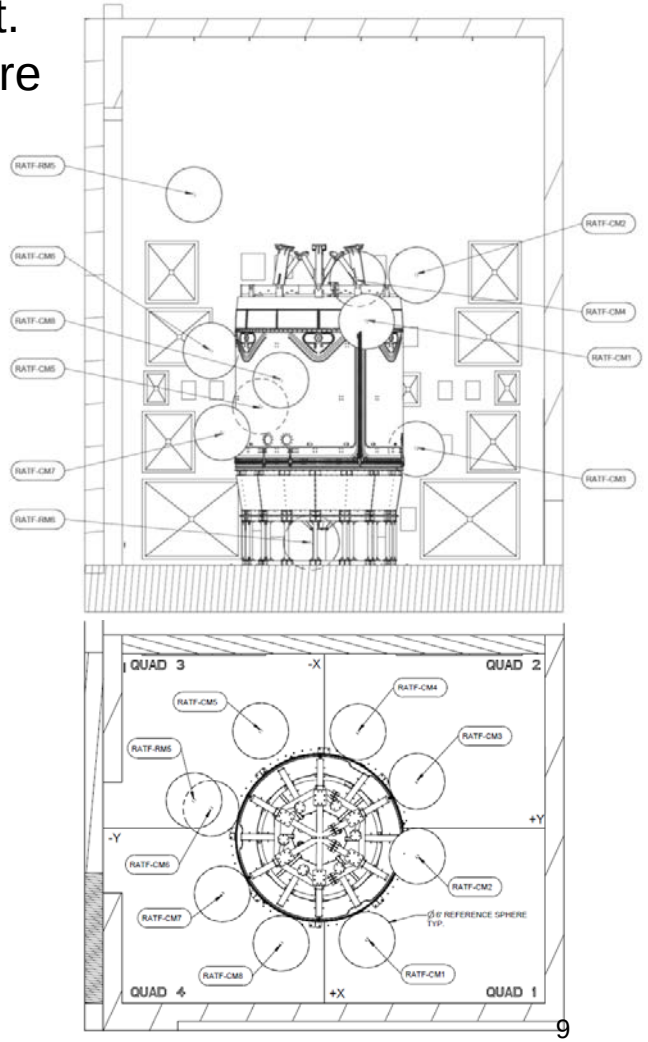
- The driving acoustic input for both the ESM structural response and for the SAW qualification was the acoustic environment in the internal cavity between ESM lateral sides and the SAJ fairings;
  - This cavity is denoted as the **SM Outer Cavity**.
- Since the SAJ fairings used for the E-STA tests were from an earlier heritage fairing design, one of the main challenges was to **tune the external acoustic levels produced by the test chamber to reach targeted levels in this SM Outer Cavity,**
  - Adjusting for the non-linearities of the SAJ fairing behavior,
  - While making sure not to damage the SAW QM.



External Test Levels

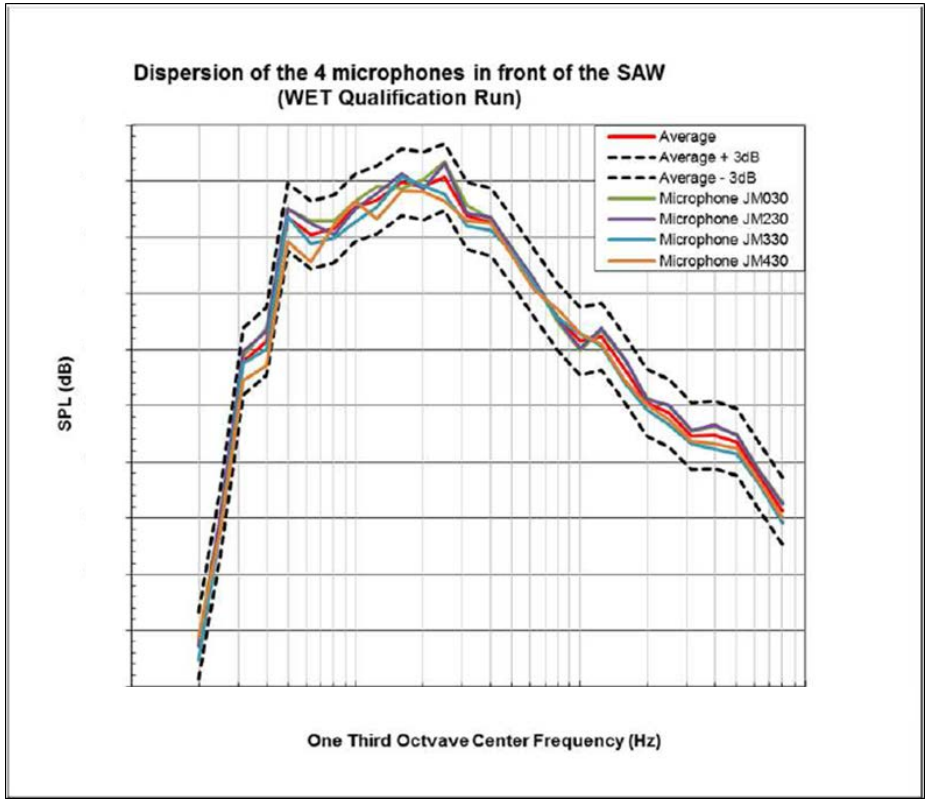
- RATF-produced external test SPLs for full level (0 dB) qualification tests were: 147.9 dB OASPL (dry, AC0243), and 149.4 dB OASPL (wet, AC0248).
  - External SPLs slightly modified before each test.
- The measured SPL at the 8 control microphones were very consistent, especially frequencies > 80 Hz.





SPL Consistency in SM Outer Cavity

- **The measured SPL uniformity of the SM Outer Cavity microphones were extremely consistent.**
  - SPL measurements were made at the 4 microphone locations in front of the flight-like SAW Qualification Model (SAW QM), and at the 12 microphone locations in front of the other three dummy SAWs.
  - This consistency greatly aided the interpretation of qualifying the SAW QM and the analysis of the ESM's components' responses.

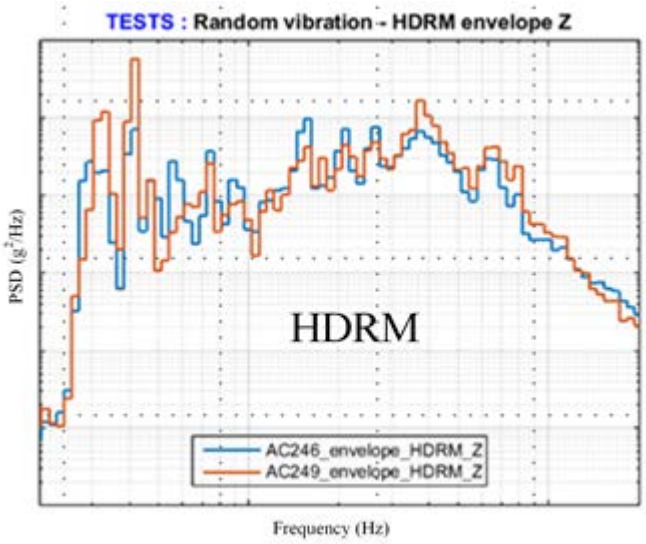


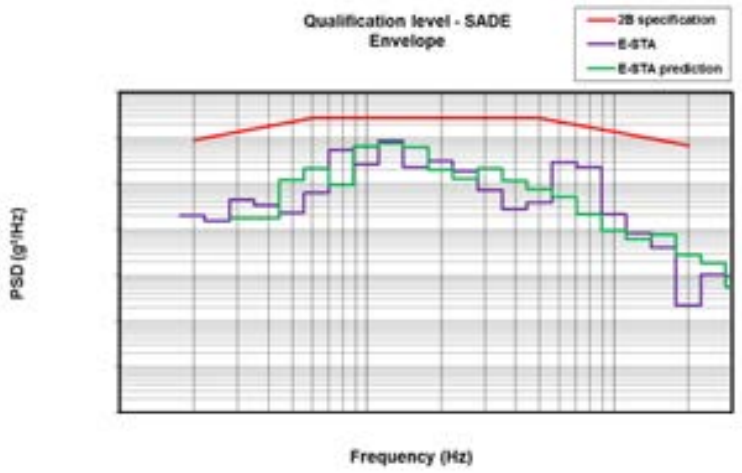
SAW Qualification

- **The SAW QM was successfully qualified by its exposure to this test program's SPLs and durations.**
  - Key was to tune the external acoustic SPL to get the targeted SM Outer Cavity SPLs, especially in the SAW's key frequency one-third octave bands.
  - The desired acoustic levels and durations were met in test.
  - Post-processing of strain gauge measurements showed high margins relative to pre-test predictions and specifications.
    - Calculated fatigue damage for the SAW assessed to be 4.4% from acoustic testing (< 25% allowable goal)

Post-Test Assessment

- **All test objectives were met, and the post-test health of the E-STA was confirmed.**
  - Compared pre and post -6 dB test data to verify no significant discrepancies in the mechanical behaviour (e.g. HDRM plot).
  - Compared acceleration Power Spectral Density on key flight-like components with their random specification (e.g. SADE plot).
  - Compared Grms loads measured on the qualification runs with allowables using criteria on Quasi Static Loads to assess the health of the dummy equipment.





Conclusions, and Thank you

- Acoustic testing of the E-STA successfully completed in April-May 2016, through the performance of 10 reverberant acoustic tests.
- A flight-response based excitation approach was utilized to achieve the targeted levels in the SM Outer Cavity.
- All acoustic test objectives were met:
  - Verified mechanical resistance of the ESM to acoustic environment,
  - Verified the ESM modeling,
  - Validated the ESM component's random vibration test levels,
  - Qualified the Solar Array Wing,
  - Tested the empty (dry) propellant tank configuration.
- Test campaign was a rewarding collaboration between ESA, Airbus, Lockheed Martin and NASA.