A New Large Vibration Test Facility Concept for the James Webb Space Telescope

28th Space Simulation Conference

November 3-6, 2014

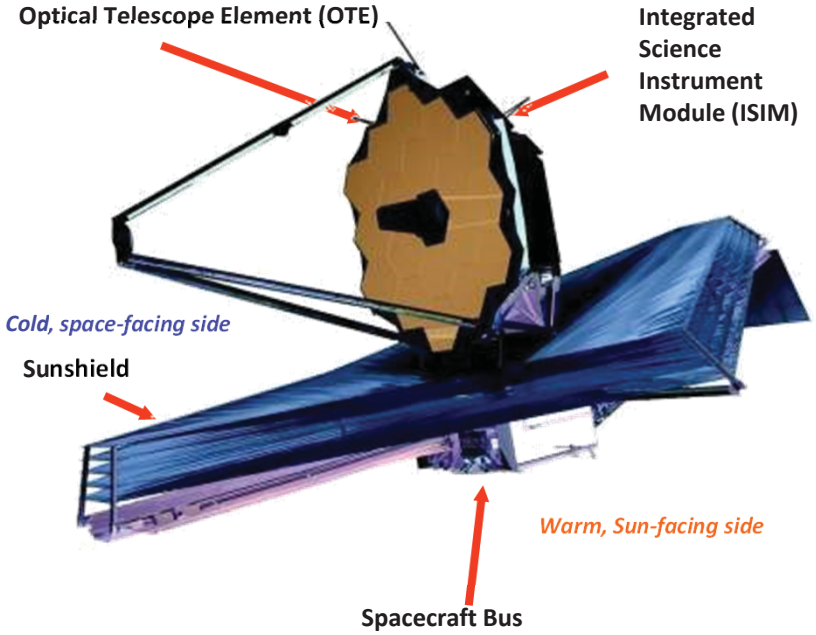
James Webb Space Telescope (JWST)

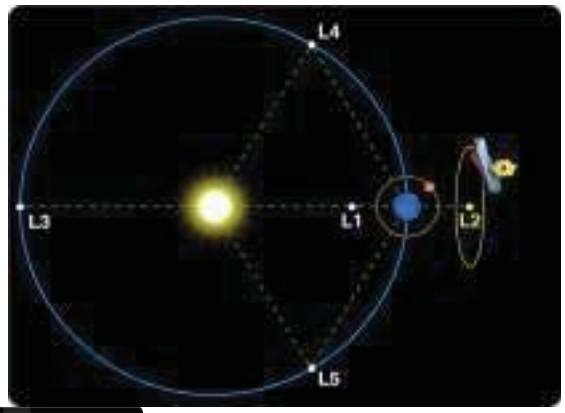
Mission Objective

- Study the origin and history of galaxies, stars and planetary systems
  - *Optimized for infrared observations (0.6 – 28 μm)*

Organization

- Mission Lead: Goddard Space Flight Center
- International collaboration with ESA & CSA
- Prime Contractor: Northrop Grumman Space Technology
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) – CSA





Description

- Deployable telescope w/ 6.5m diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch on an ESA-supplied Ariane 5 ECA rocket to Sun-Earth L2

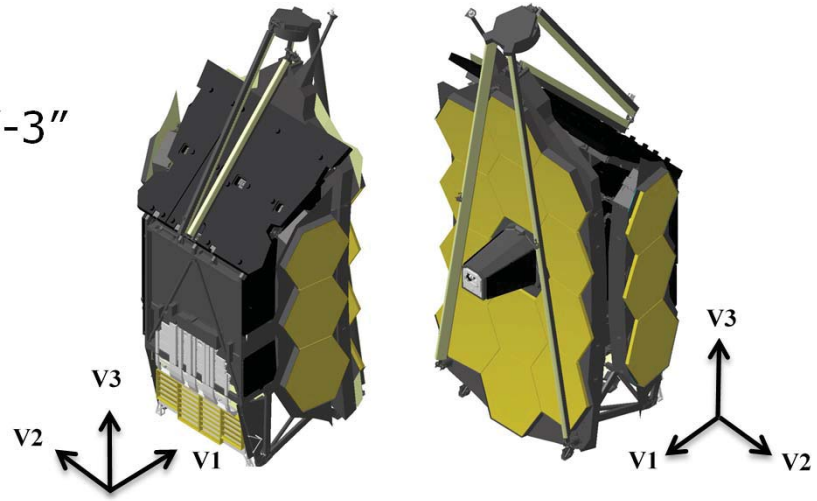
Need for a New Facility

- Goddard is assembling the OTE and ISIM Elements of JWST
  - Together the **OT**E + **IS**IM is called OTIS
  - OTIS is the cryogenic portion of JWST that is launched at ambient temperature
- The OTIS needs to be subjected to a sine vibration test
  - Qualification test for the low frequency spectrum of launch environment
  - Verify workmanship
- Current vibration facilities are inadequate because:
  - Predicted dynamic overturning moment during axial test due to OTIS lateral cg offset exceeds current facility capabilities
  - OTIS physical size
    - 131”x131” shaker mounting interface
    - Issues with current test cell access and hook height

Team corporation dp Data Physics

Critical Requirements

- Test article size
  - OTIS envelope: 8’-5” x 7’-10” x 28’-3”
  - OTIS mass: 8,686 lbs
  - Fixture mass: 6,200 lbs
- Cross-axis motion
  - Bare Table: <10%
  - OTIS Payload: <40%
- Overturning moment capacity
  - Must react moments simultaneously

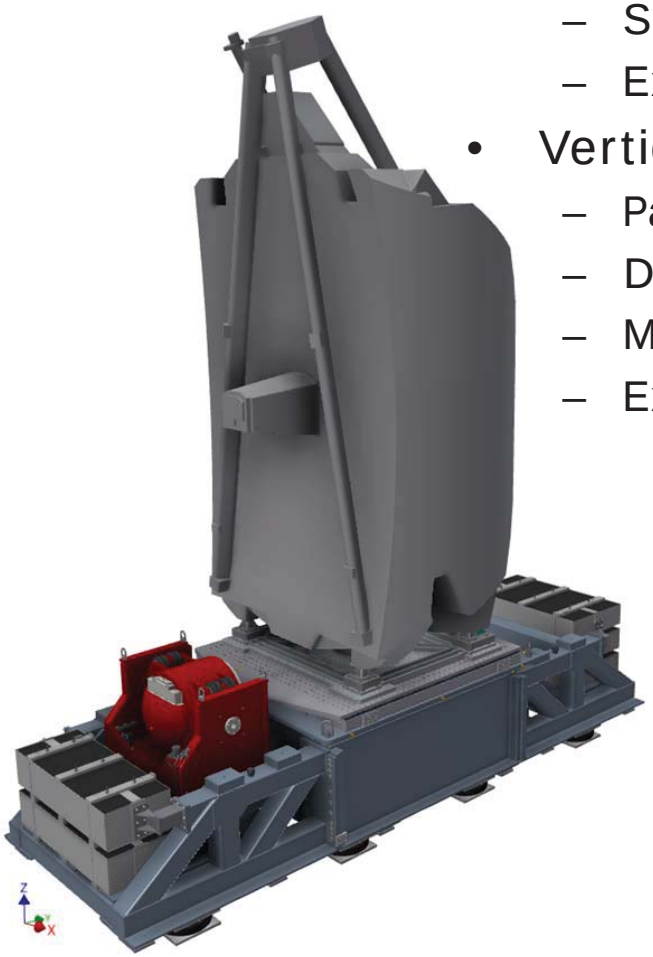


	Horizontal	Vertical
Pitch	3.50e6 in-lbf	1.30e6 in-lbf
Roll	180,000 in-lbf	400,000 in-lbf
Yaw	50,000 in-lbf	300,000 in-lbf

Axis	Frequency (Hz)	Test Level (zero to peak)
V1	5-50	1.00 g
	50-80	1.25 g
	80-100	1.00 g
V2	5-50	1.00 g
	50-60	1.50 g
	60-80	1.00 g
	80-100	1.50 g
V3	5-20	1.50 g
	20-40	0.75 g
	40-60	1.25 g
	60-100	1.00 g

Dual Shaker Systems

- Horizontal system
  - T-film slip table system
  - Single ED shaker
  - Excite V1 & V2 axis
- Vertical System
  - Patented inertial mass guidance
  - Dual ED shakers
  - MIMO control
  - Excite V3



Team corporation

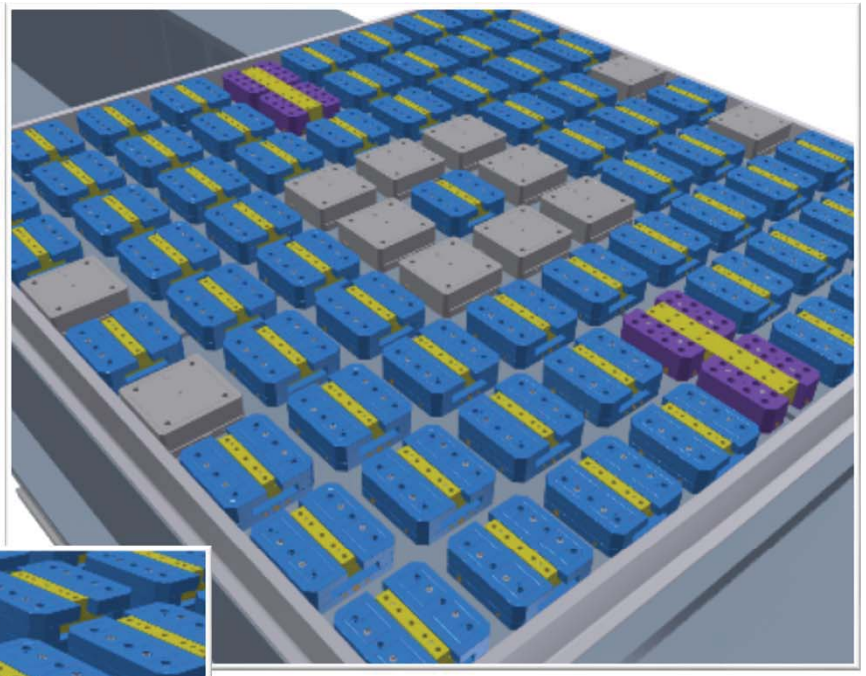
Data Physics

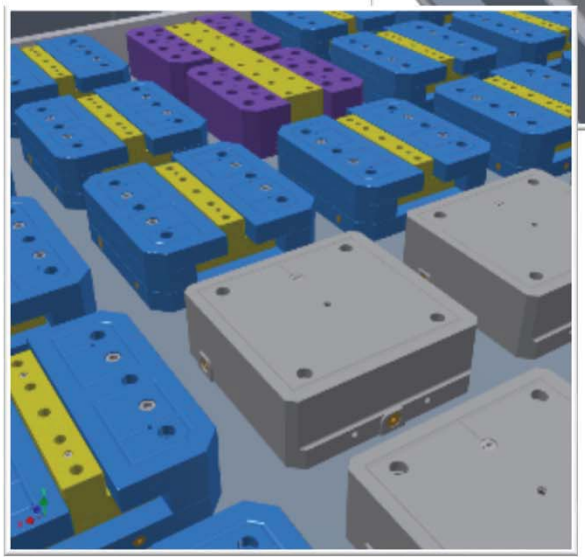
Horizontal Vibration System

- Design Concept: T-Film slip table with high rotary inertia reaction base
  - Expansion of standard Team T-Film Table to accommodate extremely large overturning moments
- Design Components:
  - Electrodynamic Shaker
    - Single 50,000 lbf shaker
    - Air isolated trunnion mount
  - T-Film Table
    - Hydrostatic Bearings
    - Couples overturning moments into reaction base
  - Reaction Base
    - High rotary inertia
    - Air isolated
    - High density concrete masses

Horizontal System – Hydrostatic Bearings

- T-Film Bearings
  - Fundamental element in Team slip tables
  - Reacts roll and pitch moments
  - Placed in load path from OTIS to reaction base
- Yaw Bearings
  - Reacts yaw moment
  - Guides slip plate in shaker axial direction
- Filler Elements
  - Static load support
  - Do not react moments
- 5-degrees of control





Horizontal System – Moment Factor of Safety

- Rated dynamic load of Team bearings:
  - T-Film Bearings: 19,500 lbf
  - Yaw Bearings: 16,000 lbf
- Pitch and Roll overturning moments are reacted by T-Film bearings
- Yaw moment reacted only by Yaw bearings
- LVTS simultaneous moment requirement:
  - Pitch: 3.5e6 in-lbf
  - Roll: 180,000 in-lbf

	Moment Capacity
Pitch	13.0e6 in-lbf
Roll	10.7e6 in-lbf
Yaw	1.89e6 in-lbf

$$M_{ratio} = \frac{M_{P.app}}{13e6} + \frac{M_{R.req}}{10.7e6} < 1.0$$

- Applied simultaneous roll & pitch moment must satisfy given inequality

$$M_{ratio} = \frac{3.5e6}{13e6} + \frac{180{,}000}{10.7e6} = 0.286$$

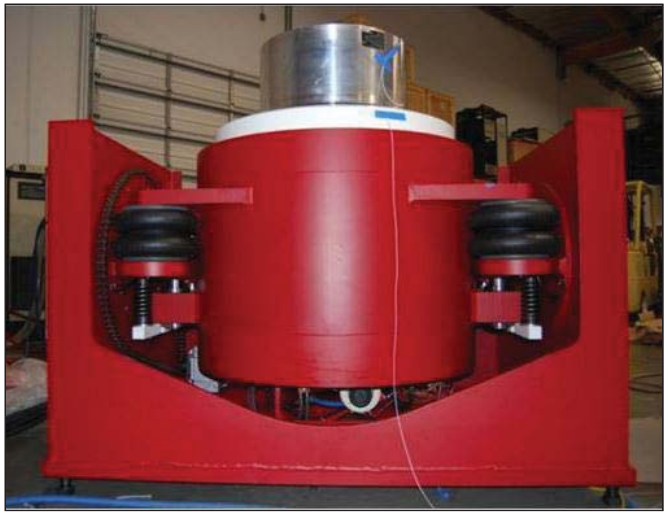
- Factor of Safety on simultaneous moments & yaw moment

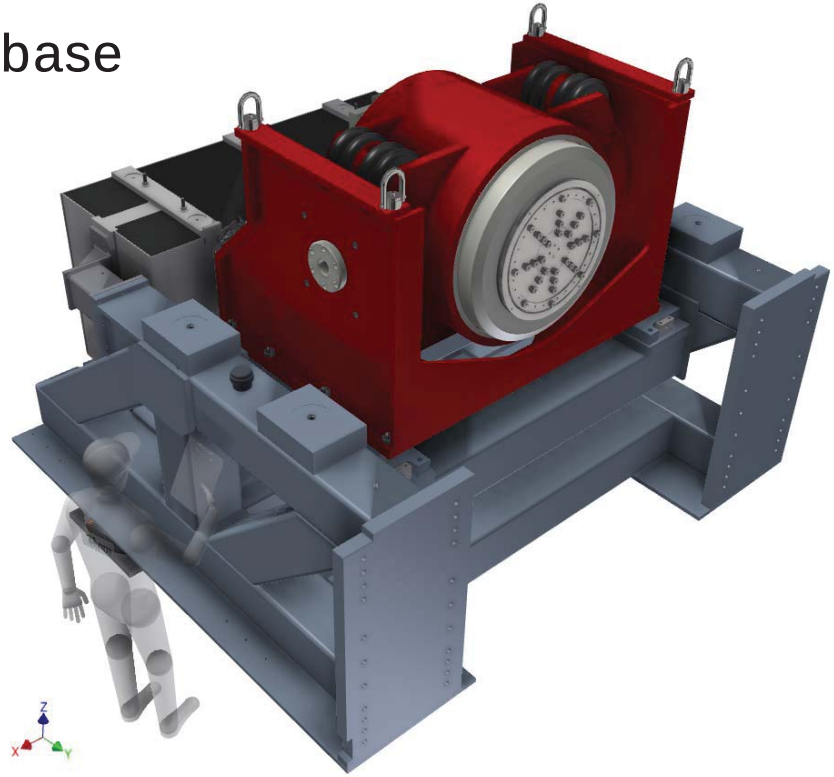
$$N_{roll-pitch} = \frac{1}{M_{ratio}} = 3.5$$

$$N_{yaw} = \frac{M_{y.all}}{M_{y.req}} = \frac{1.89e6}{500{,}000} = 3.8$$

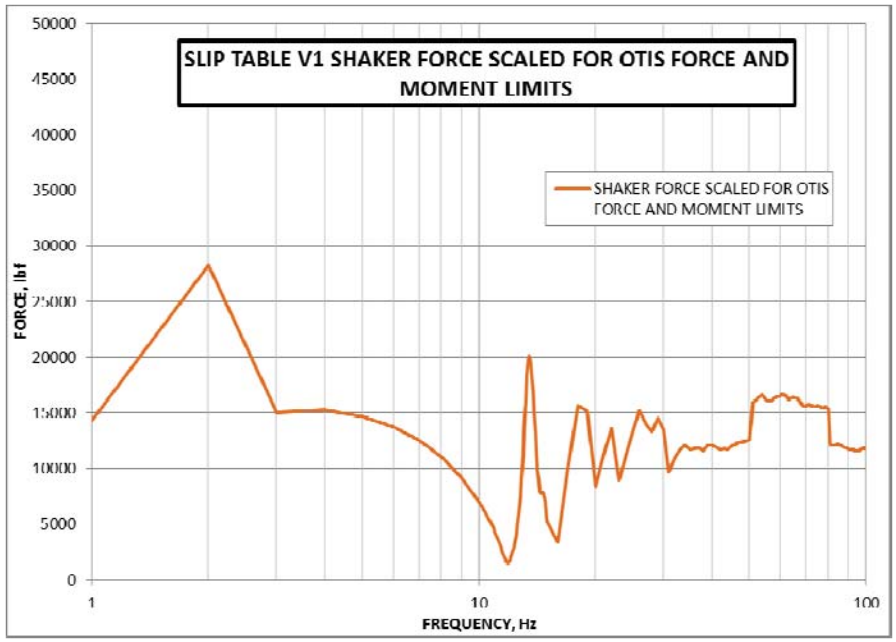
Horizontal System – Electrodynamic Shaker

- Single Data Physics LE-5022 – 50,000 lbf shaker
- Air isolated trunnion mount
  - Low natural frequency (1.7-2.0 Hz)
- Shaker Body Mass = 14,535 lbm
- Shaker body provides sufficient reaction mass
- Mounted to horizontal reaction base

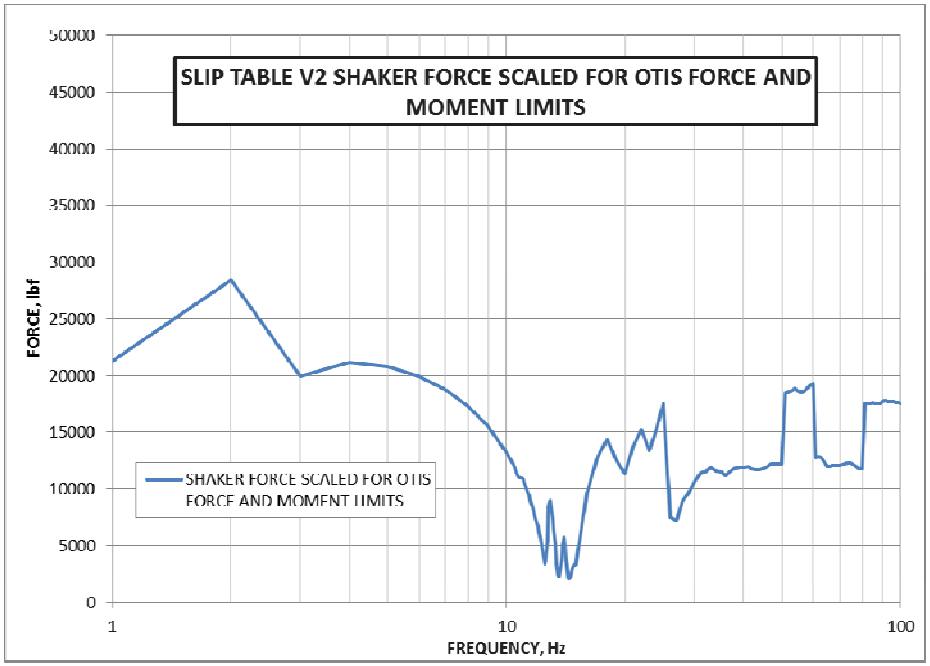




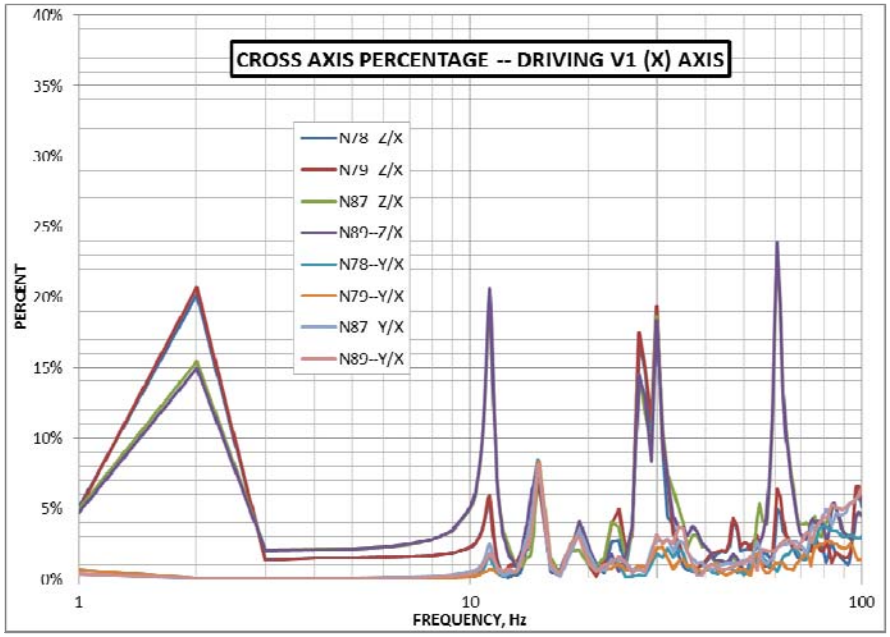
Horizontal System – Shaker Force – V1 & V2 Axes

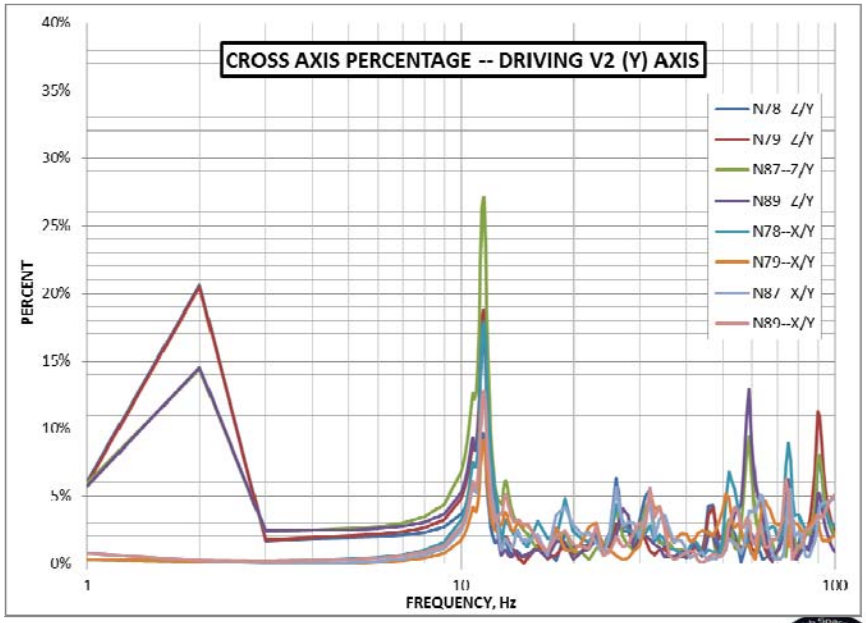


- Otis payload & fixture mass
- Incorporates force limits as notches in test profile near OTIS modes
- Plots FEM force vs. frequency
- Peak shaker force ~ 22,000 lbf
- Approximate margin of 2 on shaker force



Horizontal System – Cross Axis Motion w/ OTIS

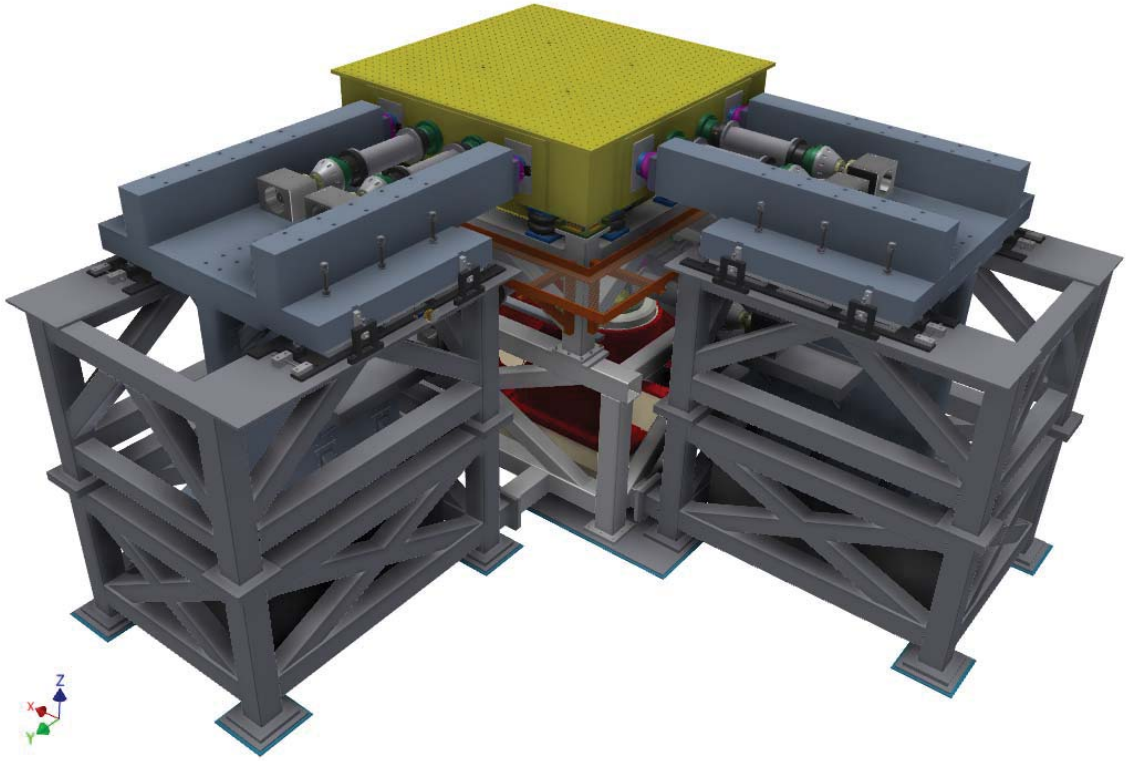




- Driving Both orientations
- Ratio of lateral and vertical acceleration relative to axis being driven
- Measured at four OTIS interface nodes
- Response down to 1 Hz
  - Accounts for air isolators
- Peak response inside required bandwidth is below 24% & 27% for driving V1 & V2, respectively

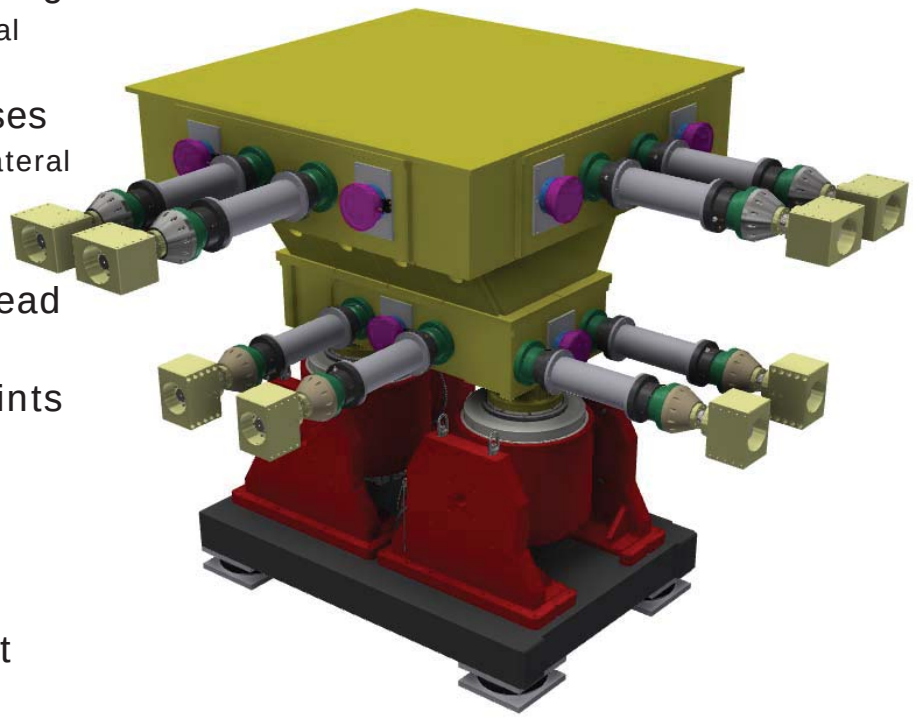
Vertical Vibration System

- Design Concept: Inertial Mass Guided Head Expander
  - Expansion of a patented system delivered to Orbital Sciences in support of the Dawn Program
  - Reduced Cross-Axis motion from 250% down to 14%
  - US Patent 7,267,010 B2
- Design Components:
  - Electrodynamic Excitation
    - Dual 50,000 lb shakers
  - Guided Head Expander
    - Transmits energy from shaker to test article
  - Inertial Masses
    - React moments generated by test article
  - Hydrostatic bearings
    - Provides short, stiff load path into masses
  - Air Isolated Supports
    - Isolates vibration system from building

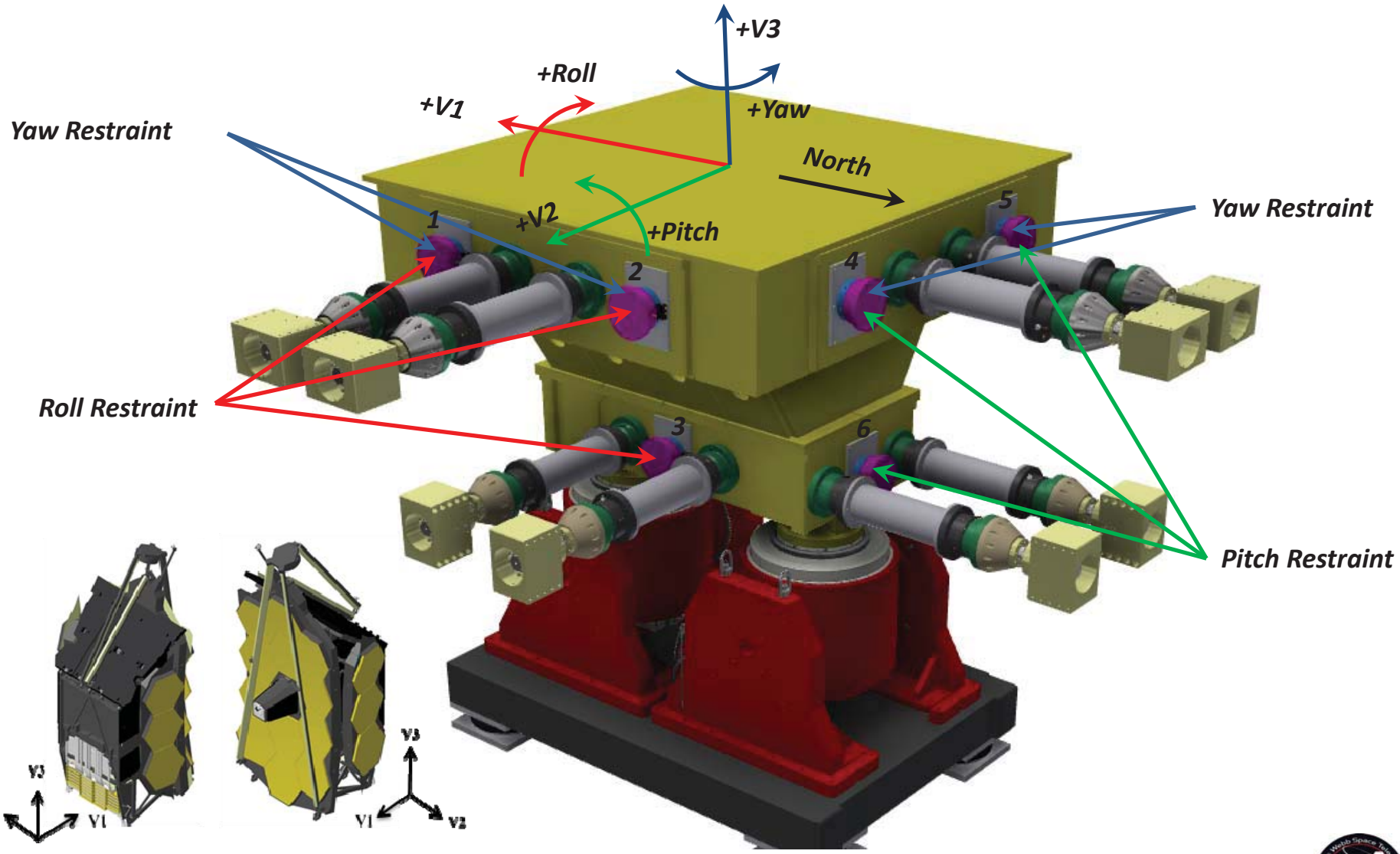


Vertical System – Guidance Mechanism

- Inertial masses located close to head expander
  - Minimizes dynamics of restraining structure
  - Inertial masses located on two sides of the head expander
  - Independent masses – NO precision aligning required
  - Each mass constrains 3-DOF – together constrain 5-DOF
- Head expander coupled to masses via pad bearings
  - Three pad bearings per inertial mass – define a vertical plane
- Pad bearings provide a stiff connection to masses
  - Each constrain 1-DOF, allow 5-DOF (3 rotations & 2 lateral translations)
- Pad bearings require an external preload
- Preload actuator and spherical couplings pull head expander against pad bearings and masses
- Dual spherical couplings act as ball & socket joints on each end
- Preload actuator acts as constant force, low stiffness spring
- Spherical couplings allow for vertical motion
- Low spring stiffness of actuator allows for slight axial motion required due system geometry & kinematics
- **End result** – 1-DOF guided head expander with extremely low cross-axis motion



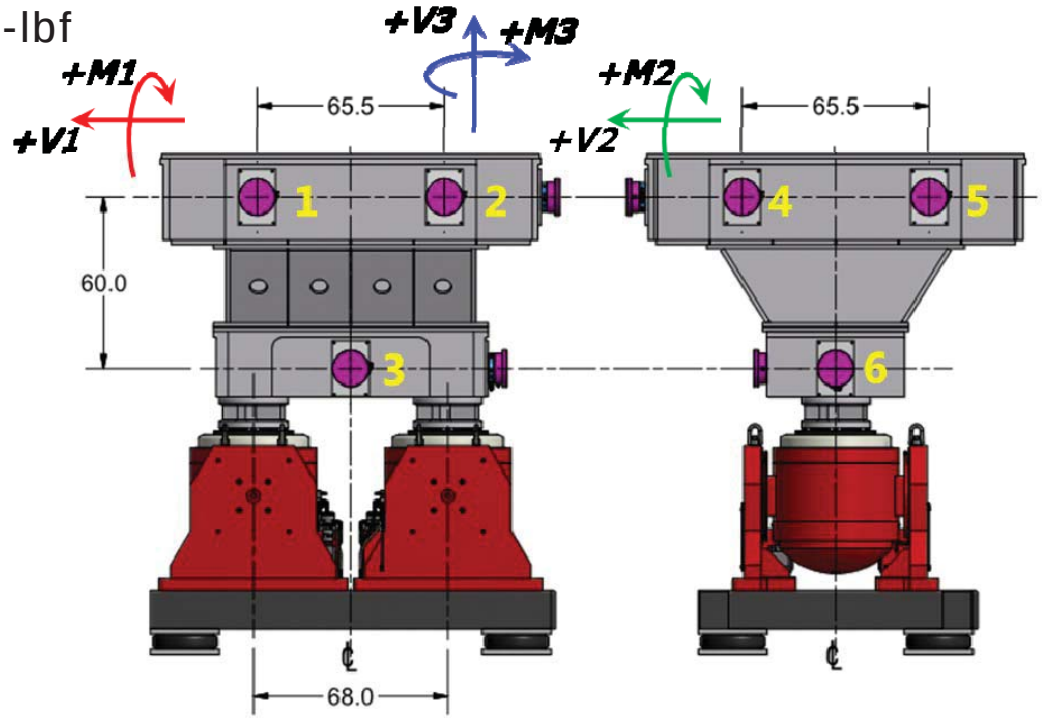
Vertical System – Pad Bearing & Preload Actuator Configuration



Vertical System – Moment Factor of Safety

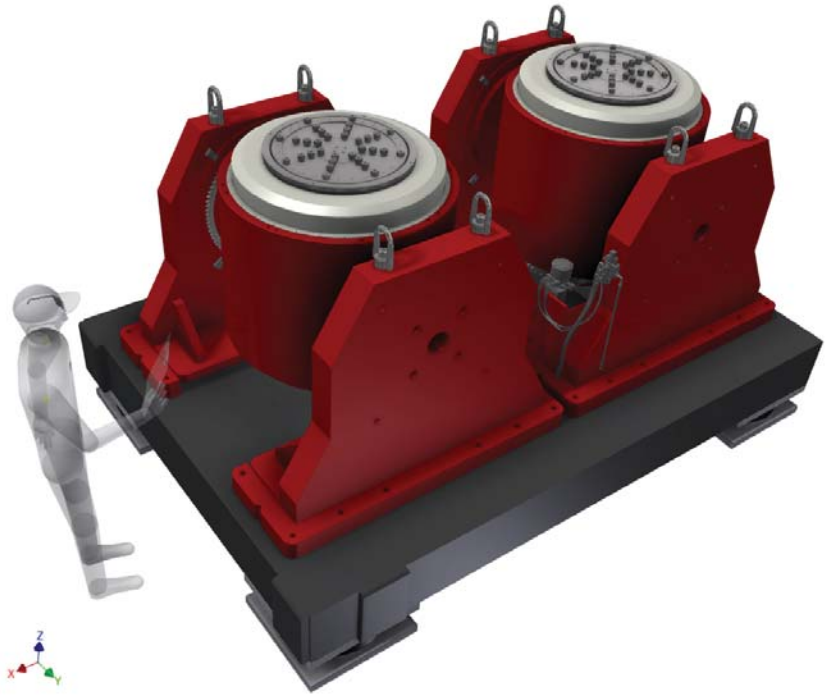
- Pad capacity is defined by applied preload – pad must remain in compression
- Upper pad bearing preload: 24,200 lbf each – two upper pads
- Lower pad bearing preload: 48,400 lbf
- Each mass reacts either Roll (M_1) or Pitch (M_2)
- Both masses react Yaw (M_3)
- M_1 & M_2 single axis capacity: 2.90e6 in-lbf
- M_3 single axis capacity: 3.17e6 in-lbf
- Simultaneous moments
  Factor of Safety: 1.84

Axis	Capacity	Requirement
M_1 (Roll)	2.9e6 in-lbf	1.3e6 in-lbf
M_2 (Pitch)	2.9e6 in-lbf	400,000 in-lbf
M_3 (Yaw)	3.17e6 in-lbf	300,000 in-lbf



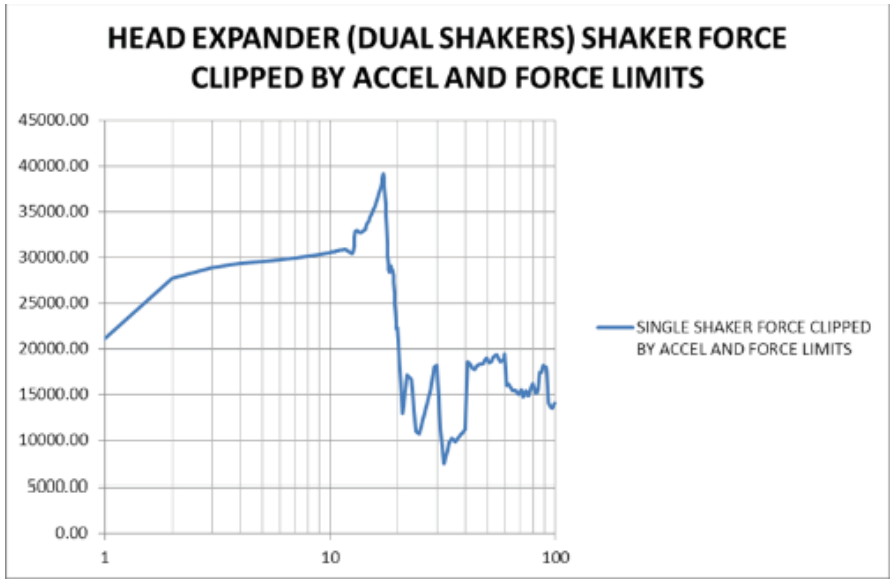
Vertical System – Electrodynamic Shaker

- Dual Data Physics LE-5022 50,000 lbf shakers – 100,000 lbf total
- Rigid trunnion mount, each shaker
- Shaker Body Mass = 22,500 lbm (each)
- Additional mass required to reduce body motion and remain within shaker stroke limits
- Common shaker base

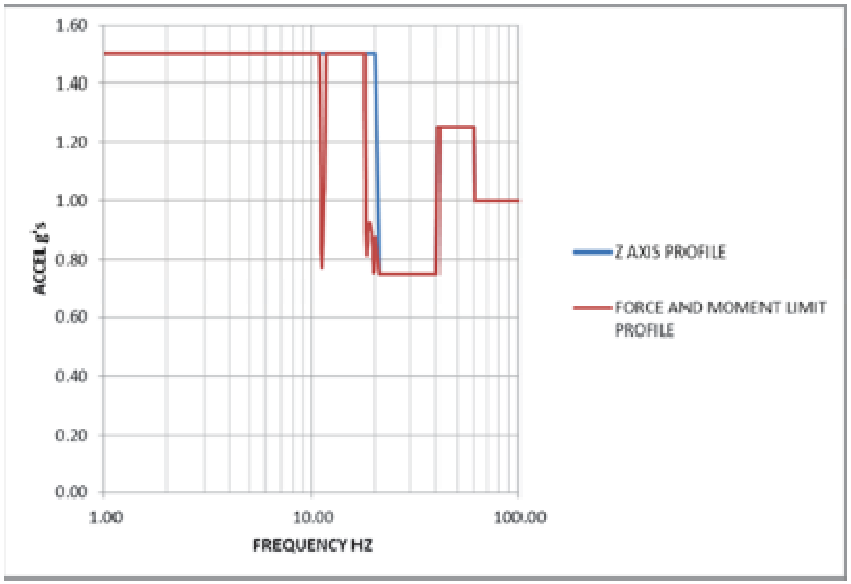


Vertical System – Shaker Force – V3 Axis

- Dual shaker FEM results
- Incorporates force limits as notches in test profile near OTIS modes
- Plots FEM force vs. frequency
- Peak shaker force ~ 38,000 lbf
- Approximate margin of 2.6 on shaker force



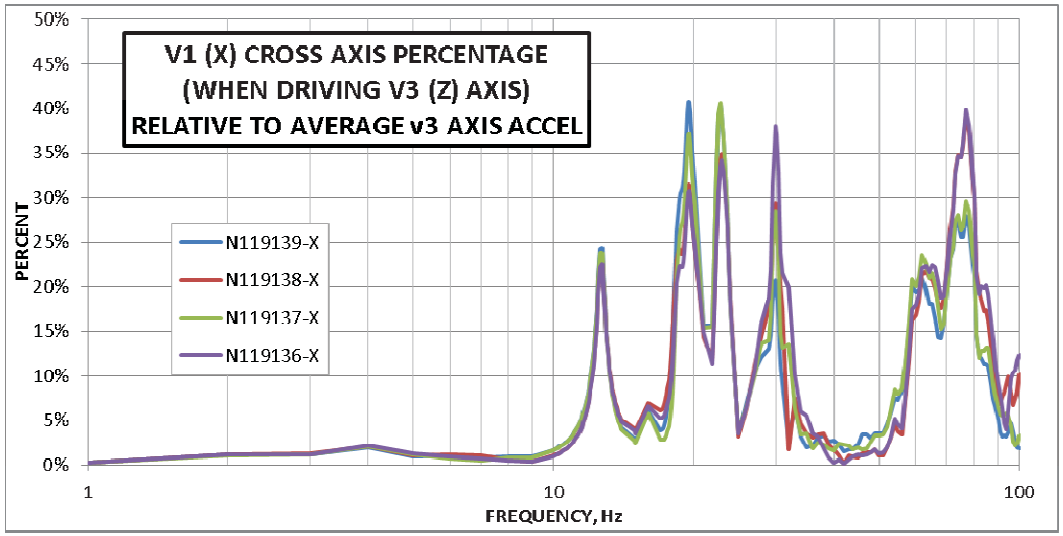
Dynamic Force - FEM

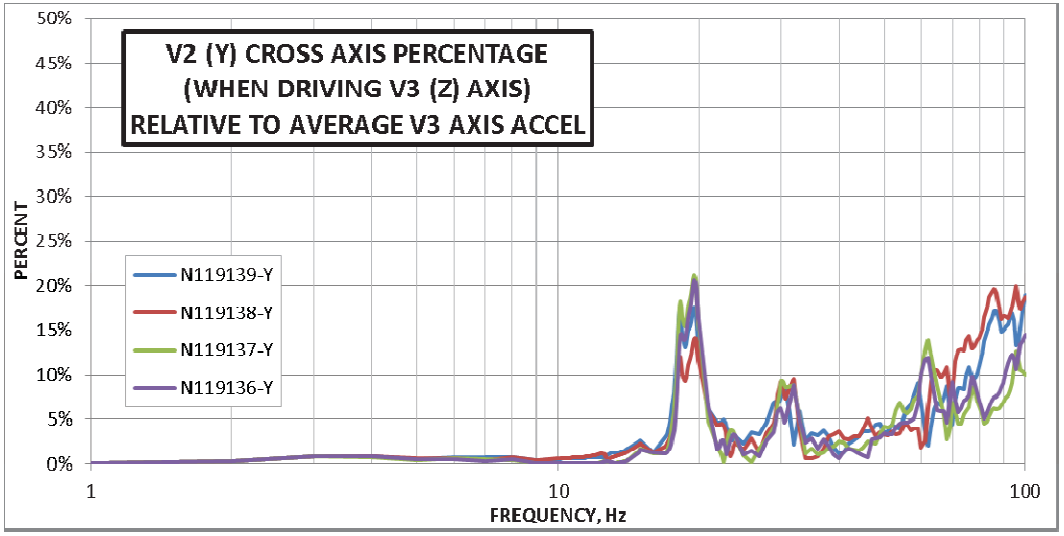


Sine Test Profile with Notching

Vertical System – Cross Axis Motion V1 / V3

- Vertical FEM cross axis motion
- Percent cross-axis motion for both lateral directions, relative to average vertical response
- Plots response at head expander corners – both lateral directions
- Peak response: 40%
  - @ OTIS modes





Questions?