On the Use of 3dB Qualification Margin for Structural Parts on ELV

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Introduction

- The standard qualification approach for ELV random vibration qualification is MPE+6dB for 4x life duration
  - Consistent with MIL-STD-1540 (no applicable NASA standard)
  - "Life" is flight + acceptance testing
- This can be a severe environment for fatigue sensitive structure
- Redesigns are costly
- NASA KSC has investigated to determine if the standard qualification requirement can be reduced

Definitions and Scope

- This study includes fatigue sensitive structural elements:
  - Ducts
  - Bellows
  - Hoses
  - Probes needed for tanking only
  - Any other element that is non-functional during flight

- This study does not include:
  - Any item with functional parts, especially electronics
  - Primary structure
  - Secondary structure designed by peak loads or low frequency transient loads

Current Approach

- Current Methodology:
  - Data comes from flight (poor quantity) and test (poor quality)
  - Statistics are used with historical assumptions and small sample size
  - Failure modes and failure limits are not well understood for black boxes
  - Manufacturing repeatability is poorly defined
  - Test fixturing rarely duplicates flight
  - Testing is performed one axis at a time
- Historical data shows that the current methodology works
- The details above show that there is room for negotiation
- In particular, structural elements have unique features:
  - No acceptance testing
  - Failure modes are known: Peak load and fatigue
  - Quality control is achievable to control the failure modes
- Need to develop a method that addresses peak load and fatigue

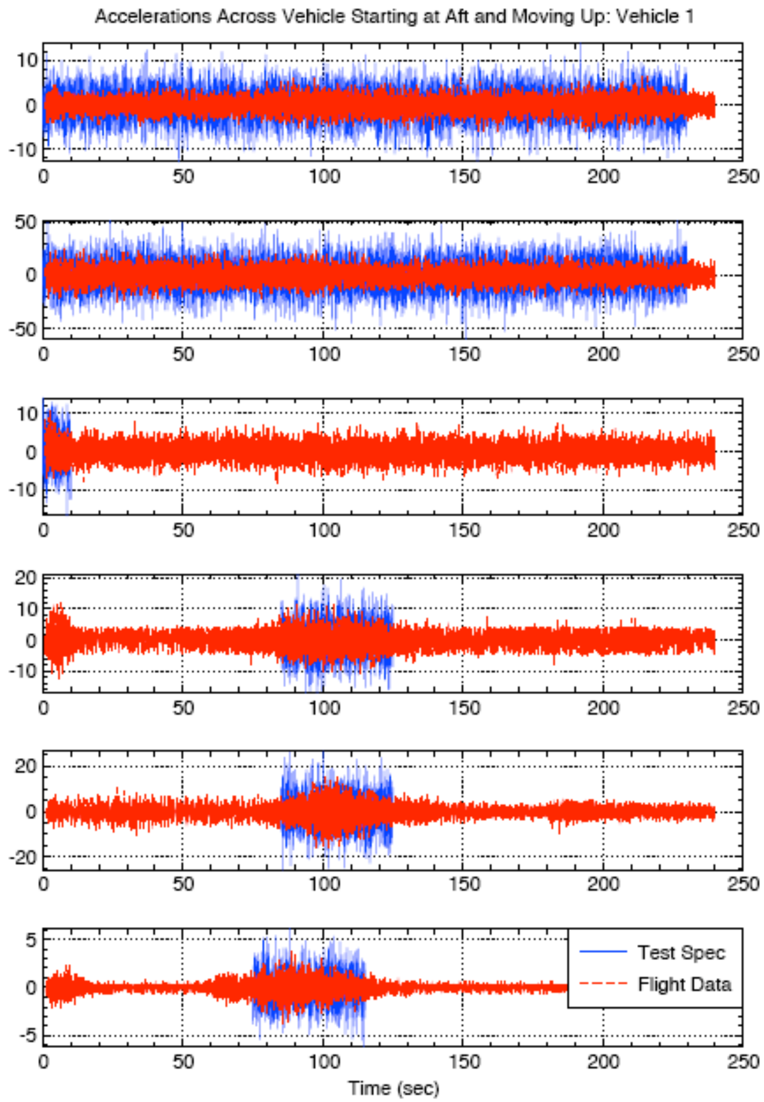
Derivation of the Environment

- Launch vehicle environments are created using statistics
- A typical PSD is created as the maximum of 1 second averages
  - Frequency peaks from different times are combined
- The event duration is typically the duration that the environment is within 6dB of the peak
  - The duration considers times at which levels are half of peak

Study Approach

- Flight data from 3 vehicles was obtained
- Multiple locations (5-6 accels) on each vehicle was included
  - Engine region, mid-body, spacecraft
- The flight data encompasses axial and lateral accelerometers
- “Fatigue damage” from flight was calculated by counting the number and magnitude of stress reversals and applying Minor’s rule
- Time histories were developed from PSD’s of MPE and MPE+3dB
  - Time histories were developed for 1x life (10 sec minimum) at the accel location
  - These are not unique and some variation was observed in the study but not enough to discount the results or change the conclusions
- Fatigue damage was calculated for MPE and MPE+3dB in the same way as flight data.
- Fatigue damage from MPE and MPE+3dB was compared

Study Data



- Red curves are the flight data
- Blue curves are the time histories derived from the MPE
- Blue curves are shown for the 1x life duration over the peak environment that defines life.
- Note that the longer the life (curve 1), the more conservative the MPE becomes because more 1-second averages are enveloped.

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Study Data

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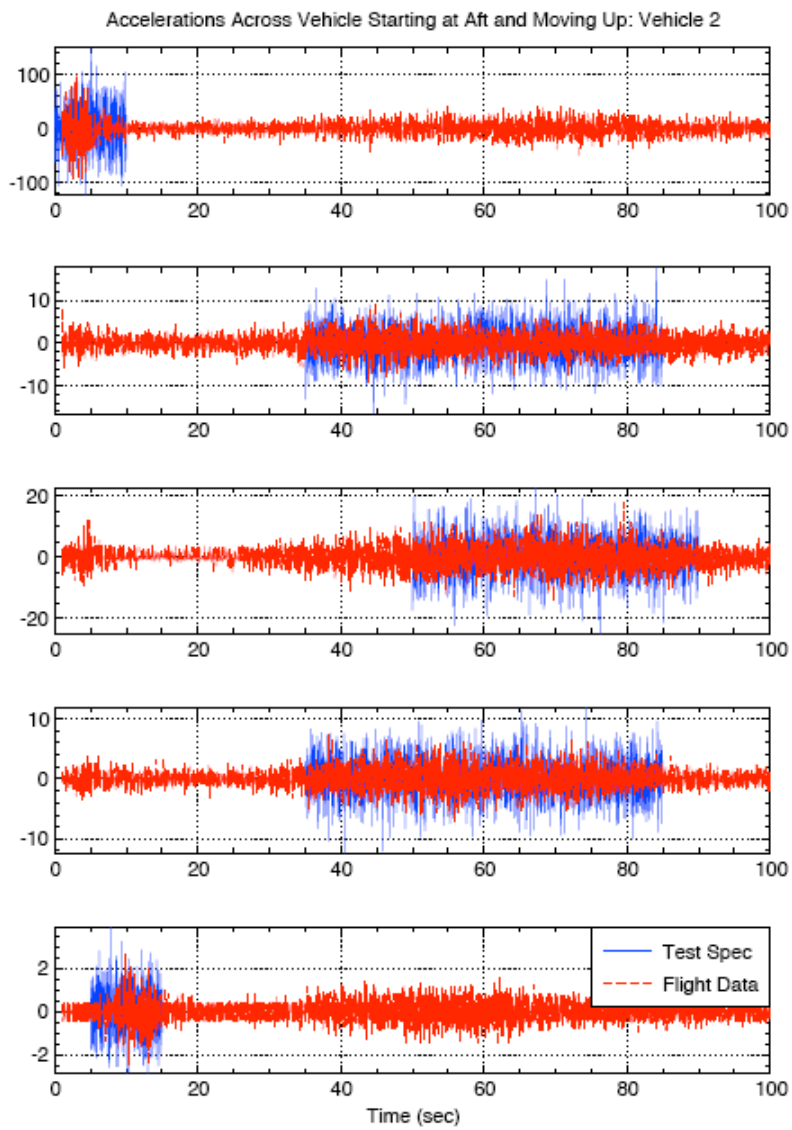
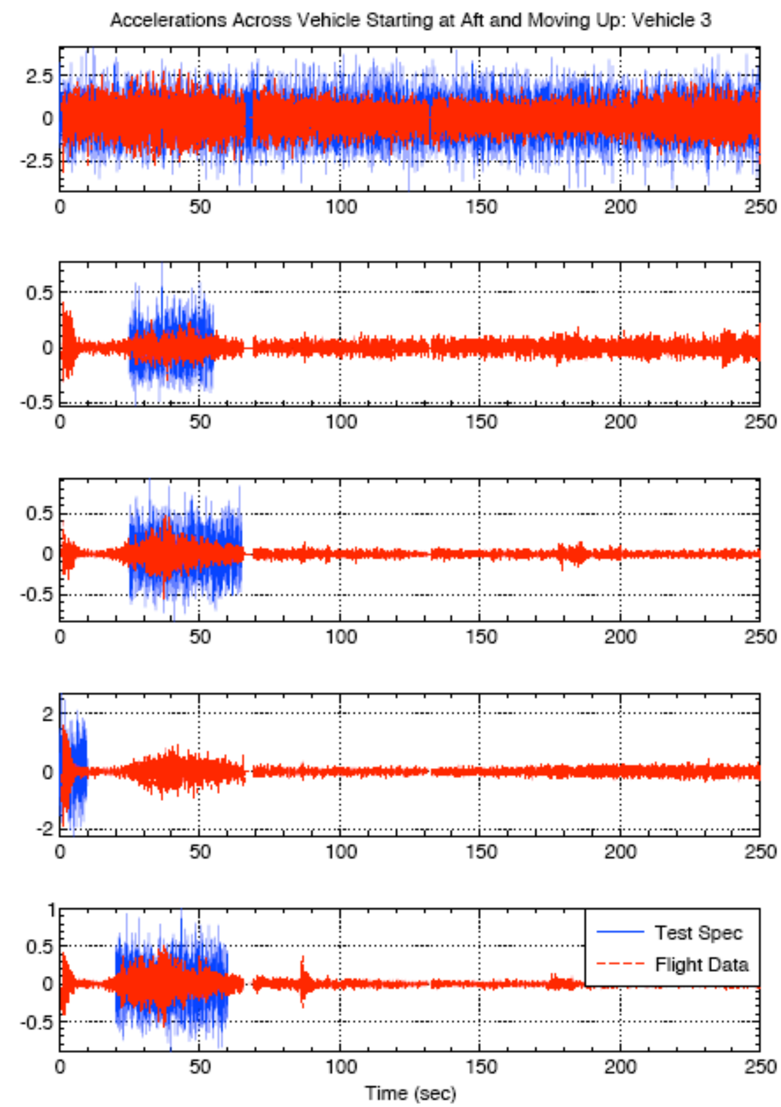




Study Results: Fatigue

Table 1: Comparison of Fatigue Life Expended by ELV Flight Data, the Associated MPE, and the Associated MPE+3dB

	Configuration 1			Configuration 2			Configuration 3		
Vehicle Location	Peak Event Duration (sec)	MPE Margin	MPE +3dB Margin	Peak Event Duration (sec)	MPE Margin	MPE +3dB Margin	Peak Event Duration (sec)	MPE Margin	MPE +3dB Margin
1	230	28.0	112	10	4.1	16.3	250	5.7	23.5
2	230	19.2	77	50	6.2	24.7	30	10.0	40.0
3	10	1.0	4.0	40	3.5	13.8	40	28.0	112.0
4	40	3.9	15.8	40	7.9	31.4	10	5.0	20.0
5	40	4.7	18.7	10	2.8	11.1	40	21.7	86.6
6	40	5.6	22.2						

Notes:
MPE Margin = (Fatigue Due to MPE for Peak Event Duration) / (Fatigue Due to Flight Data)
MPE+3dB Margin = (Fatigue Due to MPE+3dB for Peak Event Duration) / (Fatigue Due to Flight Data)

- Short duration events have the lowest fatigue margin
- At least 4x fatigue life is demonstrated for MPE+3dB in all cases

Study Results: Peak Loads

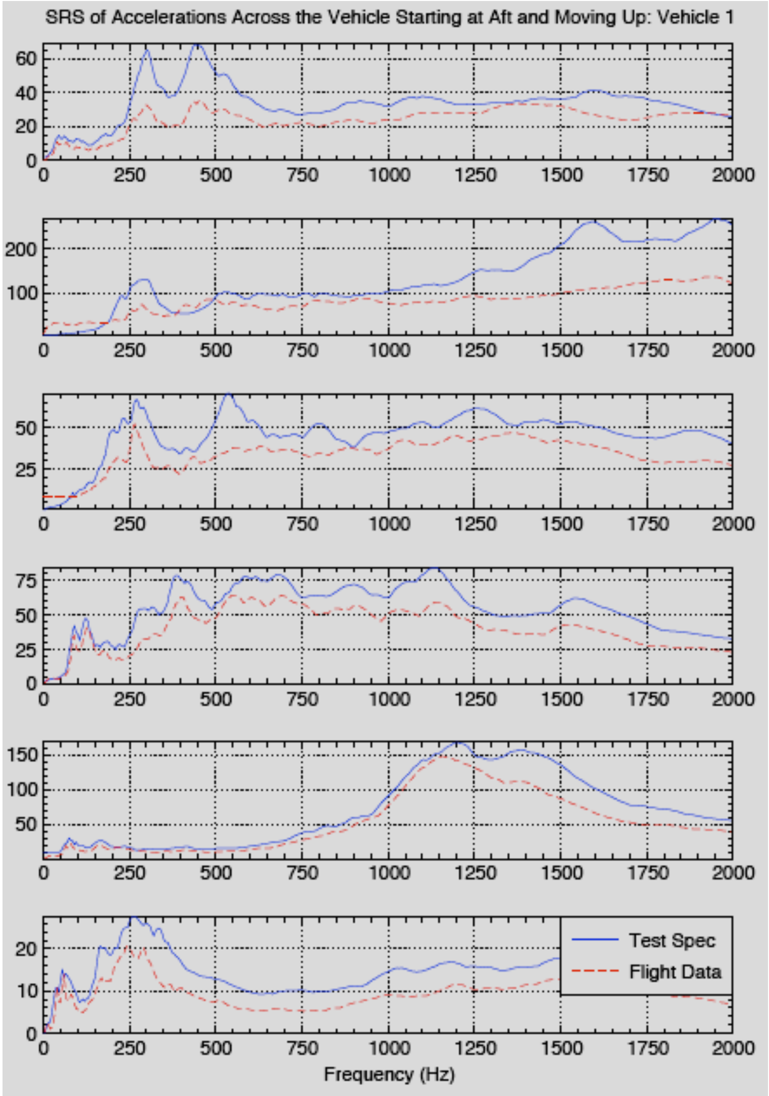
Table 2: Comparison of Expected Peak Loads from ELV Flight Data, the Associated MPE, and the Associated MPE+3dB

	Configuration 1			Configuration 2			Configuration 3		
Vehicle Location	Peak Event Duration (sec)	MPE Margin	MPE +3dB Margin	Peak Event Duration (sec)	MPE Margin	MPE +3dB Margin	Peak Event Duration (sec)	MPE Margin	MPE +3dB Margin
1	230	1.9	2.7	10	1.1	1.5	250	1.4	1.9
2	230	2.0	2.8	50	1.1	1.6	30	1.2	1.7
3	10	1.4	1.9	40	1.3	1.8	40	1.5	2.1
4	40	1.3	1.8	40	1.3	1.8	10	1.3	1.9
5	40	1.1	1.6	10	1.3	1.8	40	1.1	1.6
6	40	1.3	1.9						

Notes:
MPE Margin = (Peak Load Due to MPE for Peak Event Duration) / (Peak Load Due to Flight Data)
MPE+3dB Margin = (Peak Load Due to MPE+3dB for Peak Event Duration) / (Peak Load Due to Flight Data)

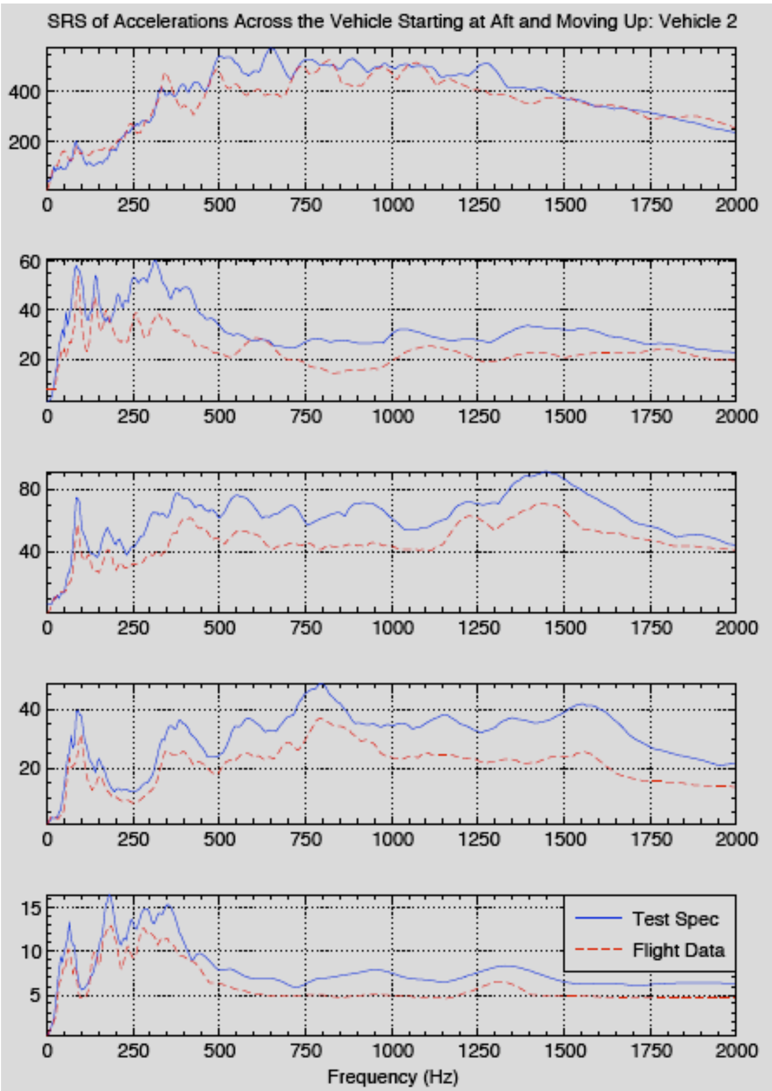
- Peak load margin is less than fatigue margin
- At least 1.5x peak load is demonstrated for MPE+3dB in all cases

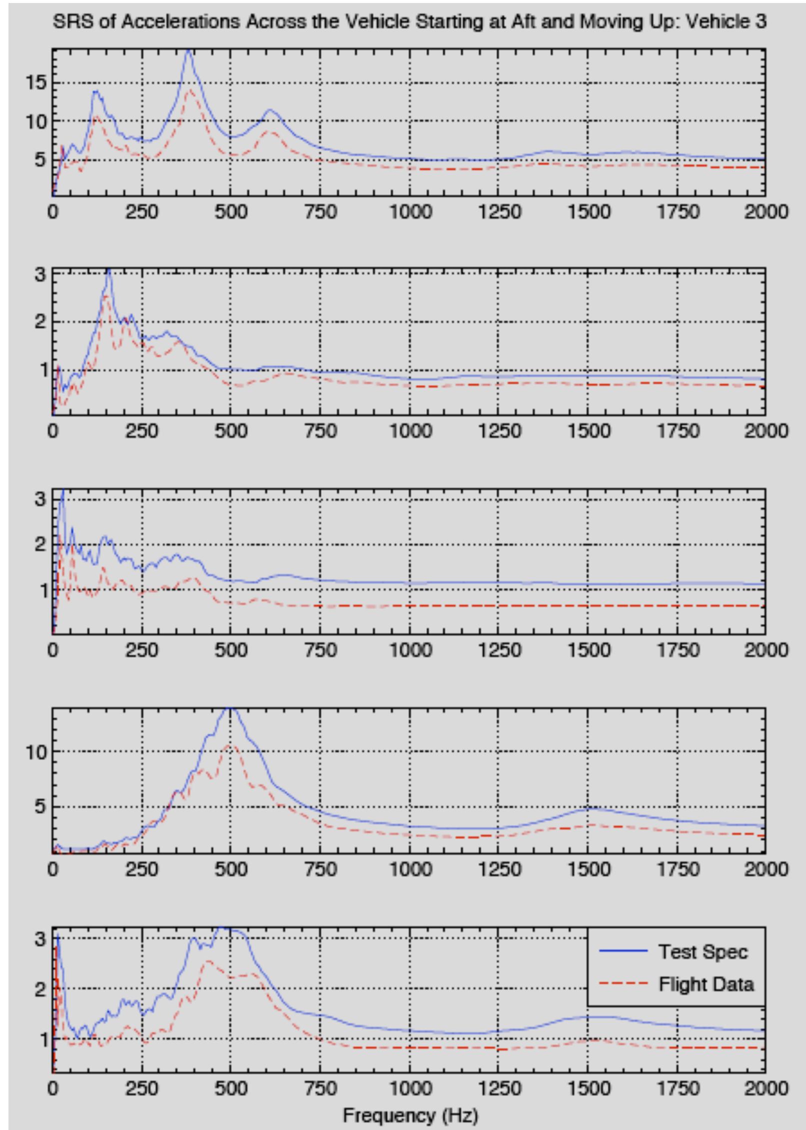
Study Results: SRS



- MPE+3dB SRS shows margin over flight at nearly all frequencies

Study Results: SRS





Summary and Conclusions

- Structure and black boxes are different
  - Black boxes have unknown failure modes and have margin only by virtue of test
  - Structure has known failure modes and can have margin by analysis against these modes
- Using standard development of MPE, structure may be qualified by MPE+3dB for 1x life
  - Standard development = max (1 second average) for duration of event
- “Structure” in this study includes: ducts, bellows, tubing, non-functional structure, etc.
- “Structure” does not include primary or secondary structure designed by transient peak loads or quasi-static loads