Comparison of Laboratory Testing Techniques For Replicating In-Flight Dynamic Loads

MSc Research Study by Kobi J. Cohen

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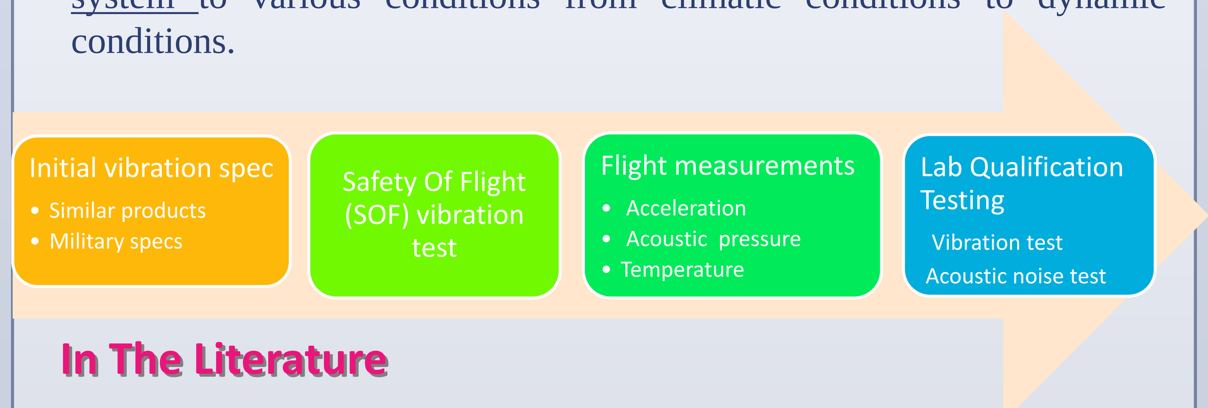
INTRODUCTION

Environmental Engineering

- Design laboratory experiments to demonstrate the durability of the system to various conditions from climatic conditions to dynamic conditions.



In The Literature

- **Mechanical** loads, of low frequency, induced by the aircraft
- **Aeroacoustic** loads, of high frequency, induced by pressure fluctuations and turbulent boundary layer.
- Deterministic numerical models of **FEM** and **BEM** are limited to the low frequency range (<300Hz)
- Stochastic models of energy analysis (**SEA**) for the high frequency range (>300Hz) , neglecting the FSI, and show discrepancies compared to measurements.
- All results refer to simplified models and **not** to a complex configuration including internal components

TEST CASE: INSTRUMENTED FLIGHT TEST

Test Setup

- **A weapon system** consists of a warhead and two add-on sections: aerodynamic and control surfaces (rear), guidance and control unit (front)
- **Flight test** was conducted with the weapon system installed on F-16 fighter aircraft.
- Flight data (time history) was acquired and synced with the sensors' acquisition system
- Inner **accelerometers** distributed along main assemblies of the system, measuring in three main directions (X-Y-Z)
- External flush-mounted **microphones** and internal microphones installed on each section.

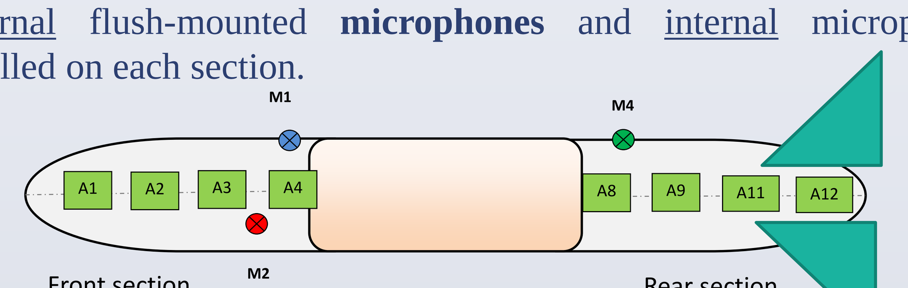


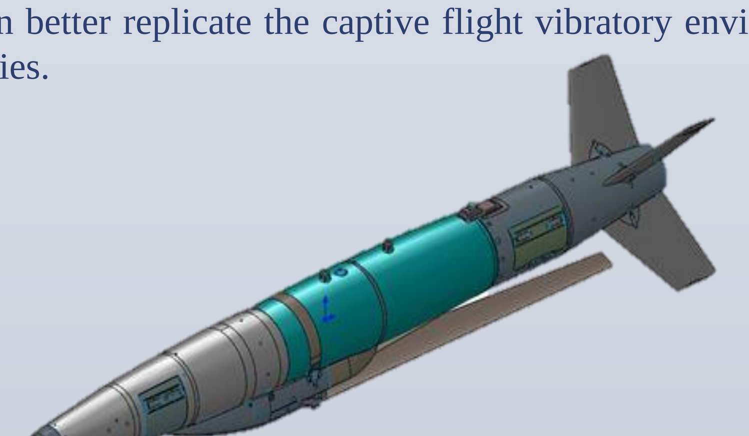
Fig. 1 – Acoustic and acceleration sensors locations

Results

- Spectral content of acceleration and acoustic pressure is proportional to the dynamic pressure.
- Acceleration PSDs for inner assemblies are higher than those measured on the front and rear ends of the warhead.

Objective

Determine which of the testing methods, mechanical or acoustic excitation, can better replicate the captive flight vibratory environment of inner assemblies.



MECHANICAL VIBRATION TEST

Experimental Setup

- The methodology is to subject a test article to mechanical vibration driven by electrodynamic shakers to attain its vibratory response to in-flight dynamic loads.
- Two shakers are driving the test article at two rigid points through a fixture interface consists of a plate and a flange.
- The control sensors were set on the front and rear parts of the warhead.

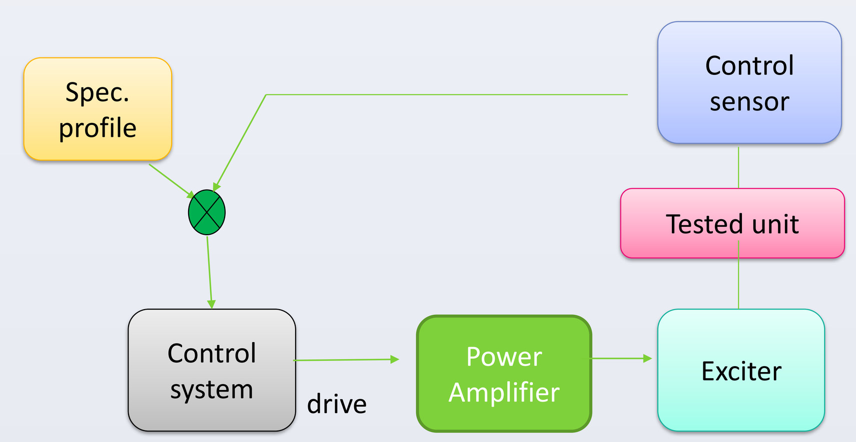


Fig. 2 – Laboratory test, control loop

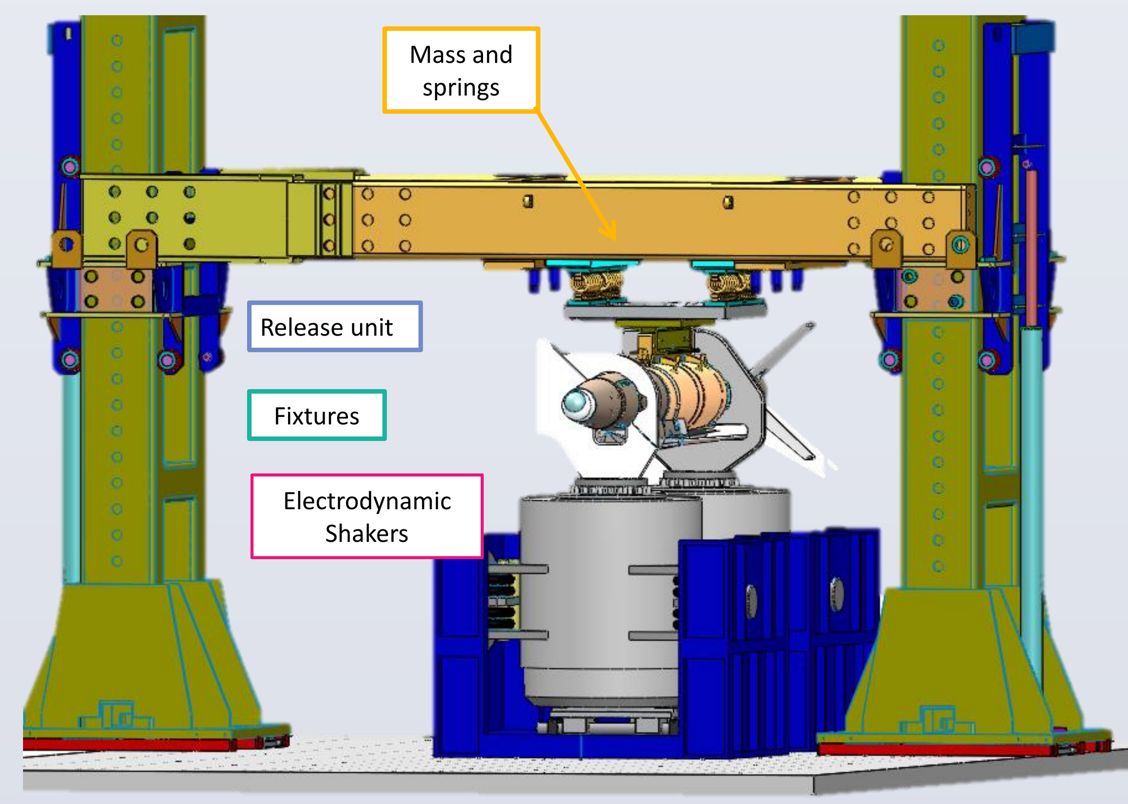


Fig. 3 – Laboratory vibration test setup for Z direction

Results

- A coupling between the two shakers is pronounced by several dominant under-test dips for the front and rear control sensors
- For both sections the assemblies response in the high frequency range (from ~500Hz) is in under-test, namely, flight dynamic responses are not replicated for the inner assemblies.

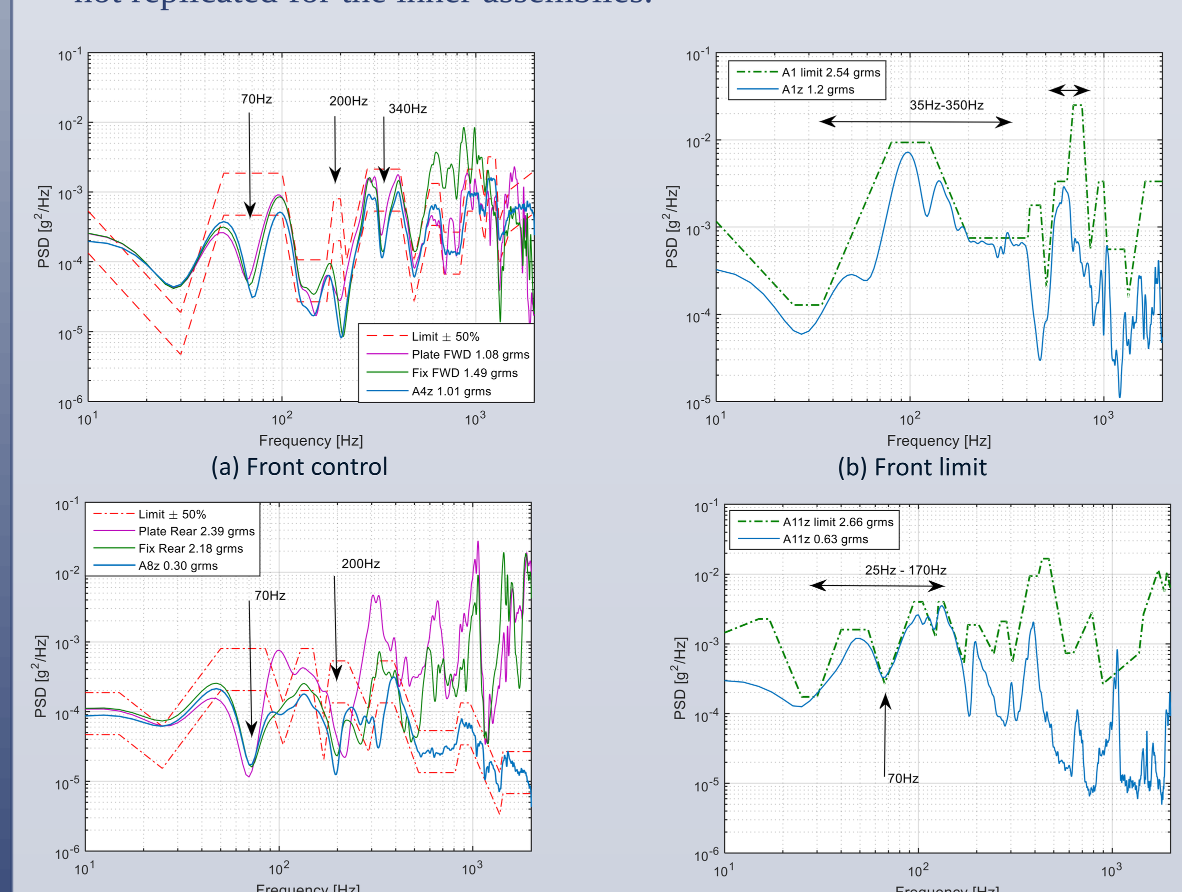


Fig. 4 – Vibration test results of (a,b) front section and (c,d) rear section

ACOUSTIC NOISE TESTS

Experimental Setup

- The methodology is to subject a test article to soundwaves created by loudspeakers in a reverberant chamber to attain its vibratory response to in-flight dynamic loads.
- Two test configurations:

(a) An enclosed configuration

(b) An exposed configuration

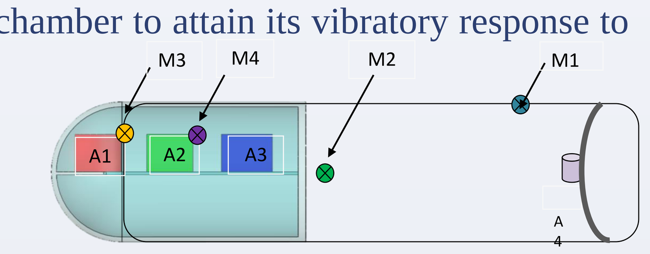


Fig. 5 – Sensors locations

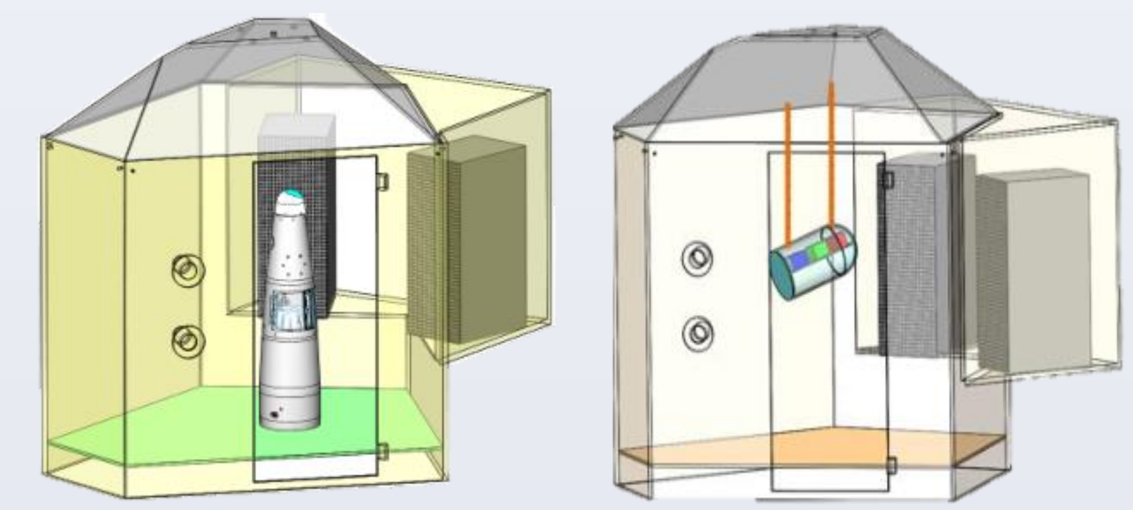


Fig. 6 – Acoustic test setup for (a) enclosed and (b) exposed configurations

- The input specification for the control system was a broadband PSD as measured in captive flight at an altitude of 20kft and 0.94M.
- Enclosed configuration: as measured by external microphone M1
- Exposed configuration: as measured by internal microphone M2

Results

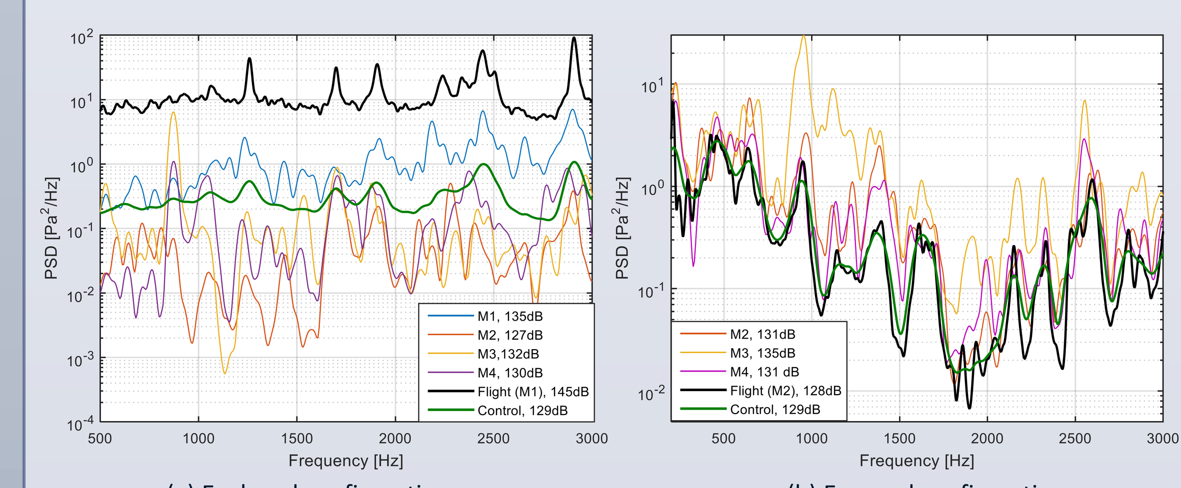


Fig. 7 – Acoustic PSDs for the (a) enclosed and (b) exposed configurations compared to flight PSD

- For the enclosed configuration, the control acoustic PSD (green) is ~15dB lower than measured in flight (black).
- The response of the inner microphones is lower by an order of magnitude than the external microphones (M1 and control)
- For the exposed configuration, the control PSD is similar to that from flight test.

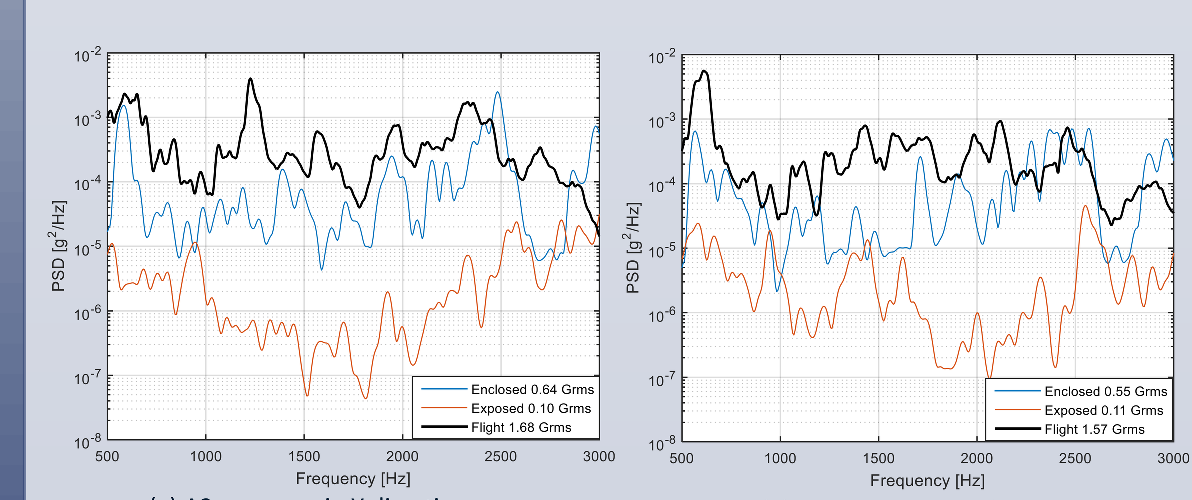


Fig. 8 – Acceleration PSDs for (a) A2 Y and (b) A1 Z, compared to flight PSD

- For both test configurations, the acceleration response of A1 in the Y and Z direction is lower than in flight (black curve).
- In the enclosed configuration (blue curve), the overall level is higher than in the exposed configuration (red curve) and the flight spectrum is well replicated.

SUMMARY AND CONCLUSIONS

Acoustic Test

- Exposed configuration:
  - Flight acoustic PSD was fully replicated (both level and spectrum).
  - Vibratory response was below the measured PSD by more than two orders of magnitude.
- Enclosed configuration:
  - Acoustic PSD is ~15dB below the measured SPL.
  - Vibratory response met the measured PSDs in some frequency bands.
- One can imagine the trapped acoustic waves inside the cylinder that turned it into a "mini acoustic chamber". Removing of the chamber canceled the structure coupling with acoustic excitation.

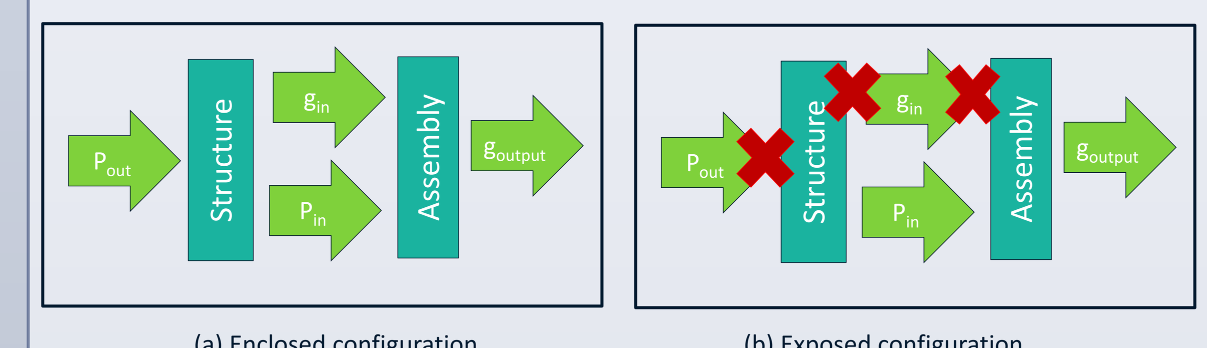


Fig. 9 – Block diagrams of energy transfer paths for (a) enclosed and (b) exposed configurations

Lab testing for a system's in-flight dynamic response

- Vibration tests are suitable for the the low frequency range, whereas the acoustic test fails to excite.
- Acoustic tests are suitable for the mid and high frequency range, and excite all directions simultaneously.
- Means of excitations (shakers \ loudspeakers) shall be set according to the test purposes:
  - structure's durability: vibration test
  - functionality of electrical components: acoustic test

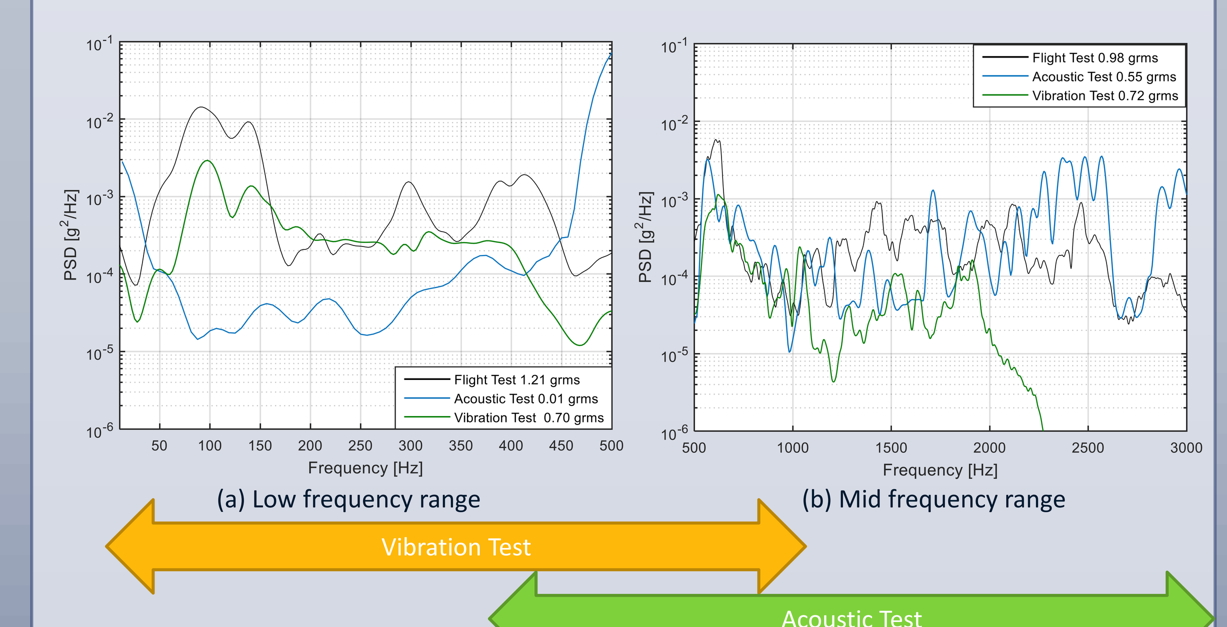


Fig. 10 –A1 response PSD (normalized to 1Grms) in the Z direction in flight and laboratory tests

FUTURE DIRECTIONS

- Design, build and test a simplified configuration of an outer shell and inner components, and use acoustic testing to calibrate simulations.
- Develop transfer functions to relate the external pressure field with internal component accelerations
- Identify sources of excitation in captive flight and use them to develop empirical models for the acceleration response due to each source
- Use the lesson learned from this study as a design criteria in an early design phase before flight tests are applicable.

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