Eliminating the Need for Payload-Specific Coupled Loads Analysis (CLA)

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The Traditional Loads-cycle Process Is an Impediment to Responsive, Affordable Space Access

Objective: Predict worst-case launch loads (for low-frequency vibration)

Typically done by payload (satellite) developer

Typically done by the launch vehicle (LV) organization

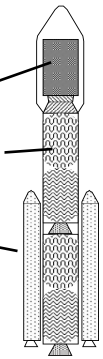
Loads Cycle

Start

Define design features

Generate component FEMs

Finite element models



Reduce models, and generate OTMs

Mathematical reduction to keep model size manageable

Output transformation matrices transform dynamic responses into meaningful output, such as member loads.

Couple models, and generate system OTM

Calculate responses to forcing functions (CLA)

- Loads
- Displacements
- Loading spectrum

Assess results

Strength, fatigue life, dynamic envelope

Modify design, if needed

A space mission typically includes at least two of these cycles, with each cycle taking between 3 and 12 months.

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Objectives for a More Efficient Alternative Approach

For launches of relatively small LV payloads,

- Eliminate the need for …
  - mission-specific CLA
  - exchanging math models between organizations
  - modal surveys and correlating math models with test data (unless needed for on-orbit jitter analysis)
  - designing a unique structural test for each payload
- while not incurring additional risk of mission failure

There's a price, of course:

Tighter constraints and (most likely) higher design loads.

We must change our mindset if we want affordable, responsive space.

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General Technical Approach

1. Define physical constraints for small launch vehicle (LV) payloads or spacecraft (S/C) payloads

Based on a study to identify desirable limits on payload natural frequencies

2. Perform variational coupled loads analysis (CLA) for the extremities of the defined payload envelope

3. Derive equivalent, single-axis design loads conducive to testing on a shaker

Simplifies the payload test process

Nonrecurring

4. Design the payload for the identified constraints and loads

5. Verify by a simple, standardized vibration test

6. Launch

Recurring

No need for payload-specific CLA, modal survey, exchange of math models, or review of structural analysis

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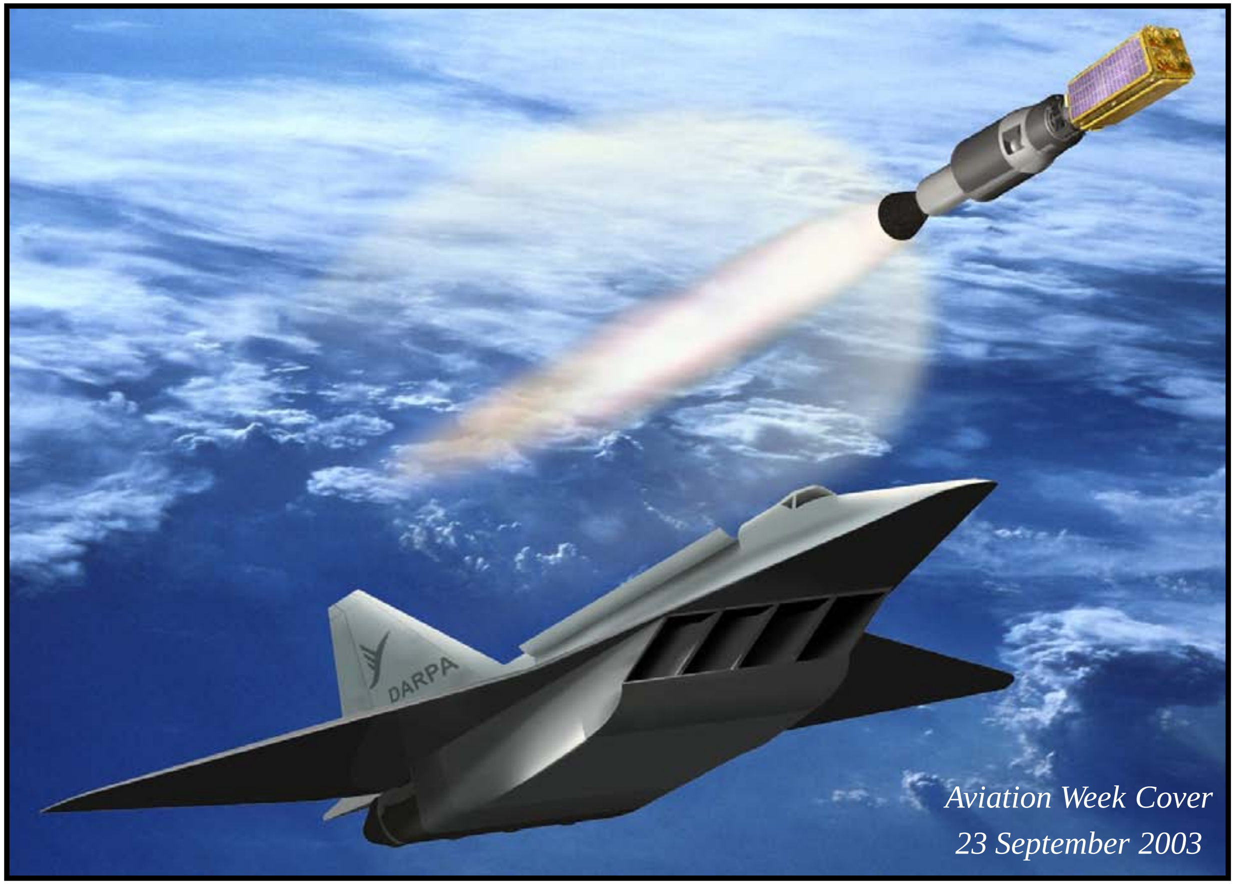
First Envisioned Use of ASD/CLAS* to Eliminate the Need for Mission-specific CLA

DARPA's RASCAL program
(Responsive Access, Small Cargo, Affordable Launch)



Aviation Week Cover
23 September 2003

- Serving as technical advisor to DARPA, Tom Sarafin introduced the idea in 2001 that RASCAL be designed such that mission-specific CLA is not necessary
  - Payload constraints
  - Vibration isolation
  - Up-front variational CLA
- Unfortunately, the program was cancelled in early 2005 before this concept could be implemented

*ASD/CLAS is commercially available CLA software developed by Applied Structural Dynamics, Inc.

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What Is an Unreasonable Design Load?

5-lb payload: 100 g's?   That's only 500 lb!

50-lb payload: 40 g's?   That's only 2000 lb!

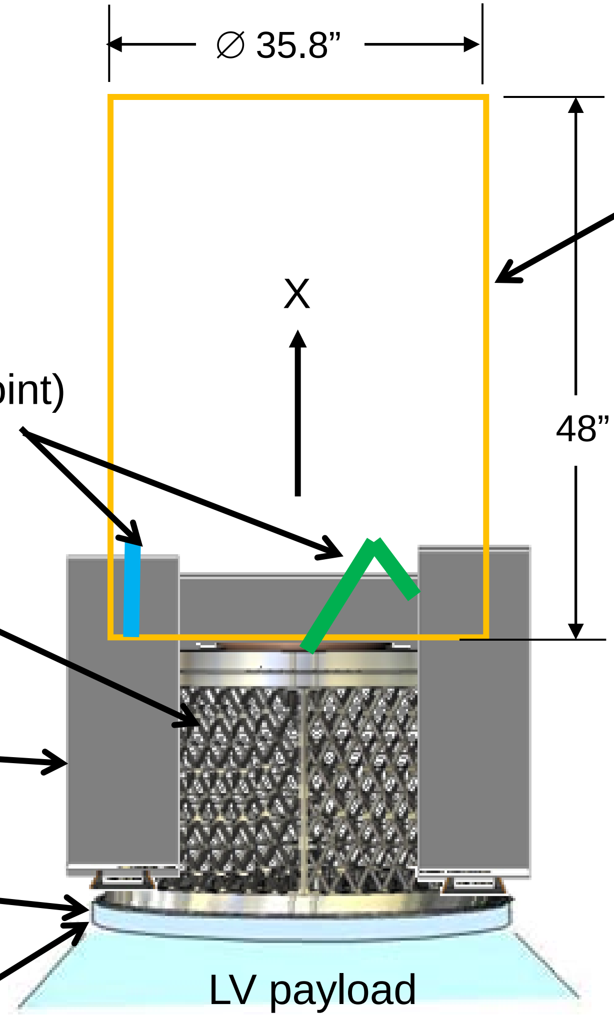
500-lb payload: 20 g's?   That's only 10,000 lb!

Two ¼"-diameter bolts will carry 10,000 lb!

For most missions, we can design satellites to loads such as these.

Responsive space has a price!

2009-2010 Project for Operationally Responsive Space (ORS)



Envelope for variable instrument (S/C payload)

Variables:

- Weight: 220 – 385 lb (mass: 100 – 175 kg
- Fundamental frequencies
- CG
- Mass moment of inertia
- Analysis performed with and without vibration isolation

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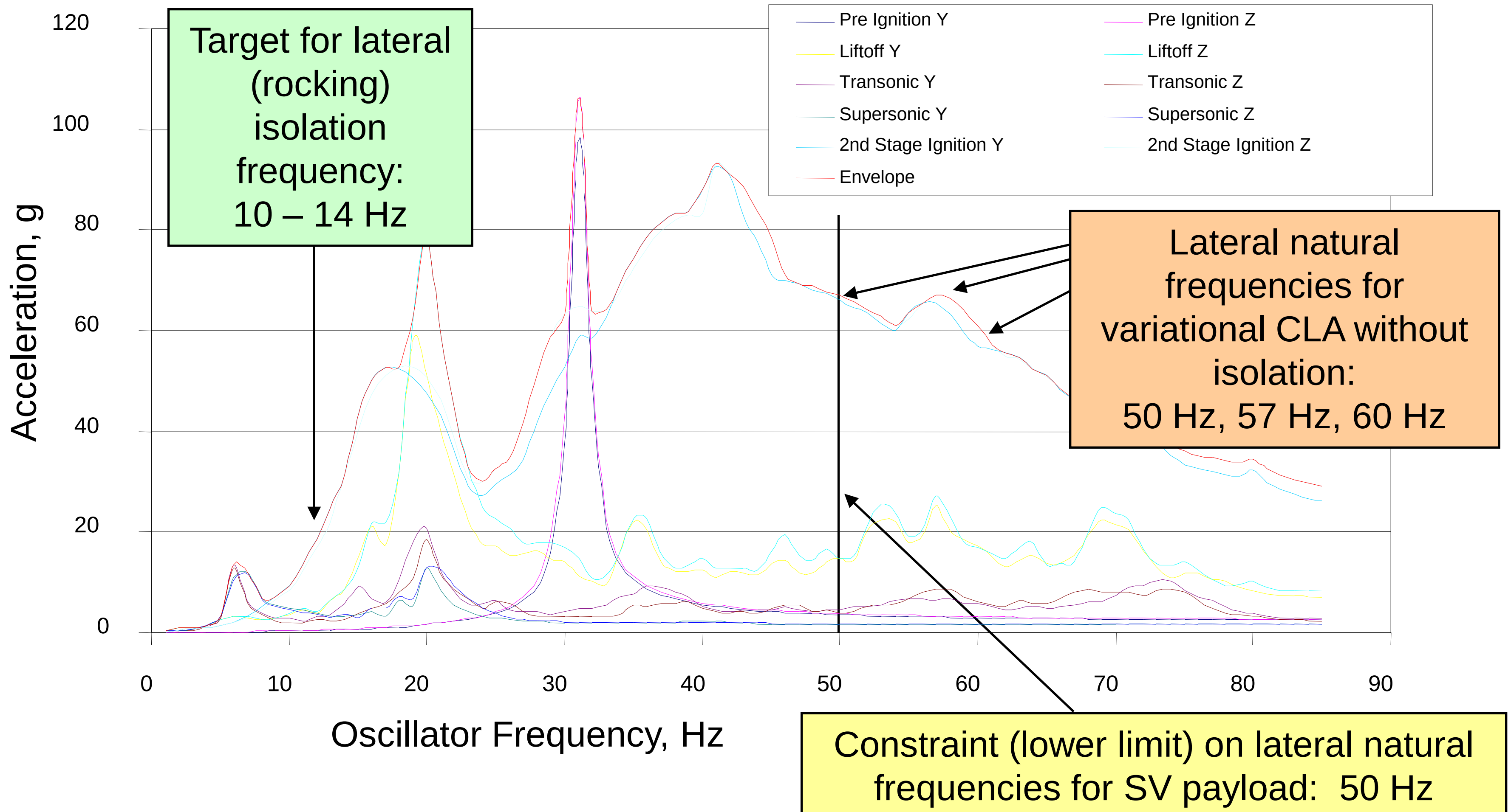
Conclusions from Pseudo-Payload CLA: Lateral Direction

To derive payload constraints and target isolation frequencies, we ran a full CLA with 0.5-lb oscillators from 1 Hz to 85 Hz, in 1-Hz increments, all three axes



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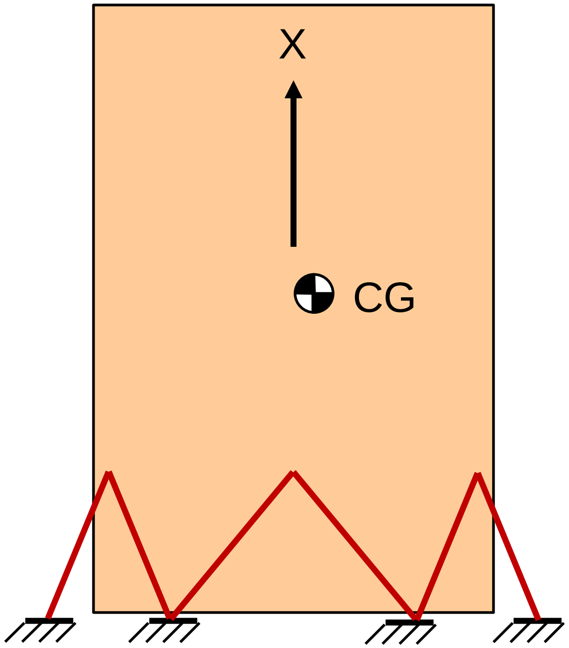
Spacecraft Payload Variations for CLA (without isolation)

- Spacecraft payload frequency constraints derived from pseudo-payload analysis (with base of mounting struts grounded):
  - Lateral frequency > 50 Hz
  - Axial (X) frequency > 60 Hz
- For variational CLA without isolation:
  - 6 combinations of max/min weight, max/min MOI (based on envelope), and max/min CG height, all with 1” lateral CG offset
  - 5 axial natural frequencies: 60, 65, 80, 85, 90 Hz
  - 3 lateral natural frequencies: 50, 57, 60 Hz



6 x 5 x 3 = 90 variations, full CLA for each

90 CLAs were performed with ASD/CLAS in approximately one day.

Results

Configuration	Payload CG Accelerations (g), absolute maxima			Equivalent Single-axis Loads (g)	
	X	Y	Z	X	Y & Z
No isolation	12.9	10.9	11.9	13.3	22.9
Isolation	5.3	4.9	4.7	12.6	10.7

The equivalent axial loads are higher than the typical 3-axis design loads for a 385-lb spacecraft payload.

This conclusion was expected, but the loads are higher than we had hoped, mostly because of the configuration we studied.

Isolation certainly makes this approach more practical.

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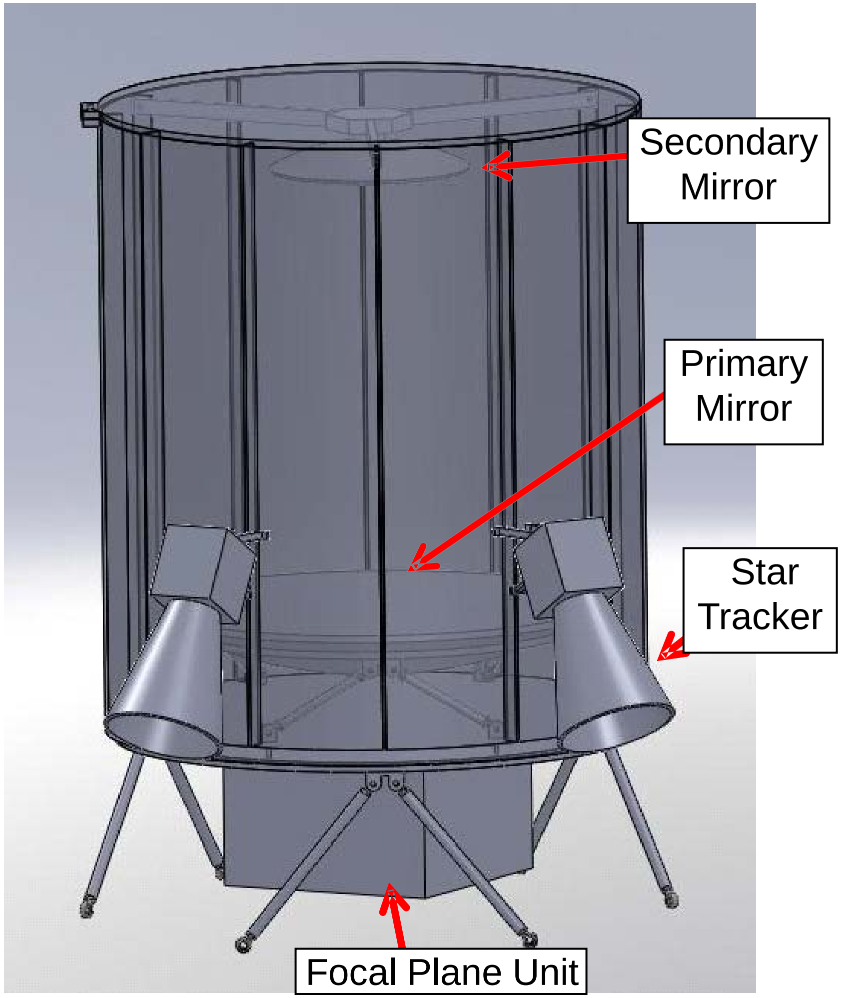
Confirmation with a Hypothetical Payload (HPL)

- We generated a conceptual design of a hypothetical S/C payload (telescope) that satisfies the defined constraints:
  - Envelope
  - Mass (175 kg) and CG (19.31” axial, 0.98” lateral)
  - Natural frequencies (50.3 Hz lateral rocking, 61.8 Hz axial)
- We set equipment modes (e.g., secondary mirror and star trackers) to be above the lower limits but below the CLA truncation frequency

Meets the derived constraints



HPL CLA Results Compared with Derived Single-axis Load Cases

(Results shown are without isolation; same conclusion applies with isolation)

Parameter	CLA	Design*	Ratio
Mounting-strut force	2307	5088	2.21
3-pt interface axial (X) force	2400	3259	1.36
3-pt I/F lateral (tangential) force	1795	6056	3.37
HPL-to-Bus I/F loads:			
ΣF_x	1918	5132	2.68
ΣF_y	2821	8837	3.13
ΣF_z	3064	8837	2.88
ΣM_y	88391	170500	1.93
ΣM_z	82666	170500	2.06

*Derived single-axis quasi-static load cases

All ratios are greater than 1, which means the load cases envelop the CLA for this hypothetical payload

Envisioned Applications

- Dedicated launches of small LV payloads (< 1000 lbs?)
  - Derive constraints and design loads, while omitting mission-specific CLA, for
    - variable LV payloads
    - variable S/C payloads or equipment with a standard bus structure
- Rideshare missions
  - Account for variations in manifest and variations in secondary payloads
  - Use variational CLA to derive constraints on secondary payloads to ensure they don't affect the primary payload
- Large payloads
  - Perform variational CLA for a large LV payload
    - Determine sensitivity associated with uncertainty in math models
    - Use loads envelope for design instead of blanket uncertainty factors
    - Reduce risk and weight (more efficient structural design)

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Conclusions

- **We have successfully demonstrated that this process is feasible**
  - **Eliminates the need for time-consuming cycles of coupled loads analysis (at least for the primary structure)**
    - **Practical for relatively small LV payloads**
    - **Less practical for large LV payloads**
  - **Greatly simplifies the structural verification process**
  - **Does not incur technical risk—actually reduces risk**
- **We can modify the process to address secondary structures and payload equipment**
- **There are many potential applications**