Progress in Reducing Vibration Levels on NPSCuL

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NPSCuL Overview

- NPSCuL is an ESPA-compatible payload with a capacity of 24 1U CubeSats using P-PODs and 6U dispensers
- 2 successful launches, OUTSat and GEMSat, on the Atlas V Aft Bulkhead Carrier (ABC) in 2012 and 2013
- 2 upcoming launches, ULTRASat and GRACE, in May and August 2015
Need for Reducing Vibration Levels

- “Test-To-Insane Levels” (TTIL) methodology applied to CubeSats on NPSCuL during random vibe
  - $\sim 15 \, G_{\text{RMS}}$ at MPE for the P-POD is considered harsh
  - Rigidly mounted, cantilevered, thin-plate structure causes amplification at P-POD interface
- Discourages more sensitive and complex payloads from gaining access to space via ABC
  - Current environment is considered “coach-class”

### Progress in Reducing Vibration Levels on NPSCuL

<table>
<thead>
<tr>
<th>Level</th>
<th>Base (Input)</th>
<th>P-POD Interface*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance (MPE +0dB)</td>
<td>7.6</td>
<td>15.1</td>
</tr>
<tr>
<td>Protoqual (MPE +3dB)</td>
<td>10.7</td>
<td>21.4</td>
</tr>
<tr>
<td>Qual (MPE +6dB)</td>
<td>15.2</td>
<td>30.3</td>
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</tbody>
</table>

*Envelope of OUTSat acceptance test data (Flight P-PODs and CubeSats)
Progression of Vibration Reduction Methods for NPSCuL

- Implemented force-limited vibration testing (FLVT) to minimize over-test caused by test set-up
  - Effective in reducing the resonance at the fundamental frequency
- Redesigned NPSCuL to increase stiffness
  - Moves fundamental frequency from ~50 Hz to ~75 Hz
  - Increased stiffness results in reduced benefit from FLVT in overall $G_{RMS}$ for the ABC input
- Obtain lower input from LV provider
  - No flight data for full test frequency range available to create test envelope
Semi-empirical method is used to calculate force limit per NASA-HDBK-7004B

- Has been repeatedly shown to be the least conservative method while still meeting test requirements

Results in a notch in the acceleration input at the fundamental frequency

Force roll-off is assumed after fundamental frequency to 500 Hz

Does not provide relief past the force-limited range

- Test data shows there is a significant amount of energy above 500 Hz at the P-POD interface
- Not a mechanism, and is not intended to be, for changing the resonant properties of the system
Redesigned NPSCuL - Isogrid

• Isogrid techniques were utilized to reduce amplification by increasing stiffness without increasing overall mass
  o Moves fundamental frequency from ~50 Hz to ~75 Hz
• NPSCuL adapter ring and base plate were unified into a single part to reduce amplification from “rocking” modes
• Increased stiffness results in reduced benefit from FLVT in overall $G_{RMS}$ for the ABC input
• No significant change in $G_{RMS}$ between isogrid and baseline NPSCuL when using FLVT set-up

Next Step – Isolators on NPSCuL

- Implement isolators with FLVT to reduce P-POD environment on NPSCuL
- Eight (8) COTS isolators incorporated between adapter ring and baseplate
- Attaches to the LV interface using eight (8) of the 24 fastener locations on the 15” ESPA standard
Isolator Installation Configurations

- Conical broad-temperature-range (BTR) silicone isolators (LORD AM-009-14) constrained using two (2) methods
  - Method 1: Fastener that goes through supported unit is threaded into supporting member
    - Elastomer is constrained in compression, tension, and shear
    - Effectively lowers the CG of NPSCuL by 0.9” with little reduction in joint stiffness
  - Method 2: Typical installation for true isolation behavior
    - Elastomer is allowed to deflect as intended by vendor
    - Generally recommended for use in compression only
    - Significant change to joint stiffness and lowers the CG
    - Use in tension is assessed on a case-by-case basis

Method 1

Method 2
Isolator Test Set-Up

• All NPSCuL configurations, integrated with 8 P-POD Mass Models (P2M2s) and a SAD EDU, were subjected to the following tests in each axis
  o Fixed-base 0.5 G sine sweep, 20-2000 Hz
  o Un-notched and force-limited ABC levels, 7.6 Grms random acceleration input (MPE)
    • FLVT is still necessary to reduce conservatism during test

• Configurations are referred to as follows:
  o Config 1: Baseline (no isolators, original NPSCuL structure)
  o Config 2a: Baseline with constrained isolators (Method 1)
  o Config 2b: Baseline with isolators, typical installation (Method 2)
Dynamic Properties of Constrained Configuration

- Isolator system is not effective in lateral directions when constrained
  - First fundamental frequency in X, Y axes shifted lower by 15 Hz
    - Most likely attributed to a lower CG
- Isolators behave as expected in Z axis
  - Indicative of much lower response after the 1\textsuperscript{st} fundamental mode
Dynamic Properties of Typical Installation Configuration

• Typical behavior for base-mounted isolators on a box-like structure
  - Results in two (2) distinct modes in each axis and no amplification of higher order modes

• Isolation system appears to produce a tuned-mass damper effect
  - Anti-resonance of isolated system occurs at fundamental frequency of baseline NPSCuL

• Peak at 1560 Hz in Z-axis is an FLVT plate mode

• Lower apparent mass results in lower response in all axes
Performance Summary

- Significant reduction in P-POD interface environment with isolated NPSCuL
  - Lower CG only contributes ~30% of total $G_{RMS}$ reduction
- Qualification $G_{RMS}$ levels would be less than current acceptance $G_{RMS}$

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*Envelope of development test data (P2M2s)
Combined Effects of FLVT and Isolation

- Isolation system alone is effective in reducing $G_{RMS}$, but conservatism is still further reduced with FLVT.
- Force-limited vibration test setup is still beneficial and plays an integral part in reducing the P-POD response.

![Graphs showing overall Grms envelope for ABC unnotched and force-limited cases.](image)
Benefits for the CubeSat Community

- Provides a COTS isolation system for NPSCuL and CubeSats
  - Isolation system for larger satellites (greater than 500 lbs) exist, but are often mission-specific
  - Applicable to other ESPA-class spacecraft of similar size
- Cost of NPSCuL isolation system is ~$2000 for 35-85% reduction in random vibration environment
  - Considerable cost reduction over existing industry customized spacecraft isolation for similar performance*
- Proposed isolation system is compatible with ESPA and PSC MLB interfaces and can be easily altered for use with any ESPA-class interface
  - Main design parameters include mass and mounting configuration on LV

*References:
Conclusion and Path Forward

- Effective and low-cost solution to provide a “first-class ride” to space for CubeSats and small spacecraft
  - Investigating other COTS isolators of comparable size that can be used in tension, compression, and shear without compromising isolator effectiveness
  - Typical isolator installation configuration in tension with current isolator may be investigated
- Qual test will be performed with final isolator selection