3.9 GHz Cryomodule Transport

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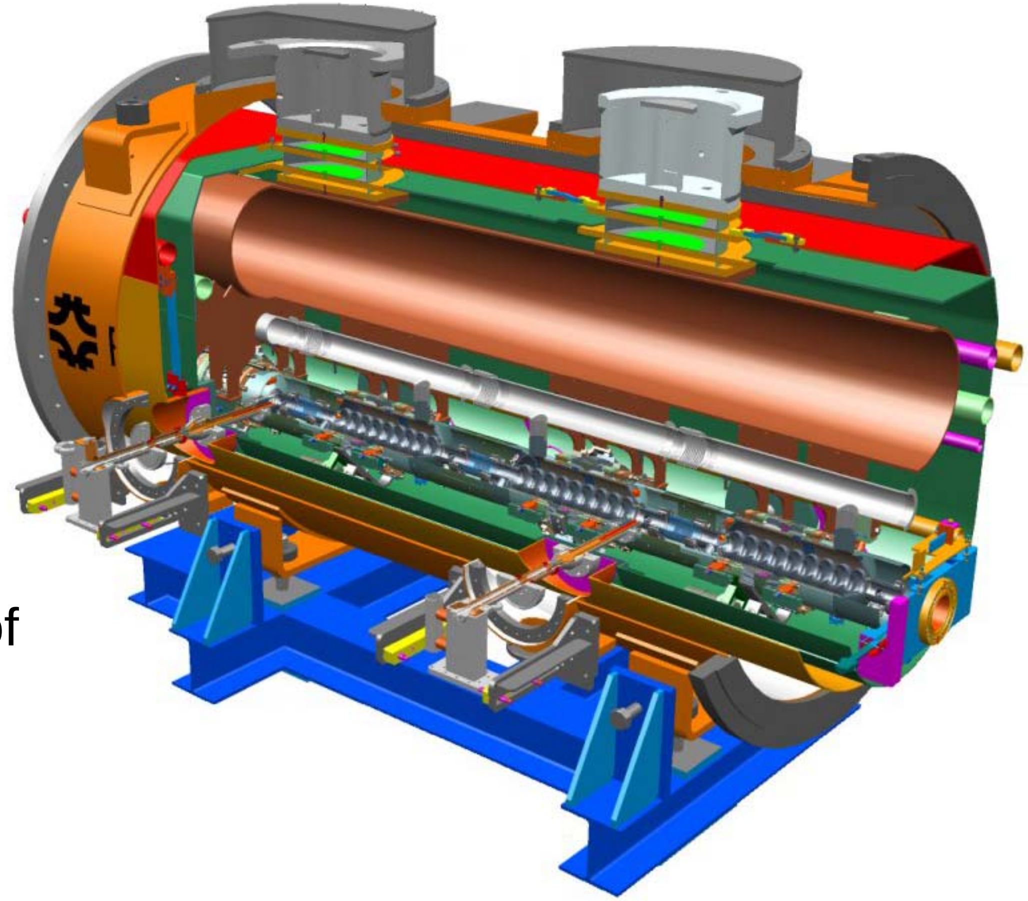
3.9 GHz Cryomodule Shock Evaluation



Preliminary Shock Criteria:
- •4g Vertically
- •5g Axially (along beamline)
- •0.5g Transverse

To be updated for 3.9 GHz, based on impact properties of materials at RT (e.g. input coupler, study by D. Olis and Germano G.)

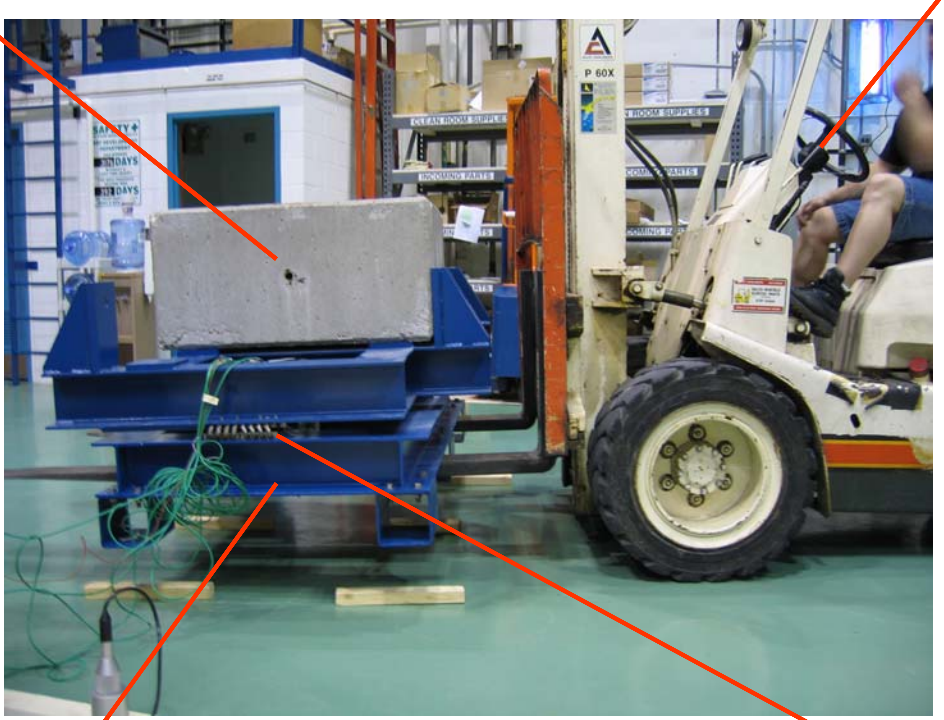
T. Whitlatch et al., “SHIPPING AND ALIGNMENT FOR THE SNS CRYOMODULE”

ILC International Linear Collider

3.9 GHz Cryomodule Shock Evaluation

Dummy Load (w/ lower C.G.)

Fork Truck



Base Frame

Isolators

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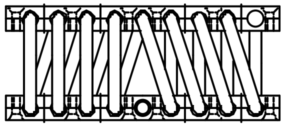
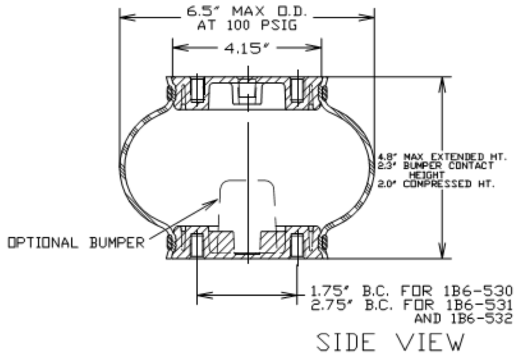
Preliminary 3.9 GHz Transport Fixture Vertical Shock Results

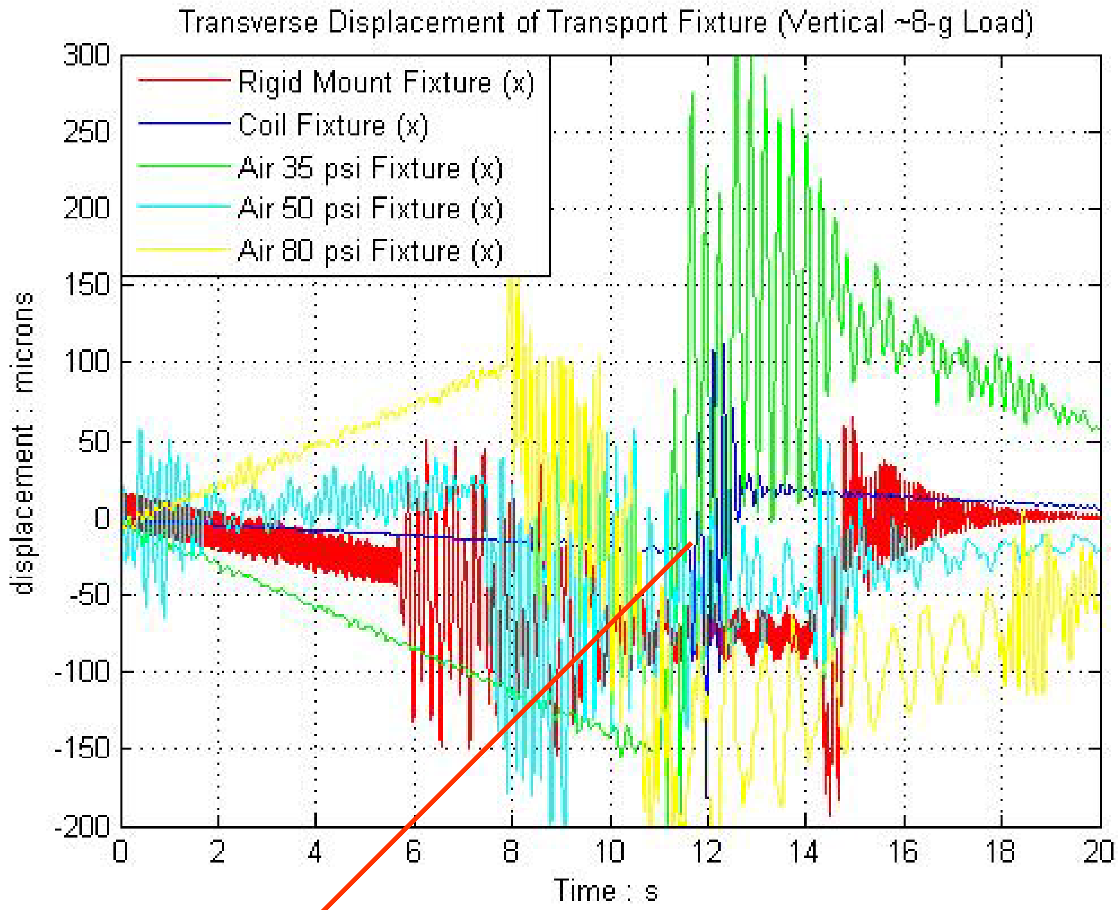
- Drop tests using a fork truck
  - Geophones and accelerometers were used to evaluate isolator designs at maximum shock load (~ 8-g vertical)
- Isolators
  - Coil type

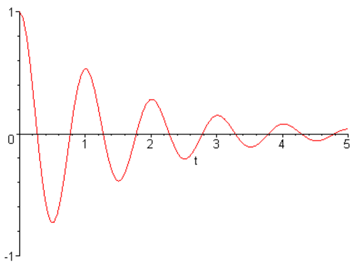


  - Goodyear air spring type
    - Inflated to 35 psi
    - Inflated to 50 psi
    - Inflated to 80 psi



Transverse Displacement Response to Vertical Shock





Under-damped systems

Coil Isolator (blue-line) had the least displacement with the quickest recovery

Coil Versus Air Spring Isolator Design

- Coil design benefit over air spring
  - Reduces shock to roughly same level
  - Handles greater shear loads
  - Reduces vibratory motion after impact
  - Leads to greater over-the-road stability
  - Offers passive design (no maintenance)
  - Reduced failure rate

3.9 GHz CM Transport Philosophy

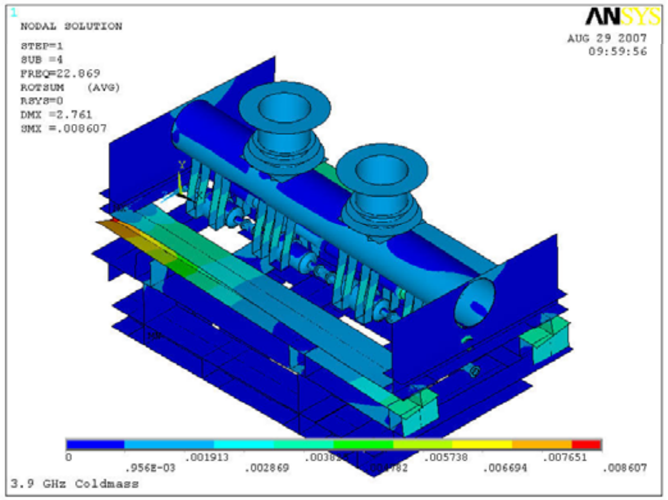
- Two Tier System Applied
  - Relatively stiff (slightly under-damped) isolation system with shock reduction of 1/2
  - Require an air ride trailer to/from Airport
  - Supervision of transitions (loading/unloading)
  - Specific details of transport have been discussed with American Overseas Transport (AOT)

3.9 GHz Cryomodule Transport Studies

- Characterize vibratory motion in terms of displacement and frequency
  - Measurement of excitation frequencies
    - For example, a diesel engine running at 1400 rpm has a 23.3 Hz excitation frequency
- Measurement of shock loads during transport
  - Found from our experience with 1.3 GHz coldmass transport that air ride trailer provided good protection against shock

Modal Studies

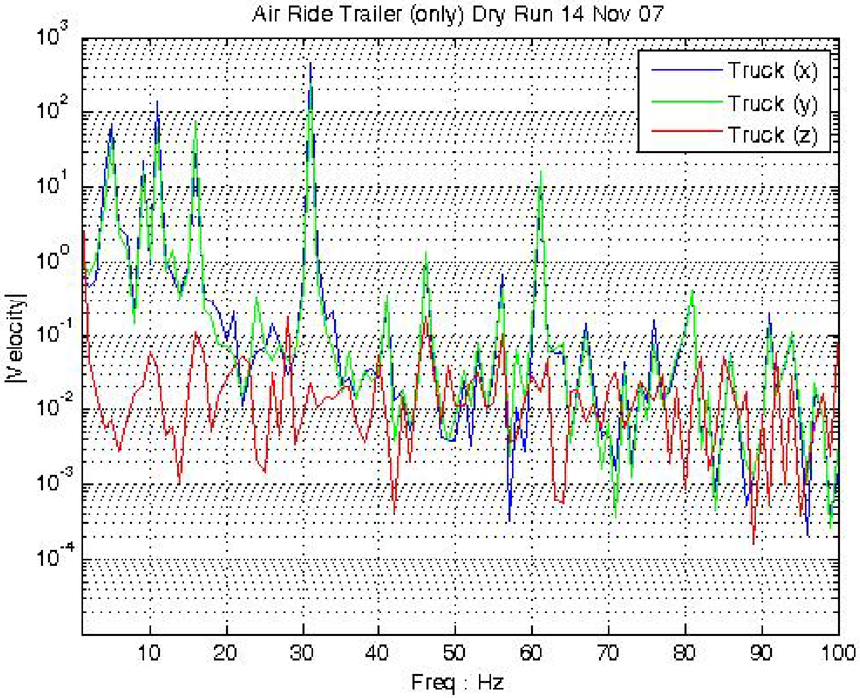
- Modal analysis can provide resonant frequencies, mode shape, ect…
- Determine appropriate instrumentation location
- Confirm and refine analytic models (such as FEA)



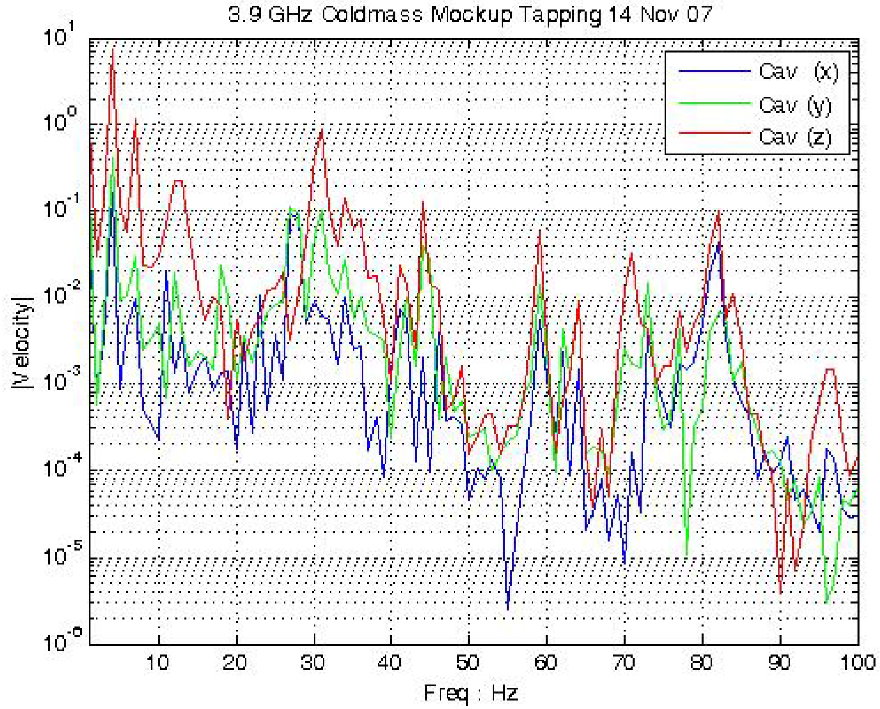
Preliminary Results

- Coldmass Mockup transport
  - Dry run results (excitation frequencies)
  - Ringing of Mockup (resonant frequencies)
  - Transport of Coldmass Mockup

3.9 GHz Coldmass Mockup (fft) Data



Excitation Frequencies



Resonant Frequencies

3.9 GHz Coldmass Mockup Table

Mode	Direction	FEA (Hz)	Ringing (Hz)	Dry Run (Hz)	Comment(s)
	x & y			5	
	z		7		
	x & y			9	
	x, y & z			10.8	
1	z	**14.3**	**14**		Movement at support brackets
	x, y & z			16	
2	y	16.8			Frame movement
3	z	**22.4**	**24**		Movement at support brackets
4	y	22.9			Coldmass movement
	z			27	
5	z	**30.7**	**31**		Frame movement

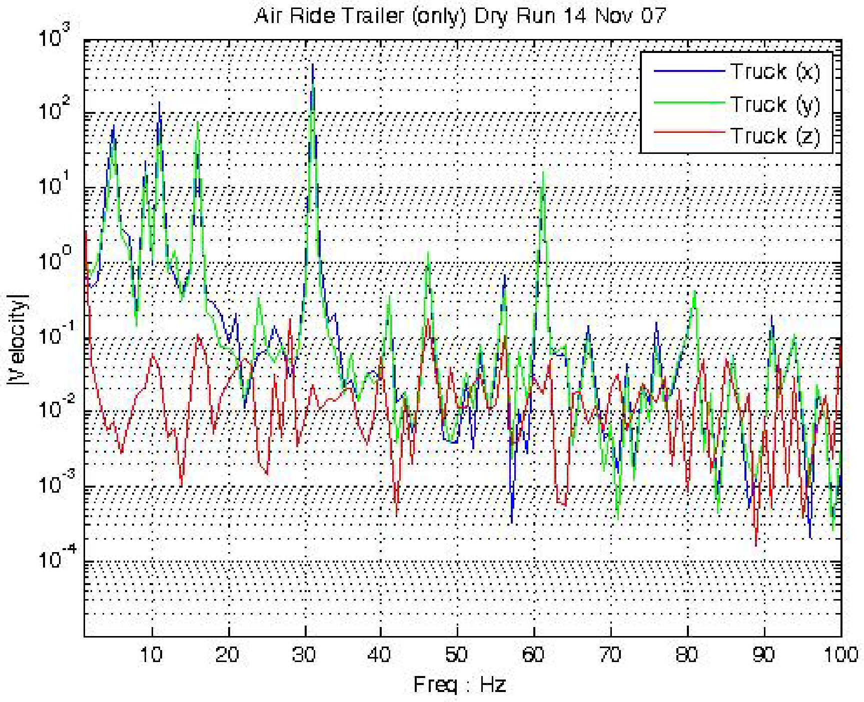
3.9 GHz Coldmass Mockup Table

Mode	Direction	FEA (Hz)	Ringing (Hz)	Dry Run (Hz)	Comment(s)
6	y	**31.4**	**31**		HeGRP movement
7	x	**36.3**	**35**		Coldmass twist
	x, y & z			37	
8	y	37.9			Local GRP movement
	x, y & z			41	
9	z	**42.2**	**42**		Mid support bracket movement
	x, y & z			45	
10	x & y	51.5			Coldmass twist
	x, y & z			55	

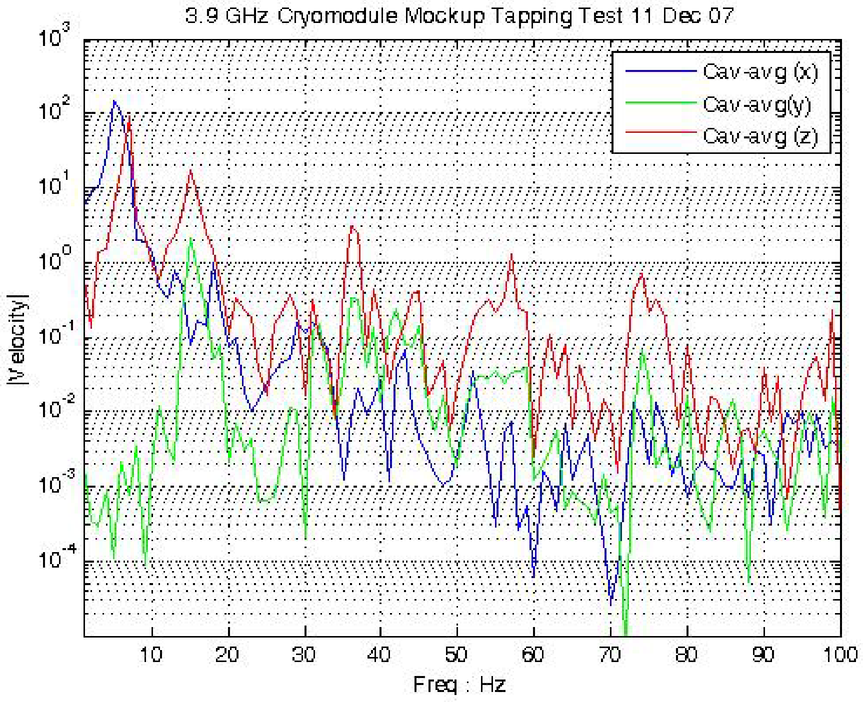
3.9 GHz Cryomodule Mockup Results

- Cryomodule Mockup transport
  - Dry run results (excitation frequencies)
  - Ringing of CM Mockup (resonant frequencies)
  - Transport of CM Mockup
    - Peak Shock
    - Acceleration (rms) versus Truck Speed
    - Shock of Transitions

3.9 GHz Cryomodule Mockup (fft) Data



Excitation Frequencies



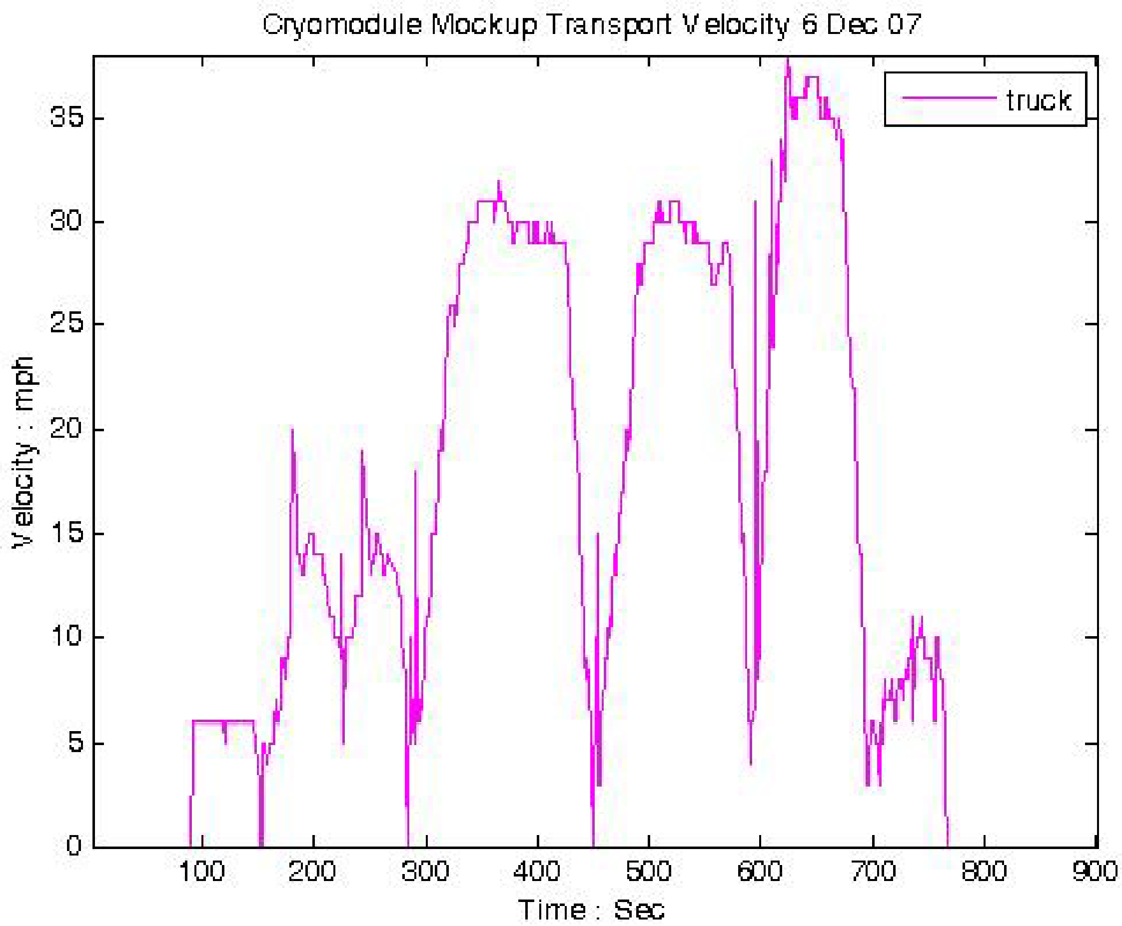
Resonant Frequencies

3.9 GHz Cryomodule Mockup Table

Direction	Ringing (Hz)	Dry Run (Hz)
x & y		**5**
z	**5**	
x & y		9
x, y & z		10.8
z & y	15	
x, y & z		16
z		27
z & y	34	
x, y & z		37
x, y & z		41
z	43	
x, y & z		45
x, y & z		55
z		57

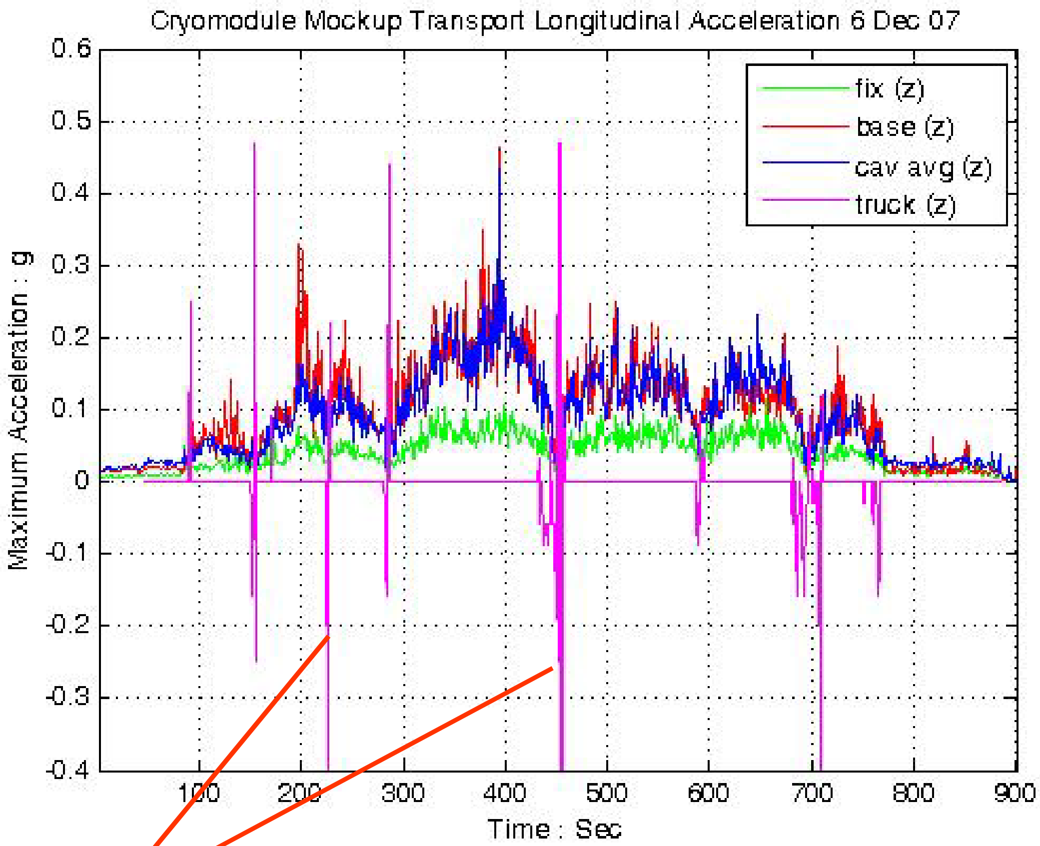
Longitudinal resonant condition (at 5 Hz) can be addressed by constraining ends

Initial Transport Study Truck Speed



Study on Fermilab Site (36 mph Max.)

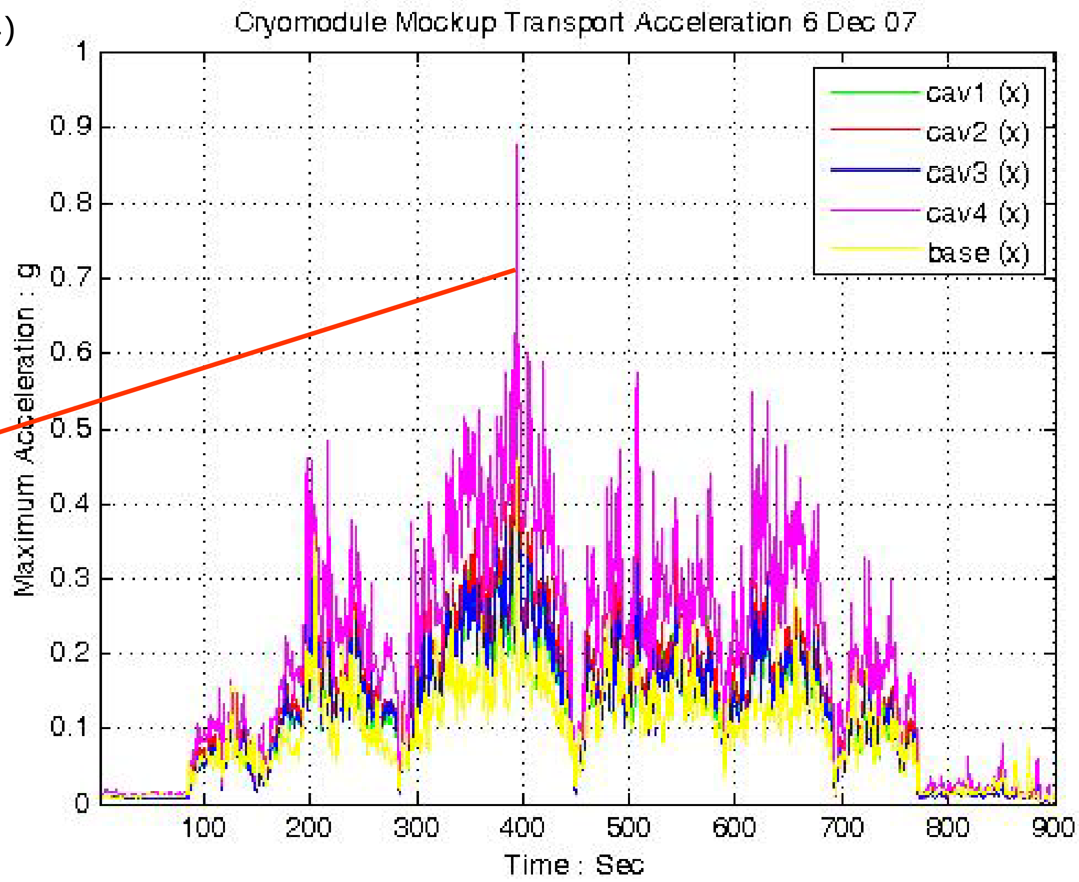
Initial Transport Study Peak Shock



GPS data used to estimate acceleration/de-acceleration of truck

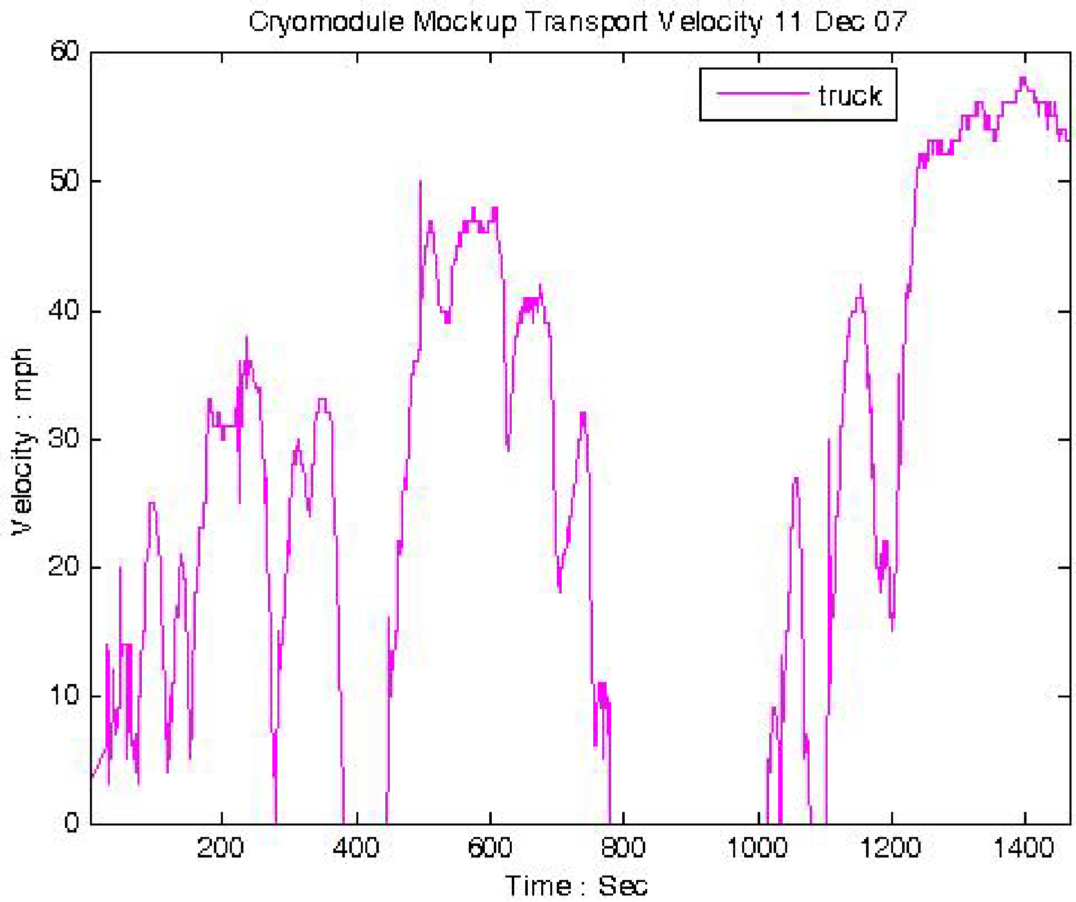
Peak Shock on Cavities (transverse (x))

Cavity #4 had only 3 (of 4) bearing lug supports



Noticed instability of partially supported cavity #4

Off-Site Transport Study Truck Speed



Study taken off-site onto I-88 (57 mph Max.)

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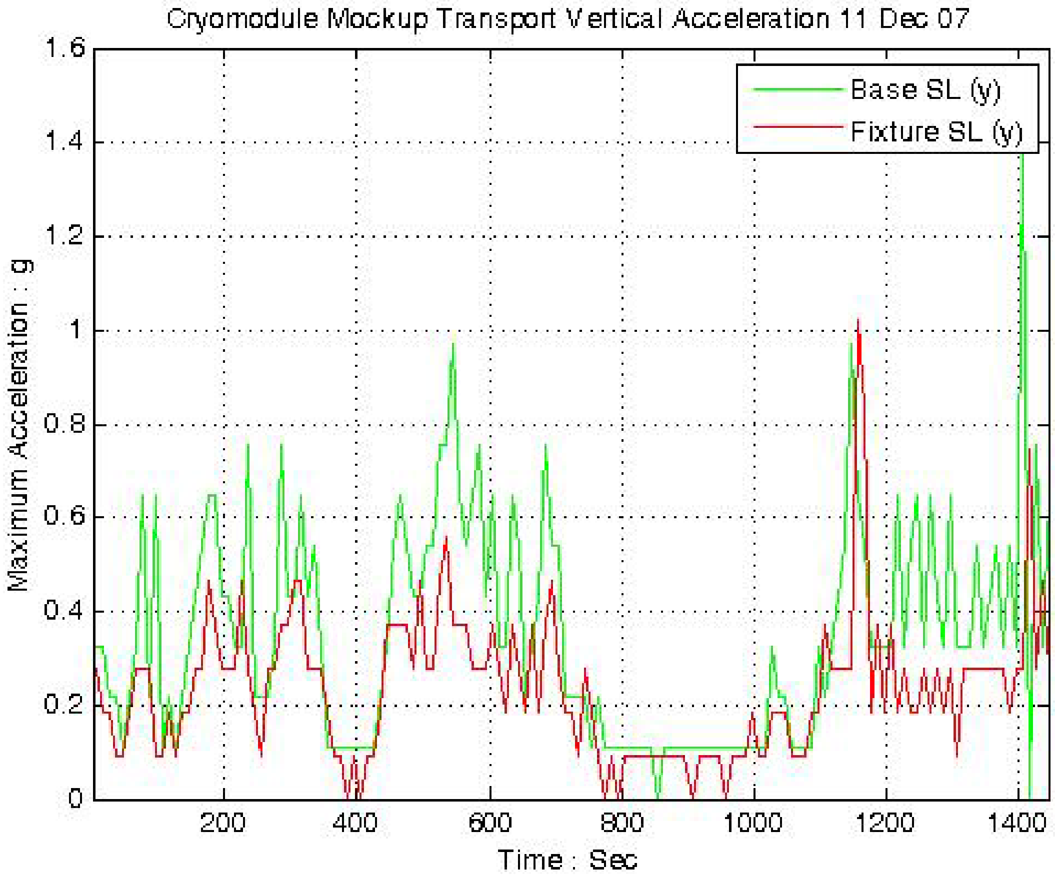
Vertical Peak Acceleration (Shocklog)



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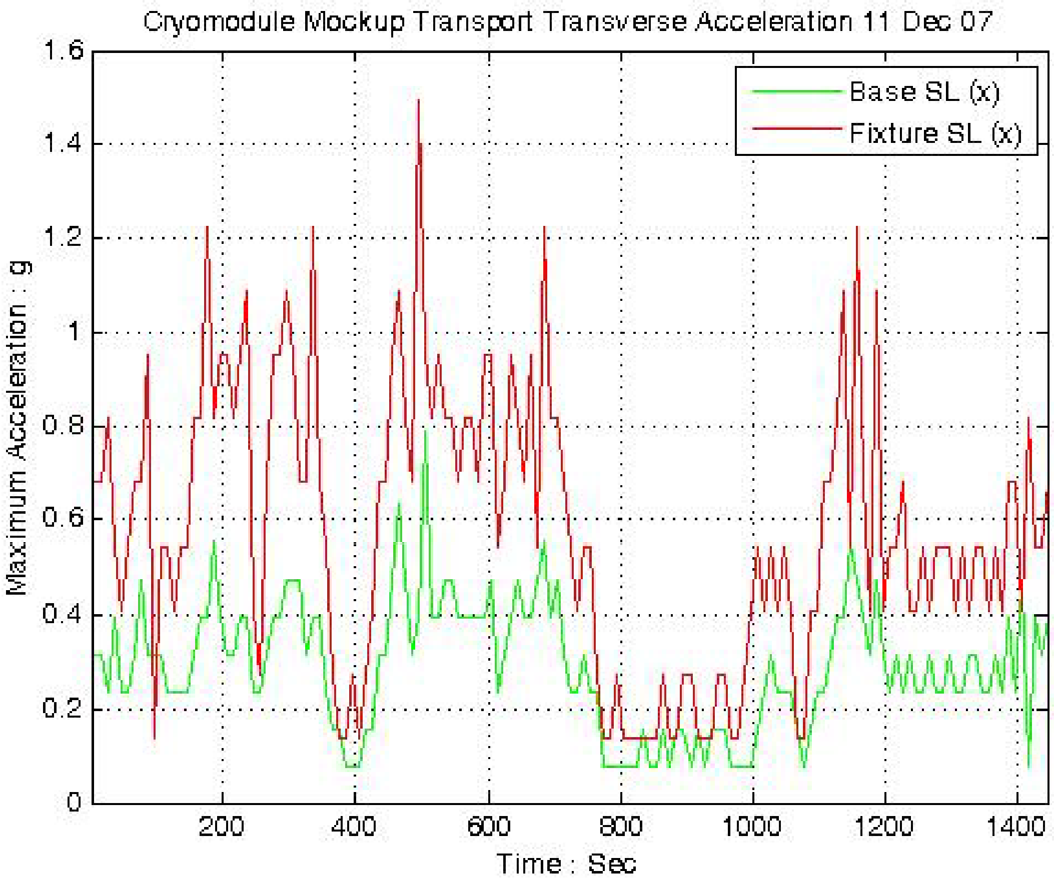
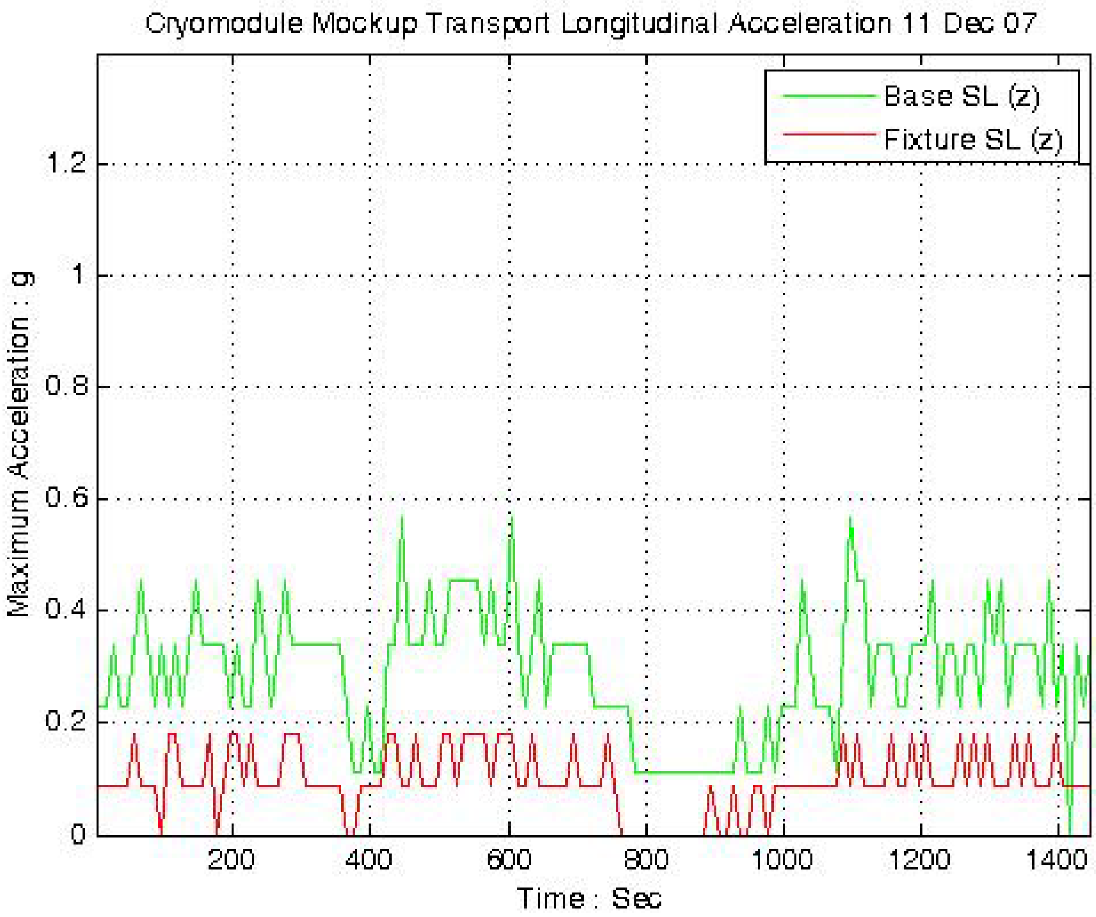
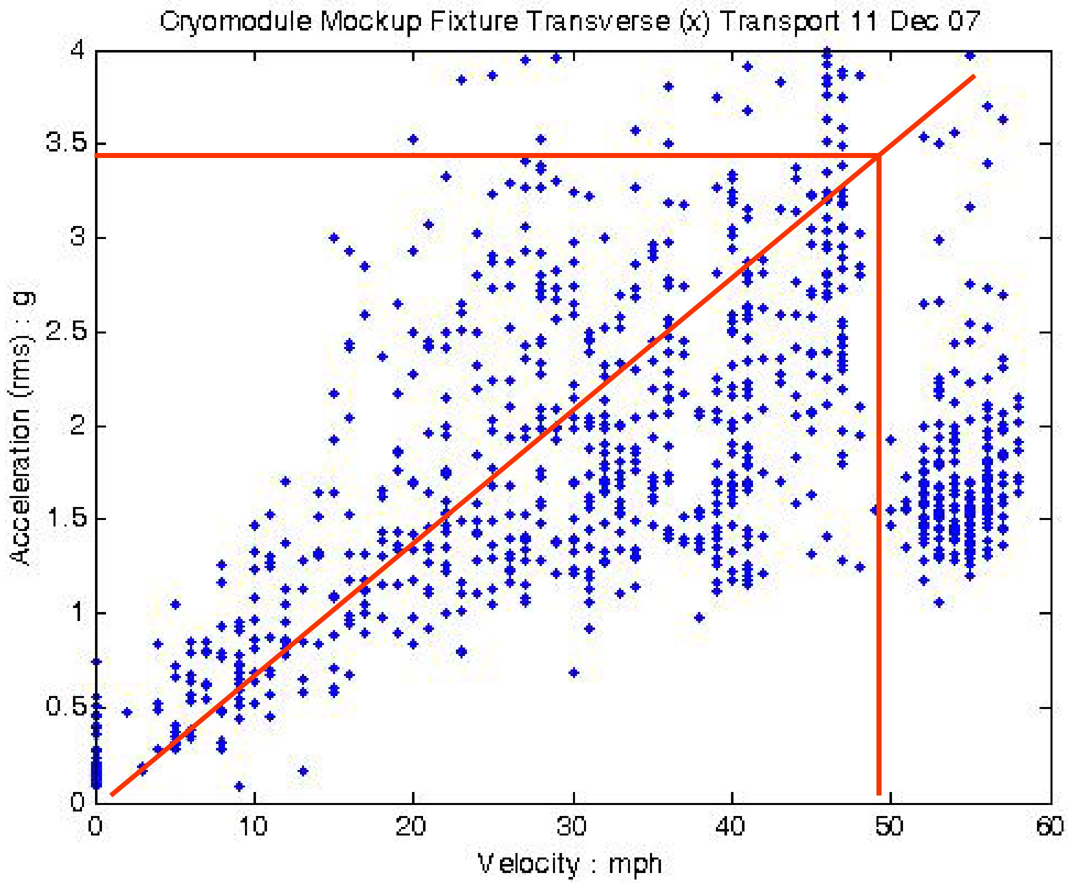
Transverse Peak Acceleration (Shocklog)



Longitudinal Peak Acceleration (SL)

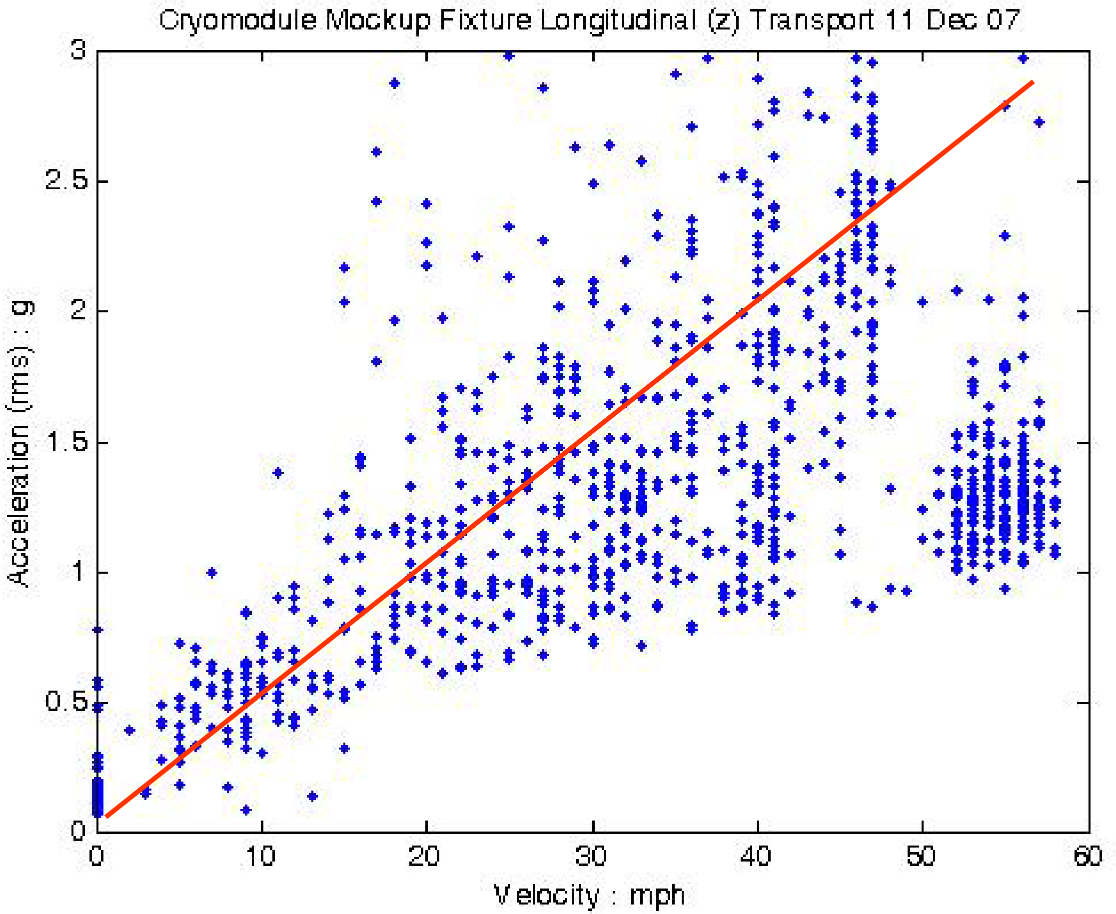


Fixture (x) Acceleration Vs Truck Speed



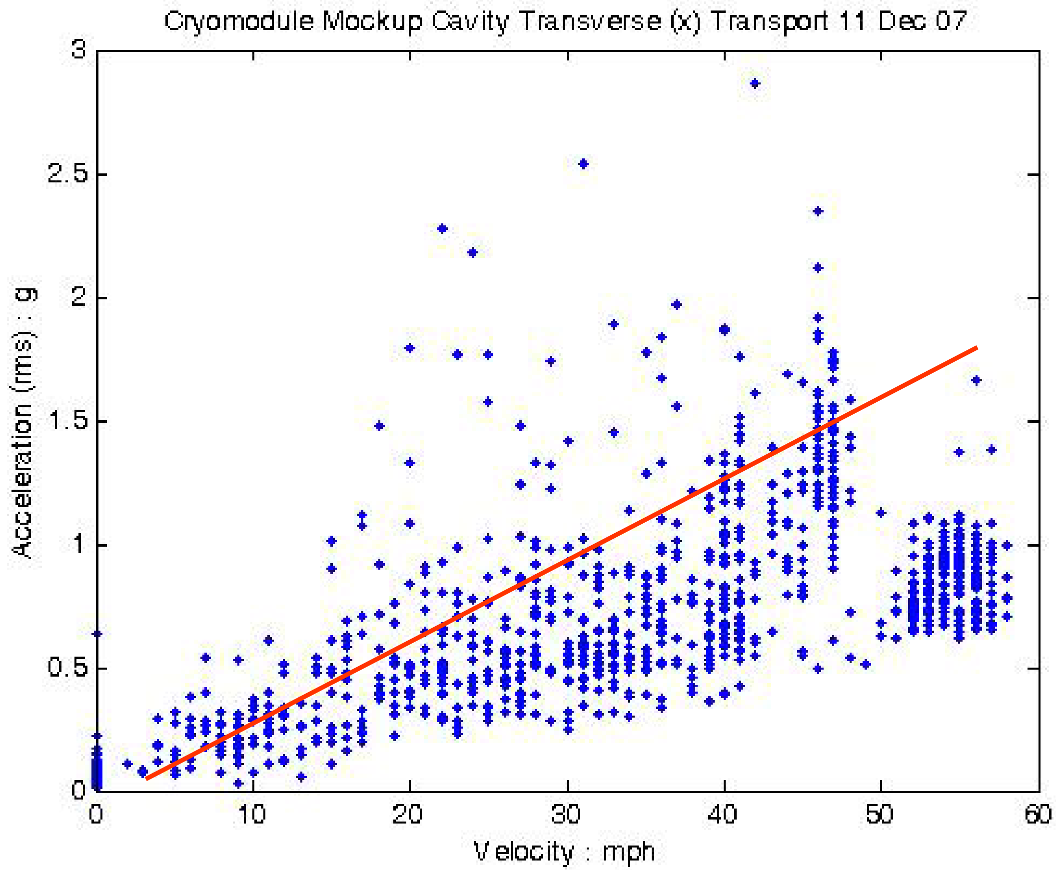
Large transverse acceleration with increasing truck speed!

Fixture (z) Acceleration Vs Truck Speed



Large longitudinal acceleration with increasing truck speed!

Cavity (x) Acceleration Vs Truck Speed



Large longitudinal acceleration also seen at cavities

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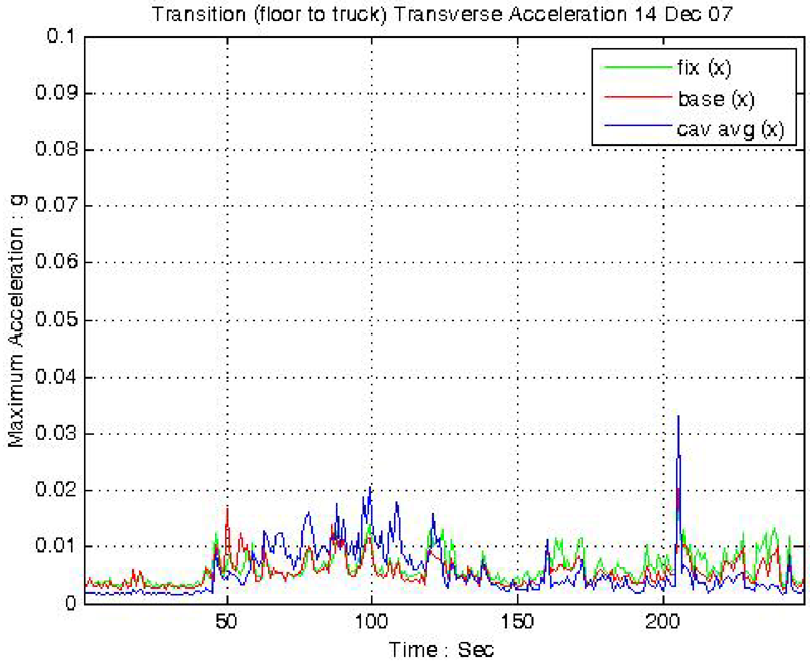
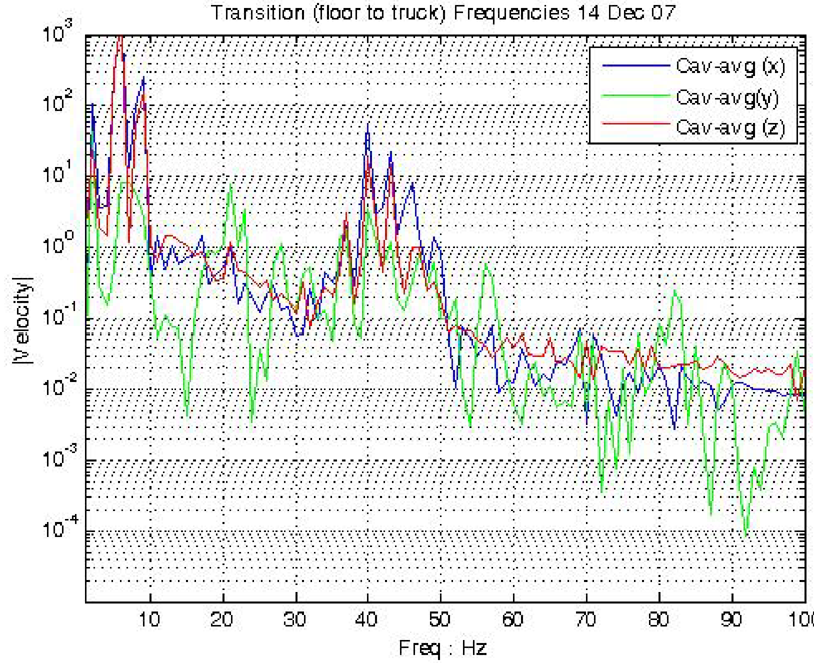
Transition Points (Loading Truck)





Transverse peak shock load while moving with crane

Averaged fft during move

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Preliminary Observations

- During the coldmass transport studies in November our isolation system was much softer with a natural frequency ~ 4Hz
- Results for the coldmass transport show peak acceleration of 1.5 g (in any direction) while moving at 40 mph

Preliminary Observations

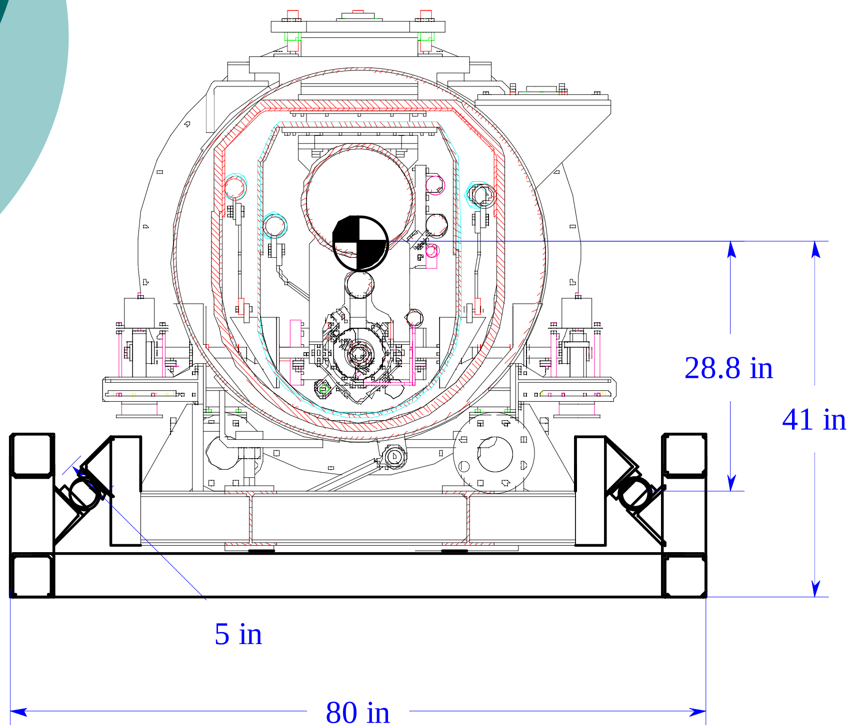
- Natural frequency of our current system ~ 5 Hz is overly stiff
- During the cryomodule transport studies we have found resonant conditions at low frequency
- Below ~5 Hz resonant conditions induce large transverse (x) and longitudinal (z) accelerations
- Above 5 Hz, this system damps shock very well

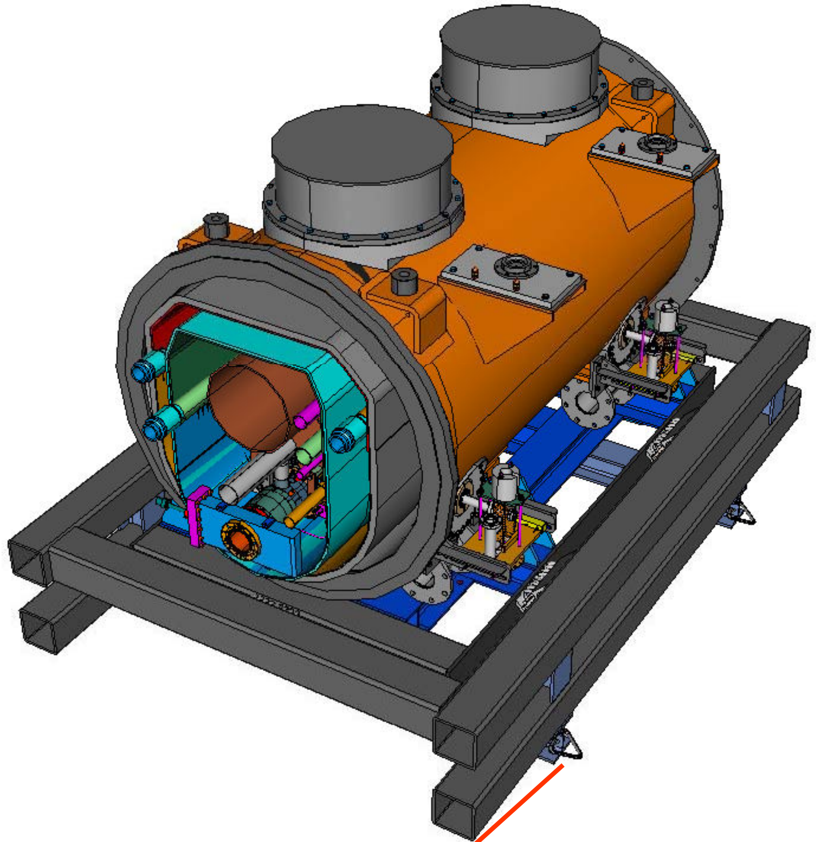
Transport Improvements

- Soften isolation system down to ~4 Hz
- Orientate vertical cavity geophones upward

Base Frame & Isolation Fixture Design

Low Profile Cradle Design

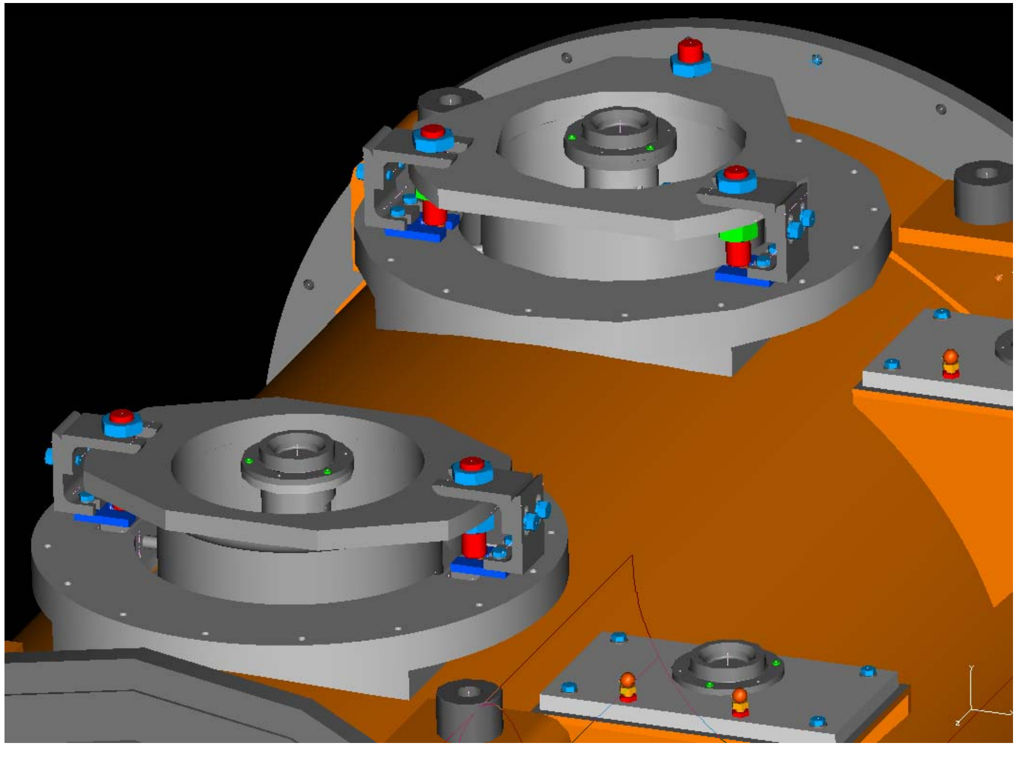




Out-riggers for securing

Update of Constraints for Transport

- Addition of constraints for cold post supports (in 6 dof)

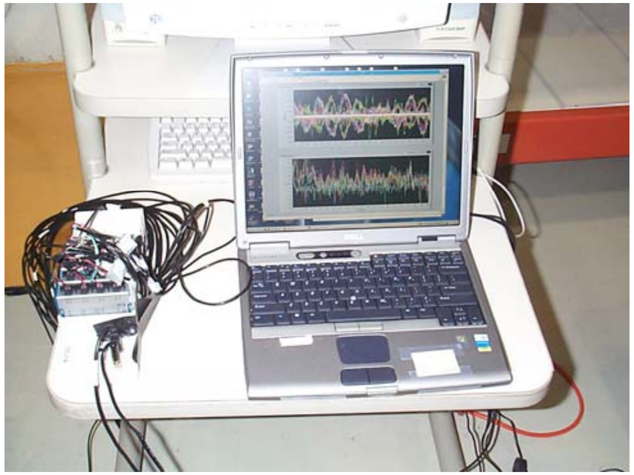


Alignment

- As found before/after transport to assess impact of transport to alignment
- Alignment Panel Design & Function

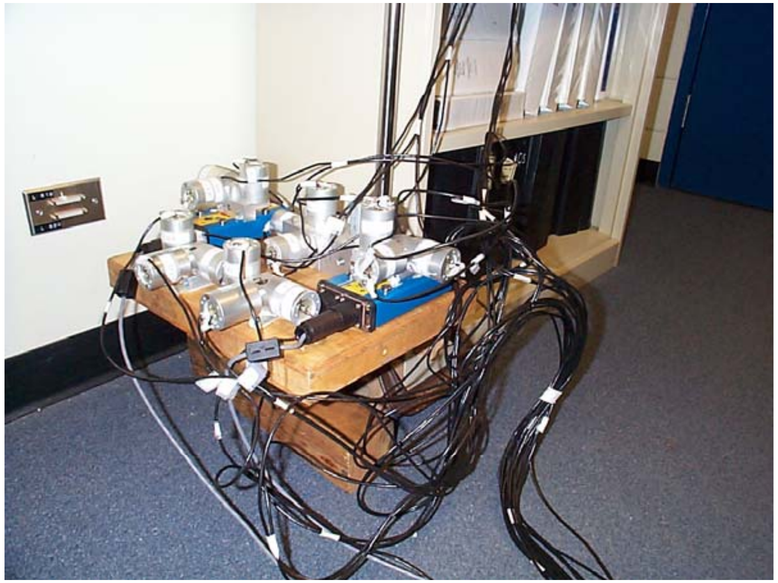
Devices & Supporting Equipment

- NI 24-Bit resolution 4-channel module
  - Digitizer with USB connection to Laptop
- 6 Modules (24-channel system)
- System can be expanded to support 32-input channels
- 5K per second sample rate



Geophone – Shocklog Correlation

- Shocklog (tri-axial accelerometer) data-logging device designed for transport
- Hammer tests at random g-loads
  - Geophones are calibrated against Shocklog devices in terms of g-loading



Instrumentation Configuration

- 18 Geophones
  - 3 geophones per cavity (x, y and z) evenly spaced in z (longitudinally)
  - 3 geophones on isolation fixture (in x, y and z)
  - 3 geophones on base frame (in x, y and z)
  - Geophones cannot be attached during actual transport to DESY
  - Addition
    - Accelerometer on bellows
    - Geophones on adjacent flanges

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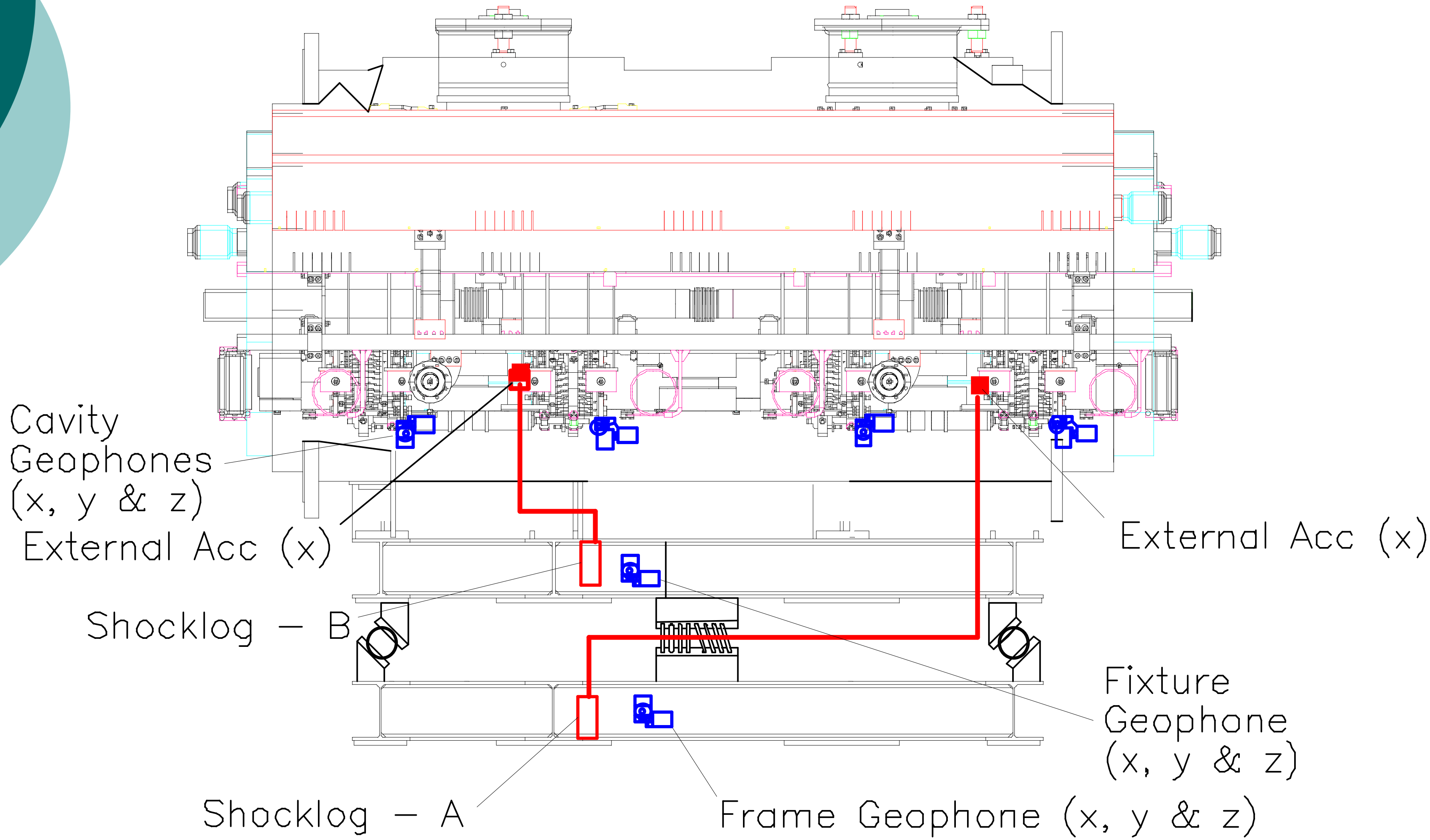
Instrumentation Configuration

- Actual transport instrumentation is limited to (3) Shocklog devices
- A Shocklog device has three internal accelerometers (in x, y and z)
  - Shocklog “A” on base frame
  - Shocklog “B” on isolation fixture
  - Shocklog “C” on Cryomodule
- Geophone to Shocklog correlation
  - Used as comparison to geophones
  - Post Transport to DESY Evaluation

Current Instrumentation Configuration



Carrier Support

- American Overseas Transport (AOT)
  - Supervised shipment
  - Cap ends of 3.9 GHz CM vacuum vessel and pressurize with dry N2
  - Jacket for vacuum vessel and monitor assembly temperature
  - Apply foam clam-shell connections at warm end of ICs (no rigid connects to vacuum vessel)
  - Constrain beamline ends

Transport Shock & Vibration Data

- Transportation Load Limit Factors (NASA)
  - Loads in terms of “g” or peak
  - Does not consider accumulate effect of repeated loads of varying magnitudes and frequencies

- Air: +- 0.5 (z), +- 2.5 (x) & +- 2.5 (y)
- Truck: +- 3.5 (z), +-2 (x) & + 6 (y)

Transport Shock & Vibration Data

- Lufthansa (G-forces for cargo aircraft)
  - Shipment must withstand 9 g's fore/apt (longitudinal), 3 g's vertical
  - Source: Jim Hammond of Clarke Packing & Crating Co. (Contracted by AOT)

Thank You!