Systems Engineering Integrative Project

"Development of Common Component-Level Environmental Requirements to Facilitate the Development of More Robust and Cost-Efficient Components for Use Across Multiple Spacecraft Programs"

Luis Aguilera
Spring 2012
Budgetary Pressure Mean Fewer Pentagon $’s

- External budget pressures crowding out defense spending
  - Years of underinvestment
  - Two protracted wars
  - Continuing economic slowdown
  - Spending on entitlement programs
  - Interest on debt

- Internal pressures and shifting priorities crowding out modernization and procurement
  - Escalating costs of personnel compensation, retirement benefits, and health programs
  - Shrinking economies of scale and build rates
  - Secretary of Defense forced to make major changes to new and existing programs
The Defense Industry could be considered an oligopoly
- Few large, competing firms respond to each other's actions
- Produce a homogeneous product; Cost/Price discriminating variable

Defense systems large and complex
- Many inputs to the Cost/Price variable

Space example:  
- Launch Segment
  - Price fixed by Launch Providers
  - No practical re-use options
  - Lowest price LV selected

- Ground Segment
  - Use existing Ground assets
  - Re-use existing SW

- Space Segment
  - Lower cost by re-using qualified S/C components
  - Re-use lowers NRE costs

Cost Savings Opportunities

Costs can be lowered by re-using existing assets and reducing development costs by building additional components to qualified requirements.

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Rationale for Topic Selection

- Objective: To develop a set of requirements applicable to components across multiple programs and missions; and through re-use minimize NRE costs.

- Rationale:
  - At time of topic selection, author involved in similar employer-funded IR&D effort.
  - Approach was to envelope different types of requirements (i.e. Performance, Environmental, Mission Assurance, etc) to meet multiple programs and missions.
  - Requirements development assigned to functional expertise RE’s.
  - Programs committing to "multi-platform" components pay NRE development costs.
  - Future programs would benefit from reduction in NRE costs.
  - Follow-on to a previous, highly successful effort 15 years prior
Benefits of Project’s Results

- Set of re-usable requirements for use across multiple-missions and platforms
  - Spacecraft-level designers
    - Locate components on the S/C with respect to LV interface to attenuate the environmental effect on a component to within capabilities
    - Design component mounting methods to attenuate environmental effects to within maximum capabilities
  - Component-level designers
    - Design implications on selection of internal components, layout, etc
    - Design standardization to maximum Launch Vehicle environmental effects
    - Designs limited by capability of internal components
The project is about requirements development and re-use.
Considers design/requirements re-use as an input to cost reduction.
Environmental requirements are interface requirements between systems:
  - Spacecraft / Ground Processing
  - Spacecraft / Launch Vehicle
  - Spacecraft / Space
Basic spacecraft design drivers and component layout considerations
  - Launch Vehicle
    • Mass properties
    • Static and dynamic envelopes
  - Spacecraft
    • Mass properties
    • Thermal balance
    • Functional location
    • Integration
    • Physical accommodation
Re-use as a Cost Saver

- Re-use as a Lean principle
  - Lean design seeks opportunities to eliminate waste during the design phase
- Many sources of process waste in product development
  - "Re-use" focuses on Re-invention waste
    - Same problem is solved repeatedly
    - Existing solutions/designs are not utilized
  - Advantages are lower costs, faster development and lower risks
- Develop component and requirements/performance standard re-use to lower costs
  - Specific-use = development NRE costs each time
  - Re-use = development NRE costs once
    - Subsequent builds incur production costs only
- Barriers to Re-use
  - Corporate culture, Program-centric mentality
- Re-use successes
  - Propulsion system components

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A Previous Successful Effort

- Approach for this project follows a portion of a similar effort done in the early 1990s for Propulsion System components
- Multiple-step process over 5 years

ID needs and components → Define and bound requirements → Develop EQ specs and standards → Evaluate vendor bids and refine requirements → Select vendors and negotiate agreements → Develop, test and qualify products → Maintain and update specs

- Accomplishments:
  - 12 subcontracted components standardized, design and tested for multiple programs application
  - > 2 dozen piece parts and assembly hardware standardized
  - ~ 10 standardized propulsion modules assembled from standardized components and piece parts
  - Streamlined test/ acceptance procedures and QA inspections for standardized components
  - Established long term agreements with Suppliers
  - Standardized piece parts in Standard Stock
  - Standardized products have been good for 15 years

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Focus on Environmental Requirements

- Interface Requirements
- Part, Materials & Processes Requirements
- Other Requirements
- Quality Assurance Requirements
- Performance Requirements
- Component-level Specification
- Environmental Requirements

S/C Pre-launch Environments
- Thermal
- A/C & GN2
- EMC (RF/ESD)
- Contamination / Cleanliness

S/C Launch Environments
- Design Load Factors
- Acoustics
- Sinusoidal Vibration
- Random Vibration
- Shock
- Thermal
- Depressurization
- Contamination
- EMI

S/C Operational Environments
- CMEs/Solar Flares
- Geomagnetic Storms
- High Energy Particles
- Electromagnetic Radiation
- Space Plasma
- Atomic Environment
- Micrometeorites
Some of the most severe environments a S/C can experience occur during lift-off/launch.

Developing a robust set of enveloping requirements begins with the selection of available Launch Vehicles (Appendix A).
- Previous efforts compared program defined environments.
- A survey approach was taken to compare environments from Mission Planner's Guides source documents.
- Enveloped environments according to a "90% rule".
  - Data points above the 95% or below the 5% would be considered "outliers" and treated on an individual basis.
- Not all LVs compared may have environments as severe as the enveloping curves but they will be "blanketed" with the approach.
Outlier Example: Pressure Transducer

- Mission Radiation requirements more severe than those used to envelope the Standardization/Re-use effort
- Pressure Transducer particularly sensitive to the radiation environment
- Options:
  - Develop a program/mission-specific component requiring entire development/qualification effort
    - Significant cost
    - Schedule penalty
  - Use an existing component with a work-around plan
    - Selected a standardized Pressure Transducer
    - Met increased radiation requirement by using a tantalum sleeve

For “outlying” requirements (beyond the enveloping requirements of a re-use/standardization component), minimally invasive engineering solutions should always be explored before deciding on new development programs.
• Thermal
• Electromagnetic Compatibility (EMC)
  – Launch Vehicle Intentional/Unintentional RF Emissions
  – Launch Range Electromagnetic Environment Limitation
  – Electrostatic Discharge
  – Lightning Mitigation
• Contamination Control/Cleanliness
• Conditioned Air /GN2 purge
• Humidity
S/C Launch Environments: Design Limit Loads

- The combined spacecraft accelerations are a function of launch vehicle characteristics as well as spacecraft dynamic characteristics.
- Design Load Factors are for use in preliminary design of primary structure.
- Axial acceleration is determined by the vehicle thrust history and drag.
- Maximum lateral acceleration is primarily determined by wind gust, engine gimbal maneuvers, first stage engine shutdowns, and other short-duration events.
- Positive axial value indicates a compressive net-center of gravity acceleration
- Negative value indicates tension.

- Two envelopes are presented because a single envelope is too conservative and impractical.
- Higher accelerations in the Taurus may be typical of solid-rocket based launch vehicles.
- Red envelope representative of the Taurus.
- Green envelope representative of the envelope for the liquid-rocket based launch vehicles.
Payload Acoustic Environment During Liftoff and Flight

- Acoustic energy is the primary source of vibration to a space launch vehicle.
- Transmitted to S/C by fluctuating pressures within the LV fairing; impinge directly on exposed S/C surfaces, inducing vibration in high gain antennae, solar panels and other components having a large ratio of area-to-mass.
- Fluctuating external pressure field causes an oscillatory response of the rocket structure, ultimately transmitted through the S/C attachment ring in the form of random vibration.
- A single enveloping requirement would be impractical and overly-conservative for smaller payload components.

Red envelope represents the enveloping acoustic requirement for the large LV class (i.e. Delta IV, Atlas V, Falcon 9 and Zenit 3L).
Green envelope represents the enveloping acoustic requirement for the small LV class (i.e., Taurus, Minotaur I & IV, Falcon 1 and Pegasus).

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S/C Launch Environments: Pyroshock

- S/C are subjected to pyroshock environments which are LV-induced but can also be self-induced.
- Pyroshock events are a result of the firing of an explosive device, usually for the purpose of initiating or performing a mechanical action.
- Spacecraft separation events, the release of propulsion system safing devices and deployable launch lock devices are typical such mechanical action.
- Pyroshock events can also occur in flight during engine firing for orbit correction.

- Units should be designed to survive a shock spectrum that considers all shock sources.
- Shock requirements may apply to in-plane or normal-to-mounting plane.
- Moving units farther away from shock sources can provide some attenuation of the shock spectrum by virtue of distance or separation by number of structural joints.

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S/C Launch Environments: Thermal

- Electronic devices are usually enclosed within a controlled thermal environment in the spacecraft interior.
- This thermal environment can be tightly controlled (5-10°C) through a combination of passive heat conduction through a high-thermal capacity base plate and active heating elements.
- Components on spacecraft exterior can be exposed to temperatures from -120 to +150°C.
- Thermal requirements are extended to a broader range to guarantee components will function after accidental loss of power or overheating.

### Maximum/Minimum Predicted Temperatures (MPT)

#### Test & Duration (Thermal Vacuum - TV)
- Acceptance: Env MPT + min range, 14 cycles
- Protoqualification: Acc ± 5°C, 27 cycles
- Qualification: Acc ± 10°C, 27 cycles

#### Test & Duration (Thermal Vacuum - non-electrical)
- Acceptance: MPT, 1 cycle
- Protoqualification: Acc ± 5°C, 3 cycles
- Qualification: Acc ± 10°C, 6 cycles

#### Test & Duration (Thermal Cycle - TC)
- Acceptance: Env MPT + min range, 14 cycles
- Protoqualification: Acc ± 5°C, 27 cycles
- Qualification: Acc ± 10°C, 27 cycles

#### Test & Duration (Combined TV and TC)
- Acceptance: Env MPT + min range, 4 TV + 10 TC cycles
- Protoqualification: Acc ± 5°C, 4 TV + 23 TC cycles
- Qualification: Acc ± 10°C, 4 TV + 23 TC cycles
Electromagnetic Compatibility (EMC) for a system or component requires that:

- It does not cause interference with other systems or equipment.
- It is not susceptible to emissions from other systems, equipment or electrical environments.
- It does not cause interference within itself that can cause the system or equipment to malfunction or behave in an undesirable manner.

Graph on left shows maximum LV emissions a component must be able to withstand.
Graph on right shows maximum emissions allowed from a S/C that a LV can withstand.
Results:
S/C Operational Environments

- Space operational environment is difficult to characterize for any given mission.
- Unknowns in mapping it and in processes that generate it.
- Environment also changes with time, including launch timeframe, mission duration, and orbit characteristics.
- Natural space environments
  - Solar-radiation events
    - Electromagnetic radiation
    - High-energy particles
    - Low-Medium energy particles
  - Atomic environment
  - Micrometeorites
- Man-made space environments
  - Space debris
  - Active spacecraft
Solar Radiation

Electromagnetic Radiation
Arrival: Immediately
Duration: 1-2 Hours
X-rays, EUV, Radio Bursts
- Satcom Interference
- Radar Interference
- Shortwave Radio Fades

High Energy Particles
Arrival: 15 Min to Few Hours
Duration: Days
Proton Events
- Satellite Disorientation
- Spacecraft Damage
- Radio Blackouts

Low-Medium Energy Particles
Arrival: 2-4 Days
Duration: Days
Geomagnetic Storms
- Spacecraft Charging
- Satellite Drag
- Power Blackouts
## Space Environment Effects and Mitigation

<table>
<thead>
<tr>
<th>Space Environment</th>
<th>Effect on Space System</th>
<th>Mitigation Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Debris</td>
<td>Puncture, Degradation, Collision</td>
<td>Threat mitigated by reducing amount of space debris</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Deorbit and re-orbiting at EOL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Passivation and discharging battery at EOL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small objects - shielding techniques</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large objects - calculate collision probability (monitoring and tracking)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collision avoidance</td>
</tr>
<tr>
<td>Active S/C</td>
<td>Unintentional: frequency disturbances</td>
<td>Development of space situational awareness systems</td>
</tr>
<tr>
<td></td>
<td>Intentional: frequency disturbances, electromagnetic fields, partial/total damage</td>
<td>- Monitor S/C, identify their missions and predict possible threats</td>
</tr>
<tr>
<td>Orbital Perturbations</td>
<td>Short-periodic, Long-periodic, Secular changes in orbital elements</td>
<td>Natural threats more un-predictable than man-made threats</td>
</tr>
<tr>
<td>CMEs/Solar Flare</td>
<td>Atmospheric drag, Material degradation, Electronic component failure</td>
<td>Threats highly dependant on mission duration, orbital altitude, and time within naturally occurring cycles</td>
</tr>
<tr>
<td>Geomagnetic Storms</td>
<td>Atmospheric drag, Electronic component failure</td>
<td>Modeling phenomenon's in future during design phase protects S/C from harsh space environment</td>
</tr>
<tr>
<td>High Energy Particles</td>
<td>Deep dielectric charging, Single-event effects, Memory failure, Degraded sensor performance</td>
<td>Real time, space environment monitoring integrated with on-board SOH sensors can allow S/C to auto-adapt to changing conditions</td>
</tr>
<tr>
<td>Electromagnetic Radiation</td>
<td>Thermal effects, Ionization, Material degradation</td>
<td>Switching off S/C during solar storms reduces damage from increased radiation dose.</td>
</tr>
<tr>
<td>Space Plasma</td>
<td>Surface charging, Induced electric current, Arc discharge</td>
<td></td>
</tr>
<tr>
<td>Atomic Environment</td>
<td>Chemical reaction with surface, Ionization, Atmospheric drag</td>
<td></td>
</tr>
<tr>
<td>Micrometeorites</td>
<td>Puncture</td>
<td></td>
</tr>
</tbody>
</table>

Source: Space Environment Threats and Their Impact on Spacecrafts in Near Earth Orbits (Singh, Anafar and Nicolas)

The Space Environment is difficult to characterize (establishing an enveloping requirement) due to it's dependence on the mission duration, orbital parameters and the time within naturally occurring space cycles.
This environment enveloping approach can be used on many spacecraft components.

- Payload components such as optical and science instruments are impractical because they are so mission-specific and few are built.
- Approach is better suited on spacecraft components such as actuators, drive units and other card based or slice-based components

Cost savings are realized as soon as a component is reused.

- The first unit incurs the NRE costs
- Each additional unit only incurs the RE costs
- These savings can be used to pass on to the Customer in subsequent proposal bids

Design re-use is an ambitious undertaking

- Can be a daunting task if scope is not clearly defined
  - Too broad can lead to 'chasing one's tail' and failure to converge on a usable set of requirements
  - Too narrow can yield none or insignificant savings
"Design reuse is just like printing money. You save non-recurring design cost, and get the product to the market quicker besides. The problem lies in developing the infrastructure required to implement broad-based design reuse."

*The Lean Design Guidebook: Everything Your Product Development Team Needs to Slash Manufacturing Cost*

Robert Mascitelli
### Launch Vehicle Systems Compared

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Atlas V</th>
<th>Delta IV</th>
<th>Delta IV-H</th>
<th>Falcon 1</th>
<th>Falcon 9</th>
<th>Pegasus XL</th>
<th>Taurus</th>
<th>Zenit 3SL</th>
<th>Minotaur I</th>
<th>Minotaur IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company</td>
<td>LMC/LA</td>
<td>BLS/ULA</td>
<td>BLS/ULA</td>
<td>SpaceX</td>
<td>SpaceX</td>
<td>Orbital</td>
<td>Orbital</td>
<td>Sea Launch</td>
<td>Orbital</td>
<td>Orbital</td>
</tr>
<tr>
<td>Stages</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3-4</td>
<td>3</td>
<td>2</td>
<td>4-5</td>
<td>4</td>
</tr>
<tr>
<td>Capacity to LEO-kg (lb)</td>
<td>12,500 (27,558) to 20,520 (45,238)</td>
<td>9,390 (20,702) to 13,360 (29,440)</td>
<td>22,977 (50,646)</td>
<td>420 (924)</td>
<td>10,450 (23,050)</td>
<td>440 (970)</td>
<td>1,458 (3,214)</td>
<td>N/A</td>
<td>580 (1,300)</td>
<td>1,735 (3,889)</td>
</tr>
<tr>
<td>Capacity to SSO-kg (lb)</td>
<td>7,095 (15,642) to 14,096 (31,076)</td>
<td>7,510 (16,550) to 11,300 (24,920)</td>
<td>22,560 (49,740)</td>
<td>420 (924)</td>
<td>8,560 (18,870)</td>
<td>190 (420)</td>
<td>1,054 (2,324)</td>
<td>N/A</td>
<td>331 (730)</td>
<td>N/A</td>
</tr>
<tr>
<td>Capacity to GTO-kg (lb)</td>
<td>4,750 (10,450) to 8,900 (19,580)</td>
<td>4,541 (10,012) to 7,020 (15,470)</td>
<td>13,399 (29,540)</td>
<td>N/A</td>
<td>4,540 (10,000)</td>
<td>N/A</td>
<td>430 (950)</td>
<td>6,180 (13,624)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Launch Sites</td>
<td>CCAFS VAFB</td>
<td>CCAFS VAFB</td>
<td>CCAFS Kwajalein</td>
<td>CCAFS Kwajalein</td>
<td>Various (air-launched)</td>
<td>VAFB</td>
<td>VAFB Pacific Ocean</td>
<td>VAFB MARS</td>
<td>VAFB MARS KLC</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
ULA is no longer producing the Delta II and is therefore excluded from the survey. Three launches of the Delta II are scheduled for 2011 with five launch vehicles remaining (unassigned). (2011 U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports)
# Appendix B: Environmental Test Levels and Durations

<table>
<thead>
<tr>
<th>Test</th>
<th>Qualification</th>
<th>Protoqualification</th>
<th>Acceptance</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Static Load</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td>1.25 x Limit Load</td>
<td>1.25 x Limit Load</td>
<td>1.0 x Limit Load</td>
<td>GSFC-STD-7000</td>
</tr>
<tr>
<td>Duration</td>
<td>1 minute</td>
<td>30 seconds</td>
<td>30 seconds</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 cycles @ full level</td>
<td>5 cycles @ full level</td>
<td>5 cycles @ full level</td>
<td></td>
</tr>
<tr>
<td><strong>Acoustics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td>6 dB above Acceptance</td>
<td>3 dB above Acceptance</td>
<td>Envelope of MPE &amp;</td>
<td>MIL-STD-1540E</td>
</tr>
<tr>
<td></td>
<td>3 minutes</td>
<td>2 minutes</td>
<td>1 minute</td>
<td></td>
</tr>
<tr>
<td><strong>Random Vibration</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td>6 dB above Acceptance</td>
<td>3 dB above Acceptance</td>
<td>Envelope of MPE and</td>
<td>MIL-STD-1540E</td>
</tr>
<tr>
<td></td>
<td>3 minutes each of 3 axes</td>
<td>2 minutes each of 3 axes</td>
<td>1 minutes each of 3 axes</td>
<td></td>
</tr>
<tr>
<td><strong>Sine Vibration</strong></td>
<td></td>
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</tr>
<tr>
<td>Level</td>
<td>1.25 x Limit Level</td>
<td>1.25 x Limit Level</td>
<td>Limit Level</td>
<td>GSFC-STD-7000</td>
</tr>
<tr>
<td></td>
<td>2 oct/min</td>
<td>4 oct/min</td>
<td>4 oct/min</td>
<td></td>
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<tr>
<td><strong>Shock</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td>6 dB above Acceptance</td>
<td>3 dB above Acceptance</td>
<td>Maximum predicted</td>
<td>MIL-STD-1540E</td>
</tr>
<tr>
<td></td>
<td>3 X both directions</td>
<td>2 X both directions</td>
<td>1 X both directions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 orthogonal axes</td>
<td>3 orthogonal axes</td>
<td>3 orthogonal axes</td>
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<tr>
<td><strong>Pressure</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Level</td>
<td>As specified in Appendix A</td>
<td>As specified in Appendix A</td>
<td>1.1 x MEOP (structures)</td>
<td>MIL-STD-1540E</td>
</tr>
<tr>
<td>Duration</td>
<td></td>
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<tr>
<td><strong>Thermal Vacuum</strong></td>
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</tr>
<tr>
<td>Level</td>
<td>±10°C beyond Acceptance</td>
<td>±5°C beyond Acceptance</td>
<td>Envelope of MPT and</td>
<td>MIL-STD-1540E</td>
</tr>
<tr>
<td></td>
<td>27 cycles</td>
<td>27 cycles</td>
<td>(~24 to 61°C)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14 cycles</td>
<td></td>
</tr>
<tr>
<td><strong>Thermal Cycle</strong></td>
<td></td>
<td></td>
<td>Maximum predicted</td>
<td>MIL-STD-1540E</td>
</tr>
<tr>
<td>Level</td>
<td>±10°C beyond Acceptance</td>
<td>±5°C beyond Acceptance</td>
<td>1 cycle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>27 cycles</td>
<td>27 cycles</td>
<td>1 cycle</td>
<td></td>
</tr>
<tr>
<td><strong>Combined Thermal</strong></td>
<td></td>
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</tr>
<tr>
<td>Level</td>
<td>±10°C beyond Acceptance</td>
<td>±5°C beyond Acceptance</td>
<td>Envelope of MPT and</td>
<td>MIL-STD-1540E</td>
</tr>
<tr>
<td></td>
<td>4 TVs + 23 TCs</td>
<td>4 TVs + 23 TCs</td>
<td>(~24 to 61°C)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14 cycles</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>4 TVs + 10 TCs</td>
<td></td>
</tr>
<tr>
<td><strong>EMC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td>12 dB</td>
<td>6dB</td>
<td>6dB</td>
<td>MIL-STD-1540E</td>
</tr>
<tr>
<td></td>
<td>Same as Acceptance</td>
<td>Same as Acceptance</td>
<td>20 min. @ each SV</td>
<td></td>
</tr>
</tbody>
</table>

Source:
- GSFC-STD-7000
- MIL-STD-1540E

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• Sinusoidal vibration is used to simulate the effects of significant flight environment launch transients.

• These transients typically produce the dominant loading on primary and secondary structure and many of the larger subsystems and assemblies.

• Only current method of adequately exciting the lower frequency dynamic modes, particularly those below 40 Hz.

• Sine vibration levels are dependent on the type of structure to which the component is attached, the local attachment stiffness, the distance from the spacecraft separation plane, and the component’s mass, size and stiffness; impractical to specify a single enveloping requirement.

• Actual practice is to specify multiple vibration spectrums based on above parameters for design guidelines.
Random vibration environment simulates the response of the spacecraft bus structure to the required acoustic spectrum.

Base-input random vibration analysis and testing is appropriate for units that are relatively compact and do not in themselves have a lot of surface area that would be directly driven by the acoustic sound pressure.

Random vibration input occurs over a broad frequency range, from about 10 Hz to 2000 Hz.

A minimum level of vibration is necessary to ferret out existing workmanship defects and potential failures.

Difficult to characterize a single enveloping Random Vibration requirement because they are affected by location from base vibration input, mass and size of the unit and the adjacent components on the panel.

Actual practice specifies several Random Vibration environments based on the above parameters.
Payload compartment pressure and depressurization rates are a function of the PLF design and trajectory.

As a launch vehicle ascends through the atmosphere, venting occurs through the aft section of the fairing and other leak paths in the vehicle.

Knowledge of depressurization rates and venting design concepts are important because improper venting of high pressure could lead to compression and thus inducing structural collapse, penetration of sealing and interference with component function.

Conversely, low pressure could result in expansion and fracture of a container, explosive expansion, loss of mechanical strength, insulation break down and arcing as well as loss of mechanical strength and alteration of electrical properties.
## Appendix B: Space Environment Threats

<table>
<thead>
<tr>
<th>Orbits (km above Earth's surface)</th>
<th>Likelihood</th>
<th>Severity (effect on SIC and/or onboard instruments and/or whole mission (SOIM))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Earth Orbit (LEO): 200 to 1,200</td>
<td>Very Seldom: $N_{oc} &lt; 3$</td>
<td>Low (LO): $\downarrow$ 0%-25% effective life time)</td>
</tr>
<tr>
<td>Medium Earth Orbit (MEO): 3,000 &lt; Apogee &lt; 30,000</td>
<td>Seldom (SE): $3 &lt; N_{oc} &lt; 5$</td>
<td>Medium (ME): $\downarrow$ 25%-50% effective life time)</td>
</tr>
<tr>
<td>Synchronous Earth Orbit (GEO): ~ 36,000</td>
<td>Often (OF): $6 &lt; N_{oc} &lt; 8$</td>
<td>Critical (CR): $\downarrow$ 50%-75% effective life time)</td>
</tr>
<tr>
<td></td>
<td>Very Often (VO): $8 &lt; N_{oc}$</td>
<td>High (HI): $\downarrow$ 75%-100% effective life time)</td>
</tr>
</tbody>
</table>

### Threats in the Low Earth Orbit (LEO)

<table>
<thead>
<tr>
<th>Threat</th>
<th>Likelihood</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Debris</td>
<td>SE</td>
<td>LO, ME, CR, HI</td>
</tr>
<tr>
<td>Active S/C</td>
<td>VS</td>
<td>Unintentional: LO Intentional: CR, HI</td>
</tr>
<tr>
<td>Orbital Perturbations</td>
<td>VO</td>
<td>LO, ME</td>
</tr>
<tr>
<td>CMEs/Solar Flare</td>
<td>SE</td>
<td>HI</td>
</tr>
<tr>
<td>Geomagnetic Storms</td>
<td>SE</td>
<td>HI</td>
</tr>
<tr>
<td>High Energy Particles</td>
<td>OF</td>
<td>CR</td>
</tr>
<tr>
<td>Electromagnetic Radiation</td>
<td>OF</td>
<td>CR</td>
</tr>
<tr>
<td>Space Plasma</td>
<td>OF</td>
<td>ME</td>
</tr>
<tr>
<td>Atomic Environment</td>
<td>OF</td>
<td>ME</td>
</tr>
<tr>
<td>Micrometeorites</td>
<td>OF</td>
<td>CR</td>
</tr>
</tbody>
</table>

### Threats in the Medium Earth Orbit (MEO)

<table>
<thead>
<tr>
<th>Threat</th>
<th>Likelihood</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Debris</td>
<td>VS</td>
<td>LO, ME, CR, HI</td>
</tr>
<tr>
<td>Active S/C</td>
<td>VS</td>
<td>Unintentional: LO Intentional: CR, HI</td>
</tr>
<tr>
<td>Orbital Perturbations</td>
<td>VO</td>
<td>LO</td>
</tr>
<tr>
<td>CMEs/Solar Flare</td>
<td>SE</td>
<td>HI</td>
</tr>
<tr>
<td>Geomagnetic Storms</td>
<td>SE</td>
<td>HI</td>
</tr>
<tr>
<td>High Energy Particles</td>
<td>OF</td>
<td>CR</td>
</tr>
<tr>
<td>Electromagnetic Radiation</td>
<td>OF</td>
<td>CR</td>
</tr>
<tr>
<td>Space Plasma</td>
<td>OF</td>
<td>ME</td>
</tr>
<tr>
<td>Atomic Environment</td>
<td>OF</td>
<td>LO</td>
</tr>
<tr>
<td>Micrometeorites</td>
<td>OF</td>
<td>CR</td>
</tr>
</tbody>
</table>

### Threats in the Geosynchronous Orbit (GEO)

<table>
<thead>
<tr>
<th>Threat</th>
<th>Likelihood</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Debris</td>
<td>VS</td>
<td>LO, ME, CR, HI</td>
</tr>
<tr>
<td>Active S/C</td>
<td>VS</td>
<td>Unintentional: LO Intentional: CR, HI</td>
</tr>
<tr>
<td>Orbital Perturbations</td>
<td>VO</td>
<td>LO</td>
</tr>
<tr>
<td>Geomagnetic Storms</td>
<td>SE</td>
<td>HI</td>
</tr>
<tr>
<td>High Energy Particles</td>
<td>OF</td>
<td>CR</td>
</tr>
<tr>
<td>Electromagnetic Radiation</td>
<td>OF</td>
<td>CR</td>
</tr>
<tr>
<td>Space Plasma</td>
<td>OF</td>
<td>ME</td>
</tr>
<tr>
<td>Atomic Environment</td>
<td>OF</td>
<td>LO</td>
</tr>
<tr>
<td>Micrometeorites</td>
<td>OF</td>
<td>CR</td>
</tr>
</tbody>
</table>

Source: Space Environment Threats and Their Impact on Spacecrafts in Near Earth Orbits (Singh, Ariafar and Nicolas)

LMU|LA Loyola Marymount University

Luis Aguilera – Spring 2012 28
## Appendix M

### Difficulties in Enveloping Operational Environments: Radiation

<table>
<thead>
<tr>
<th>Space hazard</th>
<th>Spacecraft charging</th>
<th>Single-event effects</th>
<th>Total radiation dose</th>
<th>Surface degradation</th>
<th>Plasma interference with communications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific cause</td>
<td>Surface</td>
<td>Internal</td>
<td>Cosmic rays</td>
<td>Trapped radiation</td>
<td>Solar particle</td>
</tr>
<tr>
<td>LEO &lt;60°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>LEO &gt;60°</td>
<td></td>
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<td></td>
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<tr>
<td>MEO</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>GPS</td>
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<td>GTO</td>
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<tr>
<td>GEO</td>
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</tr>
<tr>
<td>HEO</td>
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</tr>
<tr>
<td>Interplanetary</td>
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<td></td>
</tr>
</tbody>
</table>

**Key:**
- LEO <60°—low Earth orbit, less than 60 degrees inclination;
- LEO >60°—low Earth orbit, more than 60 degrees inclination;
- MEO—medium Earth orbit;
- GPS—Global Positioning System satellite orbit;
- GTO—geosynchronous transfer orbit;
- GEO—geosynchronous orbit;
- HEO—highly elliptical orbit;
- O'—atomic oxygen

**Source:**