Delta II MECO: A High-Frequency High-Force Event

Presented at the

S/C & L/V Dynamic Environments Workshop

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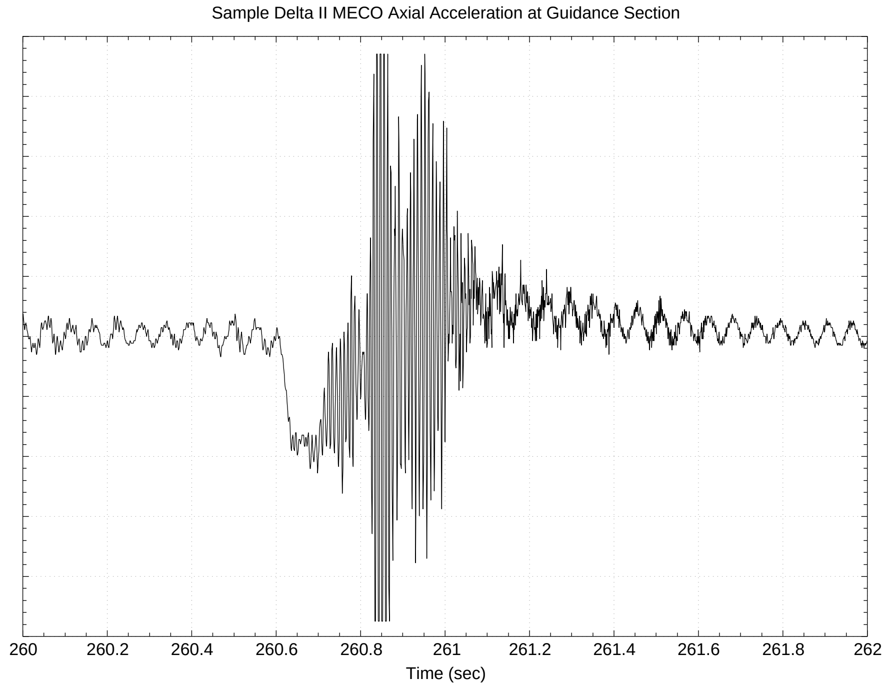
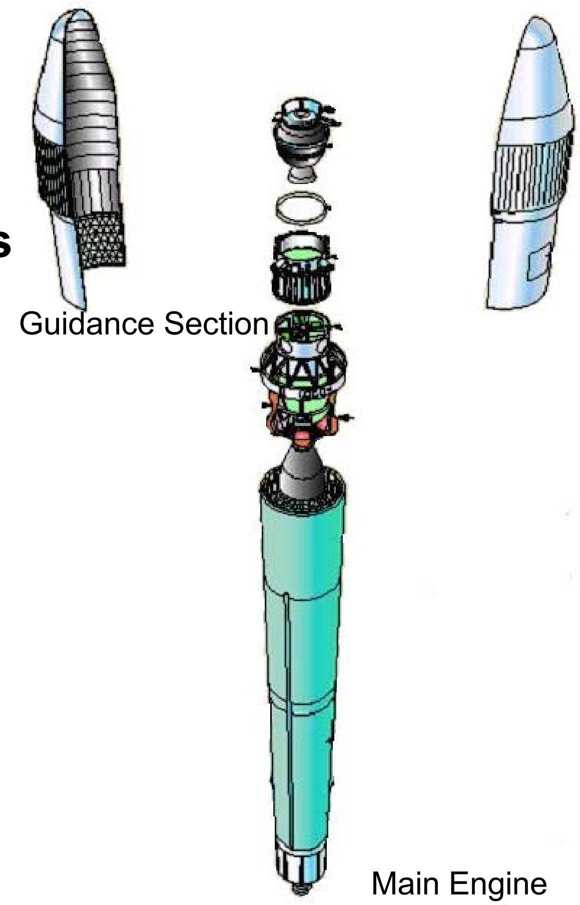
Outline

- Introduction
- Flight Data Shows MECO is Real
- Analysis Approach
- Test Approach
- Broader Implications

Introduction

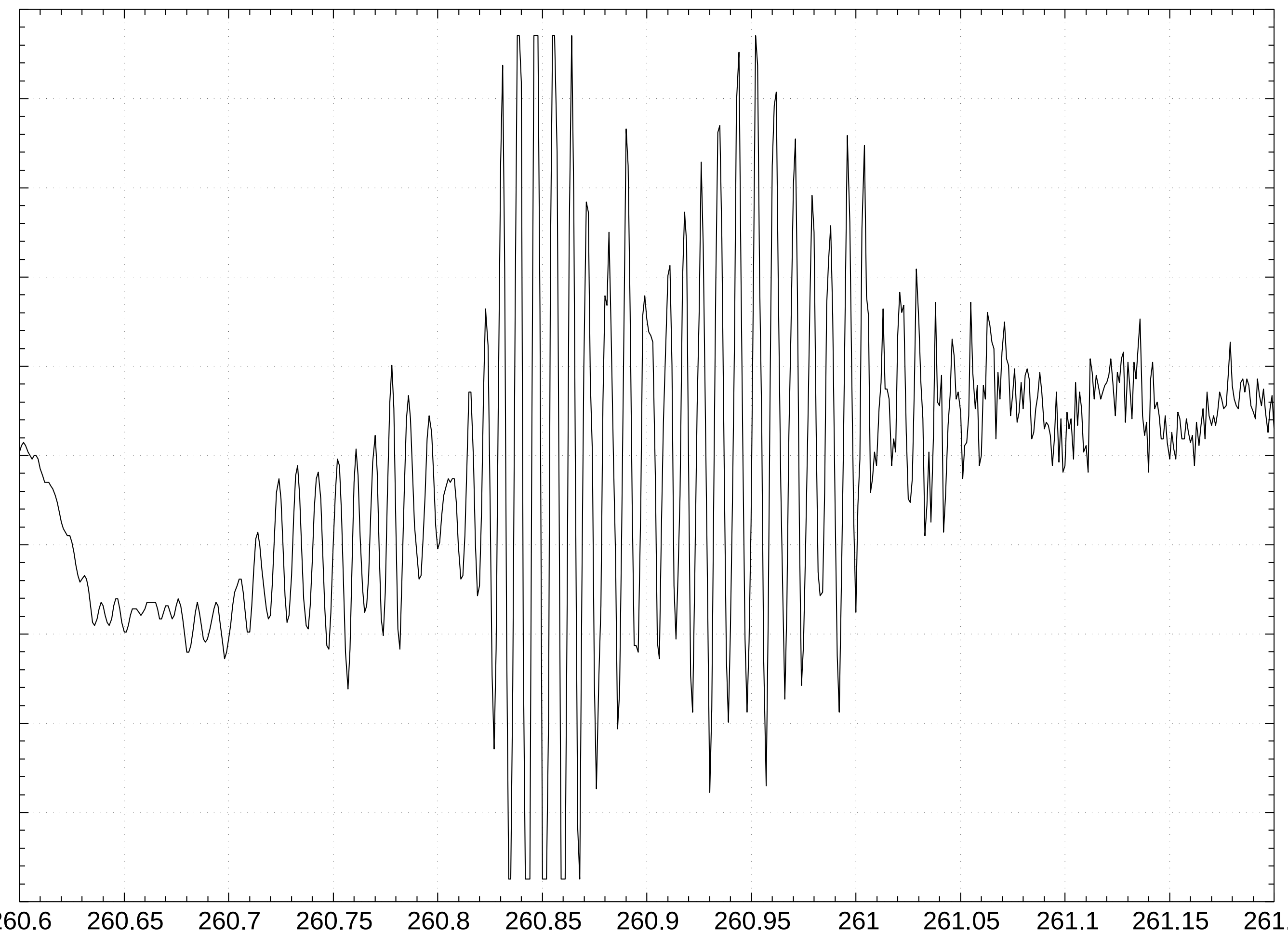
- **Delta II MECO is First Stage Main Engine Cut-off**
- **MECO is a three phase event:**
  - **Prior to MECO, oscillations are seen at 16-18 Hz**
  - **The steady state thrust drops off (MECO)**
  - **Post MECO, high frequency (115 Hz) oscillations occur for 0.2 seconds**





Introduction

Sample Delta II MECO Axial Acceleration at Guidance Section



Introduction

- MECO was always known to exist at ~120 Hz
  - Industry standard:
    - » Sine specification addressed environments below 100 Hz
    - » Shock and acoustic specifications addressed environments above 100 Hz
- In January 2002, a Boeing equivalent sine study showed:
  - MECO was higher than expected, particularly for last few missions
    - » Preliminary results suggested 4.1 g's axially at 115 Hz (using a Q of 10)
  - MECO is primarily a sinusoidal event (like a sine burst)
- The Questions for this Presentation:
  - Is an event like this a driver for spacecraft loads?
  - How do we assess this analytically?
  - How do we test for this?

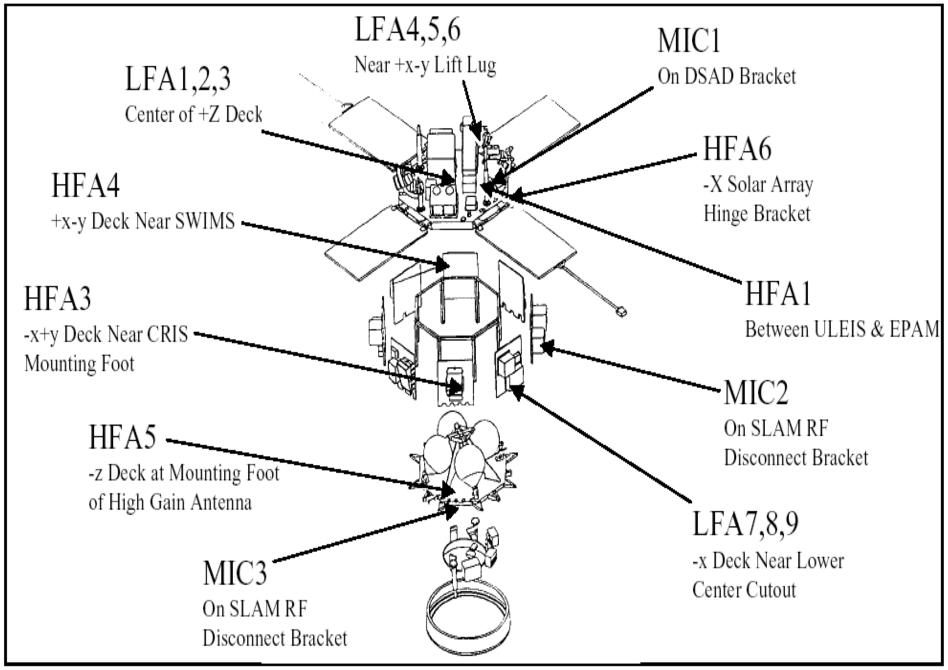
Note: This presentation focuses on the spacecraft environment. MECO is also an issue for the launch vehicle. However, the LV has the advantage of having flown successfully through many MECO's. Therefore, the solution approach is different for the LV than the spacecraft. The LV has been assessed by Boeing and KSC for MECO.

Can MECO Drive Spacecraft Loads?

- **Typical S/C response on being informed of MECO:**
  - **Disbelief**
- **This is natural reaction given the current industry standards:**
  - **Loads above 100 Hz are due to direct acoustics or structure borne random vibrations due to acoustics or shock**
  - **Significant sinusoidal loads above 100 Hz are non-existent**
  - **Structure will attenuate any high frequency input**

Can MECO Drive Spacecraft Loads?

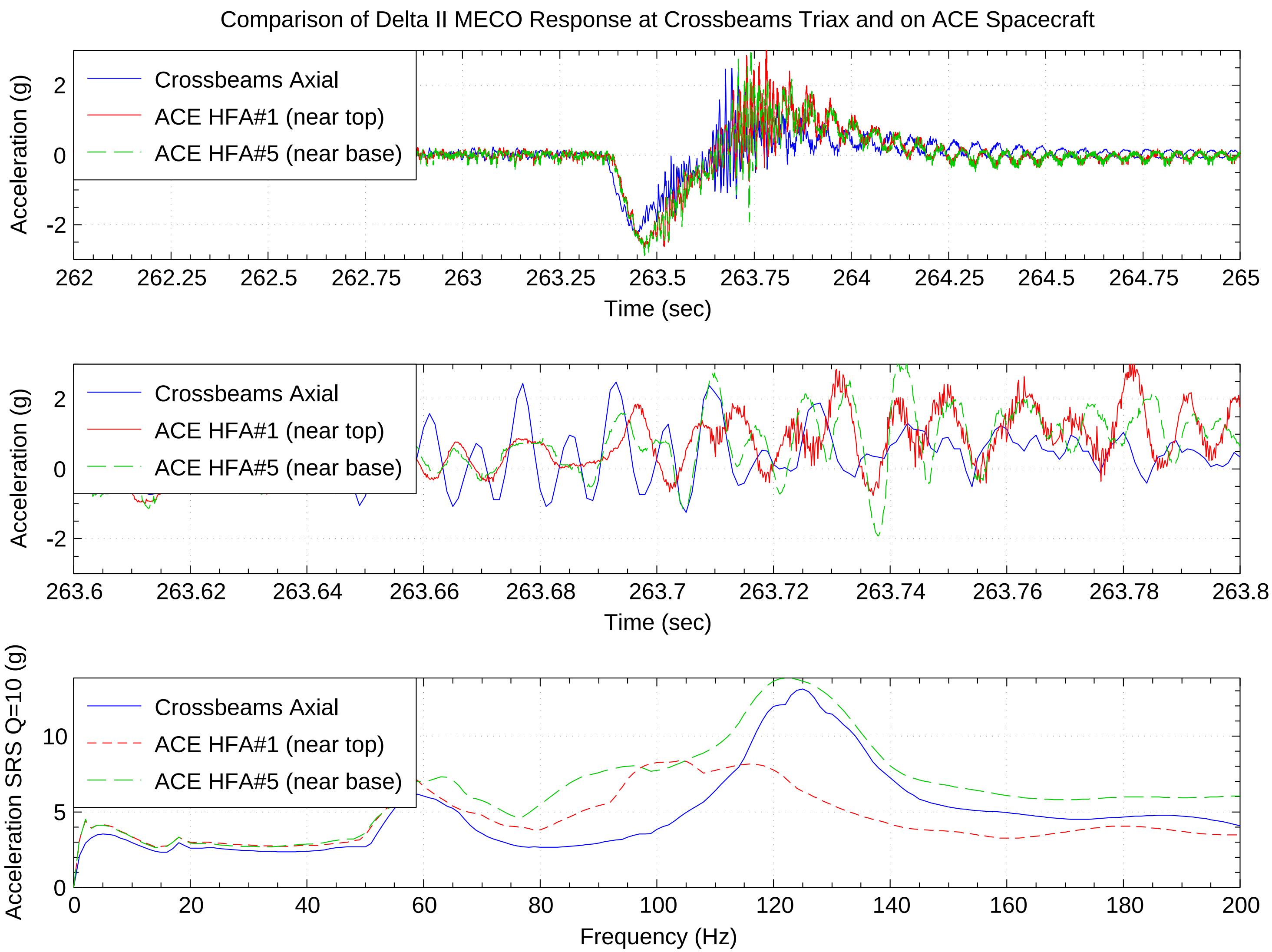
- In 1997, NASA (GSFC/APL) flew the ACE spacecraft with 5 high frequency accels & 9 low frequency (100 Hz) accels on a Delta II



High Freq Accel on +Z Dk, Btwn EPAM & ULEIS	HFA1
High Freq Accel Channel to be used for CRIS Load Cells	HFA2
High Freq Accel on -X+Y Dk, @ Base of CRIS	HFA3
High Freq Accel on +X-Y Dk, Near SWIMS	HFA4
High Freq Accel on -Z Dk, @ Mtg Foot of High Gain Ant	HFA5
High Freq Accel on -X Solar Array Hinge Bracket	HFA6
Low Freq Accel on +Z Dk, Ctr	LFA1(+x)
Low Freq Accel on +Z Dk, Ctr	LFA2(+y)
Low Freq Accel on +Z Dk, Ctr	LFA3(+z)
Low Freq Accel on +Z Dk, -Y Side	LFA4(+x)
Low Freq Accel on +Z Dk, -Y Side	LFA5(+y)
Low Freq Accel on +Z Dk, -Y Side	LFA6(+z)
Low Freq Accel on +Z Dk, Lwr Ctr	LFA7(-x top)
Low Freq Accel on +Z Dk, Lwr Ctr	LFA8(-y side)
Low Freq Accel on +Z Dk, Lwr Ctr	LFA9(+z)

- Data shows that Guidance Section axial accel is the same order of magnitude as spacecraft accels and SRS's are similar
- Low frequency (<100 Hz) accels did not capture MECO at all
- Indication: MECO could drive spacecraft internal accelerations

Can MECO Drive Spacecraft Loads?



Can MECO Drive Spacecraft Loads?

- Boeing developed high frequency models of the LV and coupled with a high frequency ACE model
  - Good comparison to flight data was achieved
  - LV&SC coupled system global mode transmits main engine input
  - Axial interface force is same order of magnitude as low frequency CLA axial force
  - Indication: MECO could be a high force input to spacecraft
- Physical explanation (maybe):
  - Possible instability in chamber as engine valves are closed and LOX and fuel are depleted
  - Sufficient main engine force is produced to drive entire system as seen by all LV instrumentation recording MECO event
  - Exact cause has not been determined: some engines have demonstrated higher shutdown transients than others (2x)
  - Indication: MECO excites entire vehicle and is expected every flight with unknown magnitude.

Can MECO Drive Spacecraft Loads?

- **Conclusions:**
  - Data to fully define MECO effect on SC is limited
  - Conservative approach is required
  - MECO shutdown transient is transmitted through the LV structure and into the spacecraft as seen by ACE accelerations
  - MECO can generate sufficient force to resonate even large spacecraft components as seen by LV/SC simulations and LV flight data
  - MECO must be treated as a high-force high-frequency event

Analysis Approach

- **Typical CLA <50 Hz, MECO ~ 115 Hz**
- **Most S/C models valid <100 Hz (at best)**
  – Not just a question of running the model higher but of model fidelity
- **Two staged approach:**

1. Present levels to SC as equivalent sine
   Base drive 150 Hz S/C model to equivalent sine levels
   - A broad sweep at peak levels is used in lieu of a MUF
   - Approach very conservative but prevents uncertain analysis

If any loads issues are identified, then:

2a. Force limited base drive
   - Force limits based on coupled LV and SC model
   - Methodology demonstrated as conservative on ACE S/C
   - A broad sweep at peak levels is used in lieu of a MUF

2b. Coupled LV & SC system transient analysis using flight data
   - Reconstruction demonstrated as accurate on ACE data
   - Methodology demonstrated as conservative on ACE data

Note: This approach and the analysis methodologies are subject to change

Test Approach

- Long term test plan not in place
  - Would like to develop good (i.e. as realistic as possible) levels to incorporate into instrument testing and/or system level testing
  - All suggestions welcome

- Short term test plan is for S/C to perform low level testing up to 150 Hz to:
  - Determine coupled system frequencies for components
  - Determine component damping for accurate evaluation

- Model correlation is not required but frequencies and damping may be needed to clear some components that have high loads created by the broadband input
  - Broadband input only used to capture model uncertainty

Broader Implications

- Delta II MECO establishes that high-frequency high-force structure borne inputs are possible and real
- A safe test qualification method is needed for spacecraft subject to this type of excitation
- An open mind is needed to see and recognize this reality sooner
- An open mind is needed to see other “outside the box” issues
  - Too much “standards” and “our way of doing business” doesn’t always work