Rapid Coupled Loads Analysis and Spacecraft Load Reduction using SoftRide

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Present Method of Identifying Loads Issues on Spacecraft Components

- Each mission has a minimum of three coupled loads analyses (CLA)
- Preliminary
  - Spacecraft models may not be fully defined
  - Many components can have lumped mass representations in approximate locations
  - Outputs from this CLA give basic understanding of loads on the structures which provide specifications for component design
- Intermediate
  - Components are more detailed
  - Responses are more accurate
  - Any components facing loads issues must be re-designed
- Final (or verification)
  - Uses a test verified FE model of spacecraft
  - Vibration test could have been conducted with fully assembled SC or possibly use mass simulators for some components
  - Possibly too late to redesign components experiencing loads issues (too far along in development, or already built and integrated)
- This method is far too lengthy and is not responsive if a satellite is to be launched within hours or days such as those proposed by Operationally Responsive Space (ORS)
Rapid Coupled Loads Analysis and Whole Spacecraft Vibration Isolation

- To proactively mitigate coupled loads issues for the spacecraft and improve CLA response time, replace current conventional CLA with an innovative spacecraft loads analysis that relies on a large, readily available database of results
  - A wide array of existing ORS-class satellites will be used (less than 1500 lbs)
  - Database will comprise CLA results from all potential ORS launch vehicles, which include the Minotaur I, Minotaur IV, Taurus, Pegasus, Falcon I
- The database will serve a two-fold purpose:
  - Allow for quick evaluation of spacecraft responses for the chosen launch vehicle
  - Determine which size SoftRide system is necessary for the mission
    » Inputs could be simple such as SC weight, 1st modal frequency, and C.G. location
    » Outputs will be SoftRide size, revised S/C to L/V random vibration environment
- This tool will benefit the small spacecraft community since more detailed loads will be available prior to mission-specific CLA
Generation of Launch Load Mitigation Database

- Launch Vehicle Dynamic Load Cases
- Spacecraft Models + Variance Analysis
- SoftRide Isolator Models
- Multiple Coupled Loads Analyses

Launch Vehicle Dynamic Models

Launch Load Mitigation Database
Use of Launch Load Mitigation Database

- Mission-Specific Spacecraft Parameters (Weight, CG, Frequencies, Other)
- SoftRide Isolator Selected for Mission
- Launch Vehicle Designation
- Contains Embedded Information on Launch Vehicles and SoftRide
- Base-Shake Dynamic Loads Provided for Test and/or Analysis
- Math Model of SoftRide Isolator Provided
SoftRide: Whole-Spacecraft Vibration Isolation Technology

**Benefits for Spacecraft:**

1. Lower risk on launch
2. Lighter structures
3. Less launch costs
4. Higher reliability
5. Lower qual testing requirements
6. Launch on multiple launch vehicles

**Standard Mounting:**
- Spacecraft hard-mounted to launch vehicle
- Vibrations from launch vehicle transmitted directly to spacecraft

**SoftRide Mounting:**
- Spacecraft mounted to launch vehicle by isolation system
- Vibrations transmitted to spacecraft greatly reduced

SoftRide Systems can greatly reduce spacecraft dynamic responses, significantly saving time and money.
Conventional Design Methodology for SoftRide

Major constraints on design
- No dynamic interference with attitude control system
- No excessive spacecraft-to-fairing relative displacement
Typical Transient Analytical Responses
(Different SC/LVs)

Red are non-isolated transient responses
Blue are isolated transient responses
Taurus / STEX Mission
Vibration Isolation Flight Data

Flown in October 1998

Air Force stated isolation system saved NRO $5-$6M in redesign costs and 9-12 months in schedule
SoftRide Flight Heritage

- Taurus / GFO: Feb 10, 1998
- Minotaur / XSS-11: April 11, 2005
- Minotaur / MTI: March 12, 2000
- Minotaur / TacSat-2: Dec 16, 2006
- Minotaur / JawSat: Jan 26, 2000
- Minotaur / COSMIC: April 14, 2006
- Pegasus / AIM: April 25, 2007
- Delta II / OSTM: June 20, 2008
- Pegasus / IBEX: October 19, 2008
- Delta 4-H / NROL-26: January 17, 2009
- Taurus / STEX: Oct 3, 1998
- Taurus / QuickTOMS and Orbview 4: Sept 21, 2001
- Minotaur / MightySat: July 19, 2000
Typical SoftRide Isolation System Installations
UniFlex and OmniFlex Isolation Systems

UniFlex
- Low profile
- Low longitudinal stiffness
- High in-plane stiffness
- Flight heritage (9 flights to date, 1 current program)

OmniFlex
- Low profile
- Low longitudinal stiffness
- Low in-plane stiffness
- Flight heritage (4 flights to date, 6 current programs)

OmniFlex is the recommended isolator for all ORS missions

Patent # 6,199,801
Awarded March 13, 2001

Patent # 7,249,756
Awarded July 31, 2007
Conclusion

- Rapid CLA and SoftRide are both necessary to enable ORS
- This research for ORS is a benefit for all small spacecraft
  - Can provide more accurate loads information prior to a mission specific CLA
  - Can ensure a safe maximum dynamic loads environment to the spacecraft by implementing a SoftRide system