Vibration-Heating in ADR Kevlar Suspension Systems

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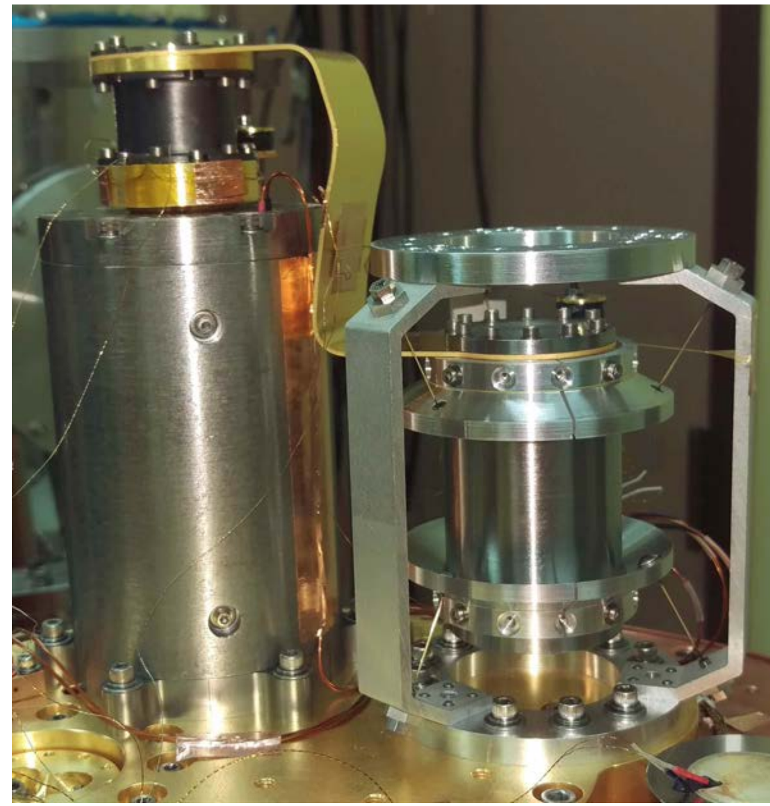
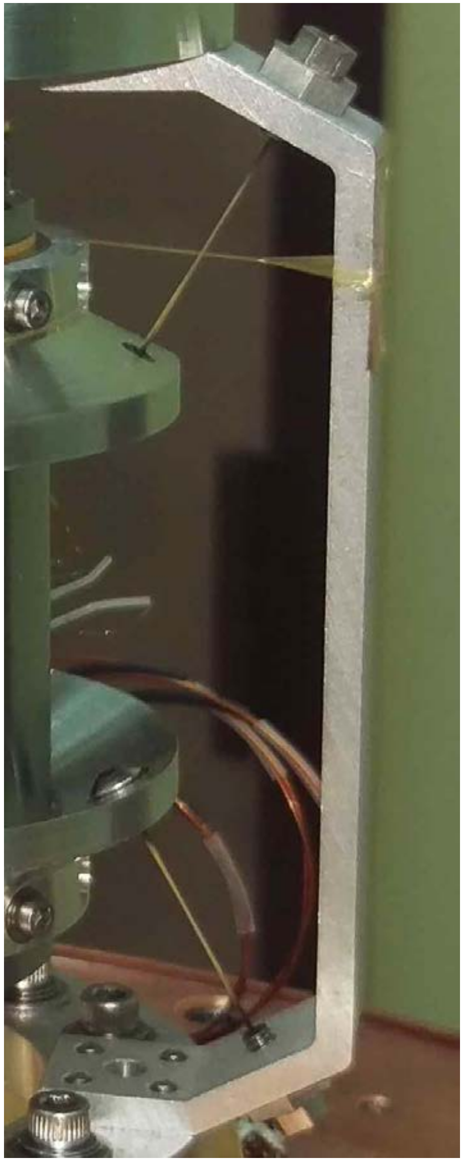
Introduction

- NASA/GSFC builds Continuous Adiabiatic Demagnetization Refrigerators (CADRs)
  - Continuous stages provide 6 μW of cooling at 50 mK
  - Challenging engineering work minimizes parasitic heat loads
- A lab CADR had intermittent excess heat loads
  - Worst-case 10 – 20 μW
  - Correlated with occasional vibration modes of aging cryocooler
  - Managed temporarily via cryostat mods
- Could cause a significant crisis for a flight ADR tested in a lab cryostat

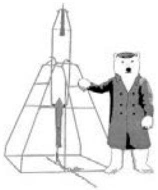


Suspected Cause of Heating

- Coldest (~ 50 mK) stages are each suspended by six tensioned Kevlar strings
- Support frame at outer end of Kevlar at ~ 3 K
- Nominal conducted heat load through six Kevlar legs is < 0.5 μW
- Assume that vibrations cause stretching and rubbing of Kevlar fibers in each string
- Heat generated in Kevlar changes its temperature profile; more heat reaches suspended cold stage
- We wanted to test this theory so we could evaluate ways of mitigating the effect



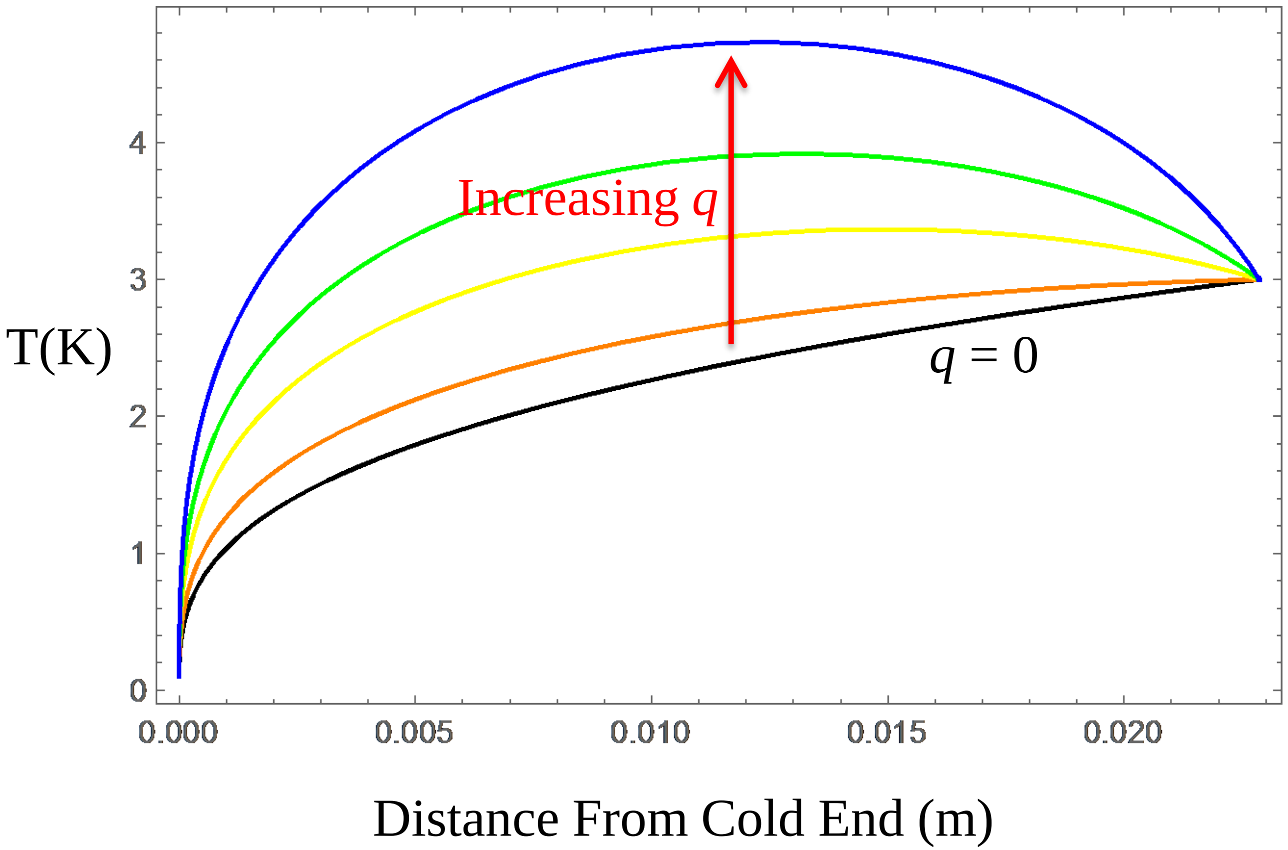
Predicted Kevlar Behavior



Cryogenics and Fluids Branch

- Assume heating is uniform along Kevlar lengths
- Can solve heat equation for Kevlar's conductivity: $k(T) = 0.0038\ T^{1.948}$
- Heat conducted to Kevlar's cold end correlates with midpoint temperature

$$\frac{\partial}{\partial x} k(T) \frac{\partial T}{\partial x} + q = 0$$

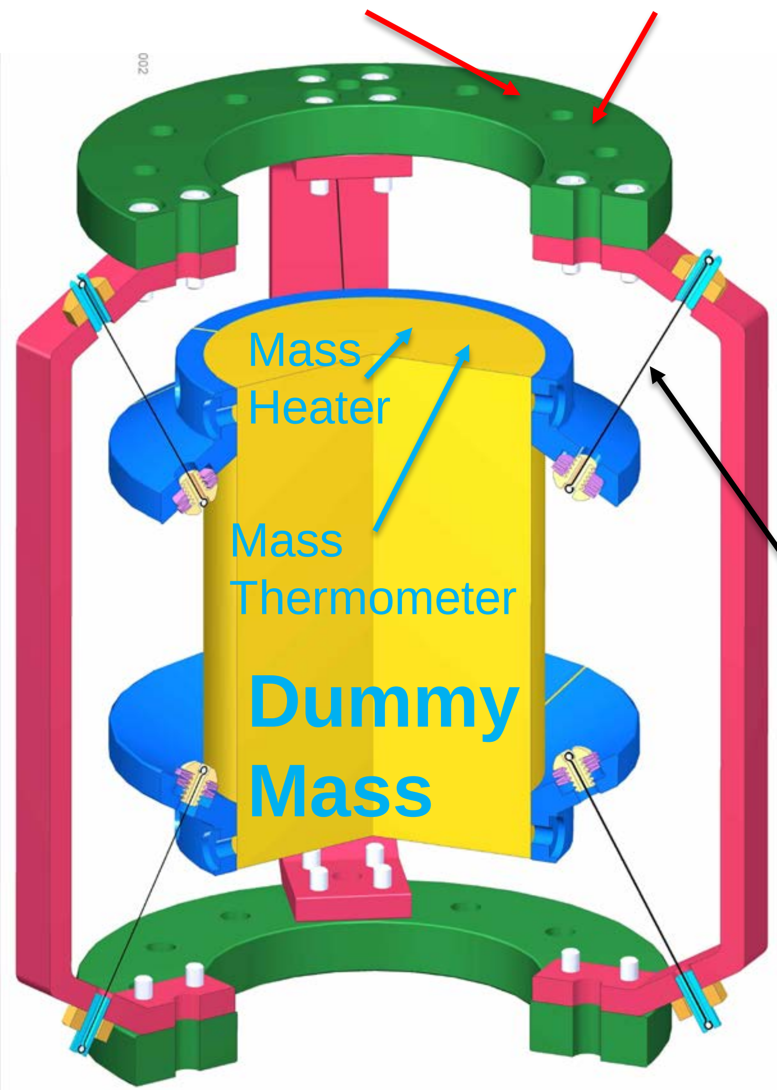


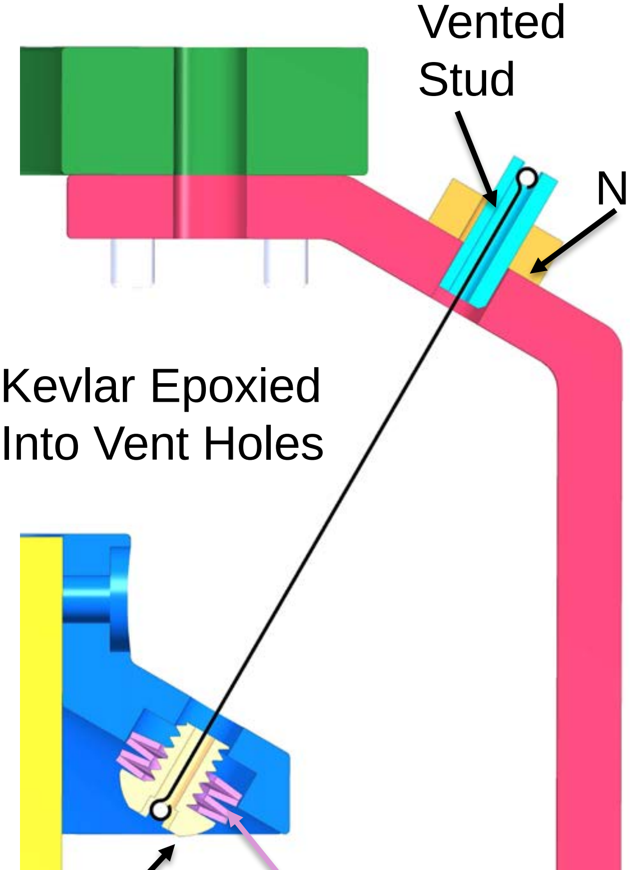
Testing Approach

- Assume that similar Kevlar heating can be seen at in a 4 K cryostat
- Suspend a dummy mass in nearly identical configuration to that of lab CADR’s stage
- Install a tiny thermometer at the midpoint of one Kevlar support leg
- Install heaters and thermometers on frame and suspended mass close to the Kevlar leg with the sensor
- Induce vibrations in the system and measure amplitude of mass motion relative to support frame
- Measure drop in suspended mass controlling power; see if it correlates with rise in Kevlar midpoint temperature according to uniform heating assumption

Test Assembly

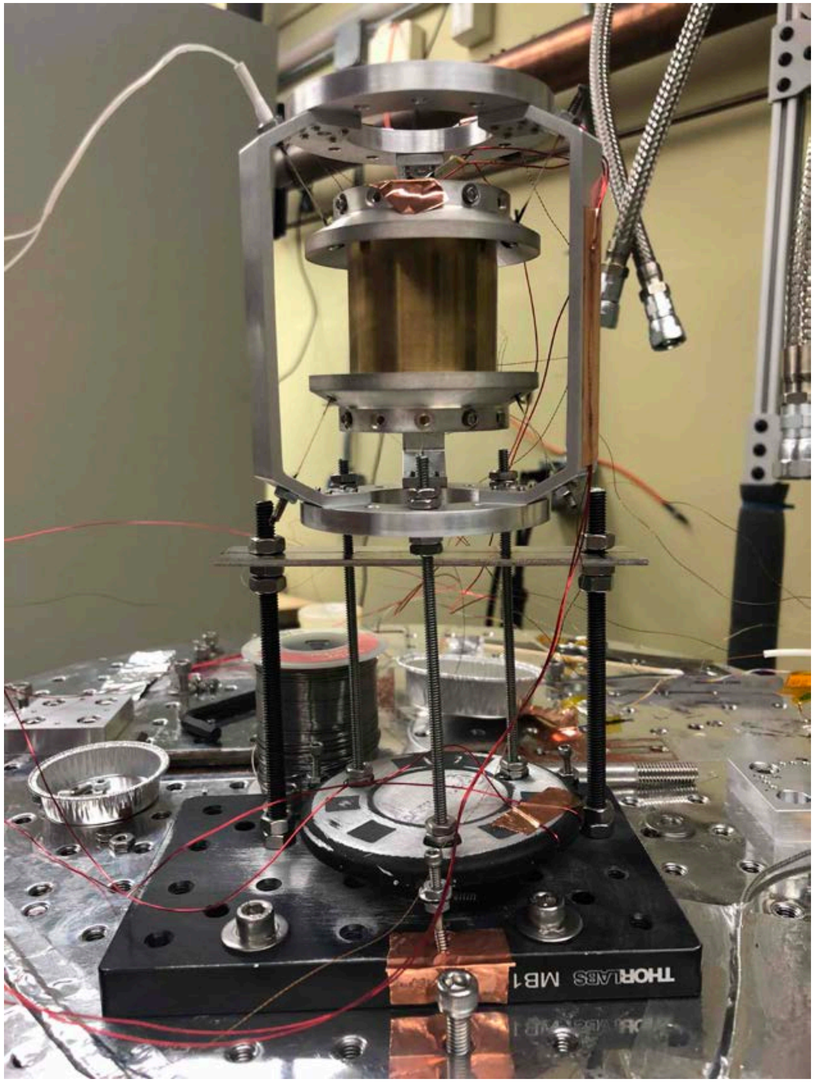
Cryogenics and Fluids Branch



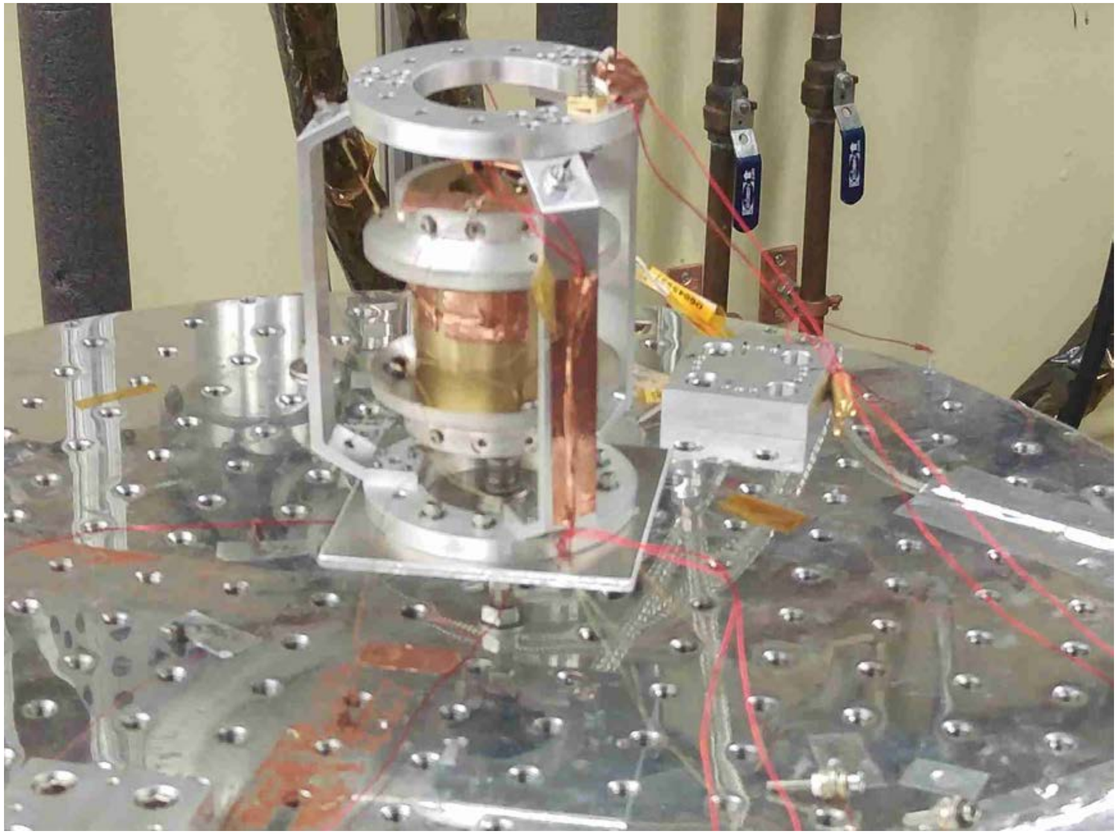


First Attempt

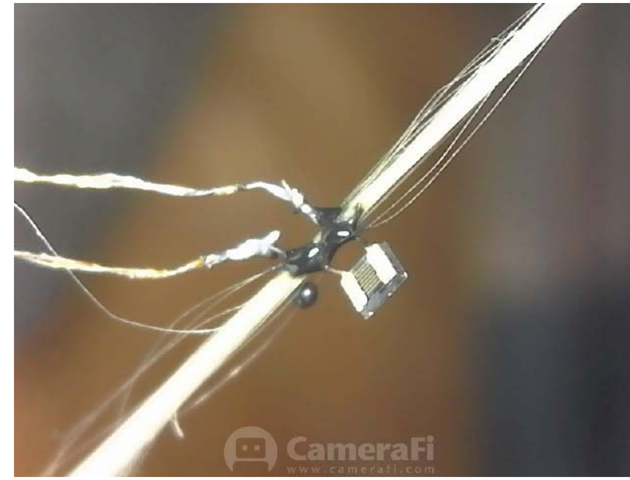
- We originally tried to couple test rig with a transducer on the cryostat’s cold plate
- Transducer and its wiring produced thermal radiation which made the experiment impossible
- It’s difficult to resolve a few μW at 4 Kelvin!

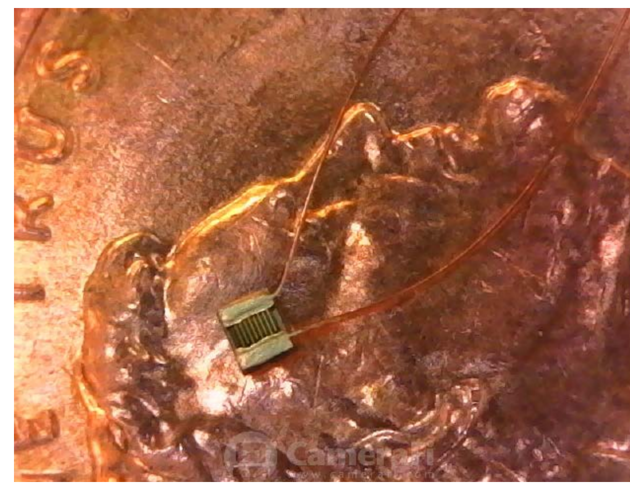


Reconfiguration



Test rig mounted above 4 K cryostat cold plate



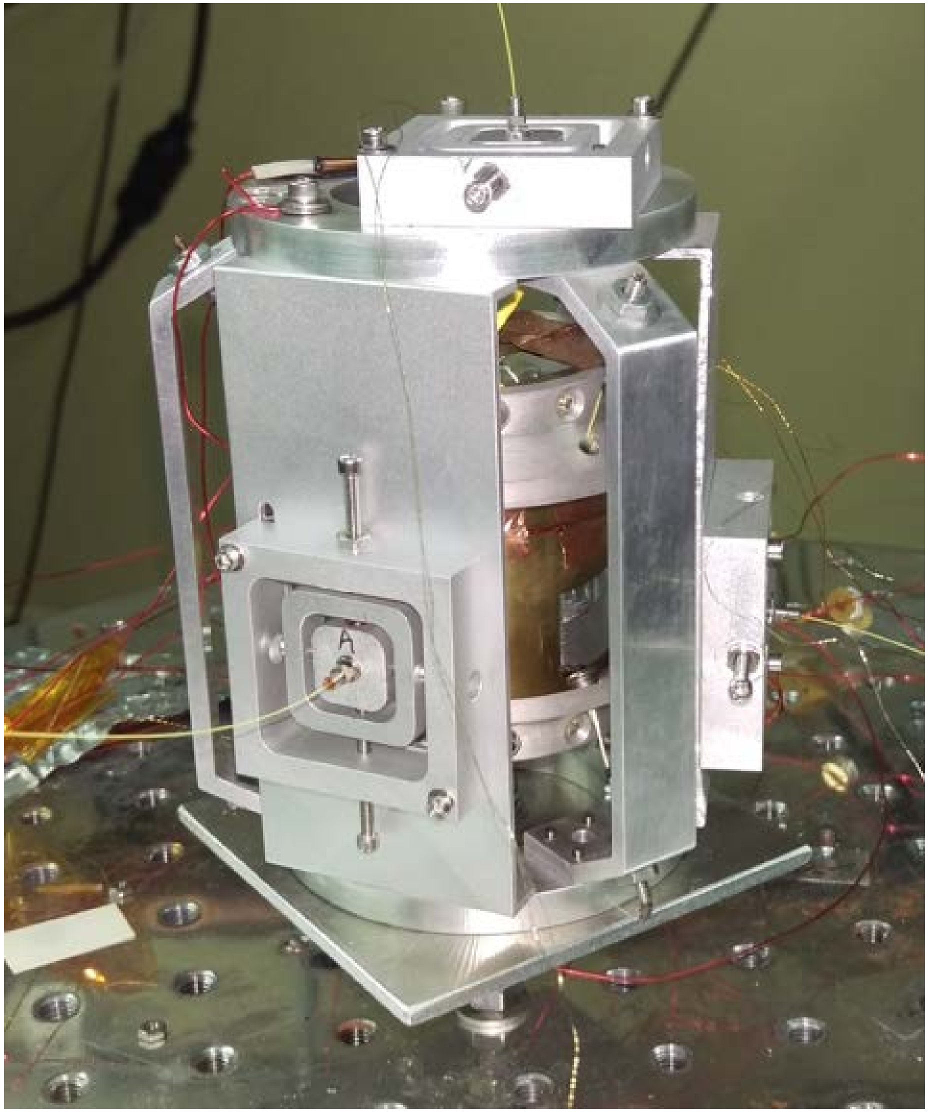


LakeShore bare-chip Cernox sensor on Kevlar

Add Displacement Sensors

Cryogenics and Fluids Branch

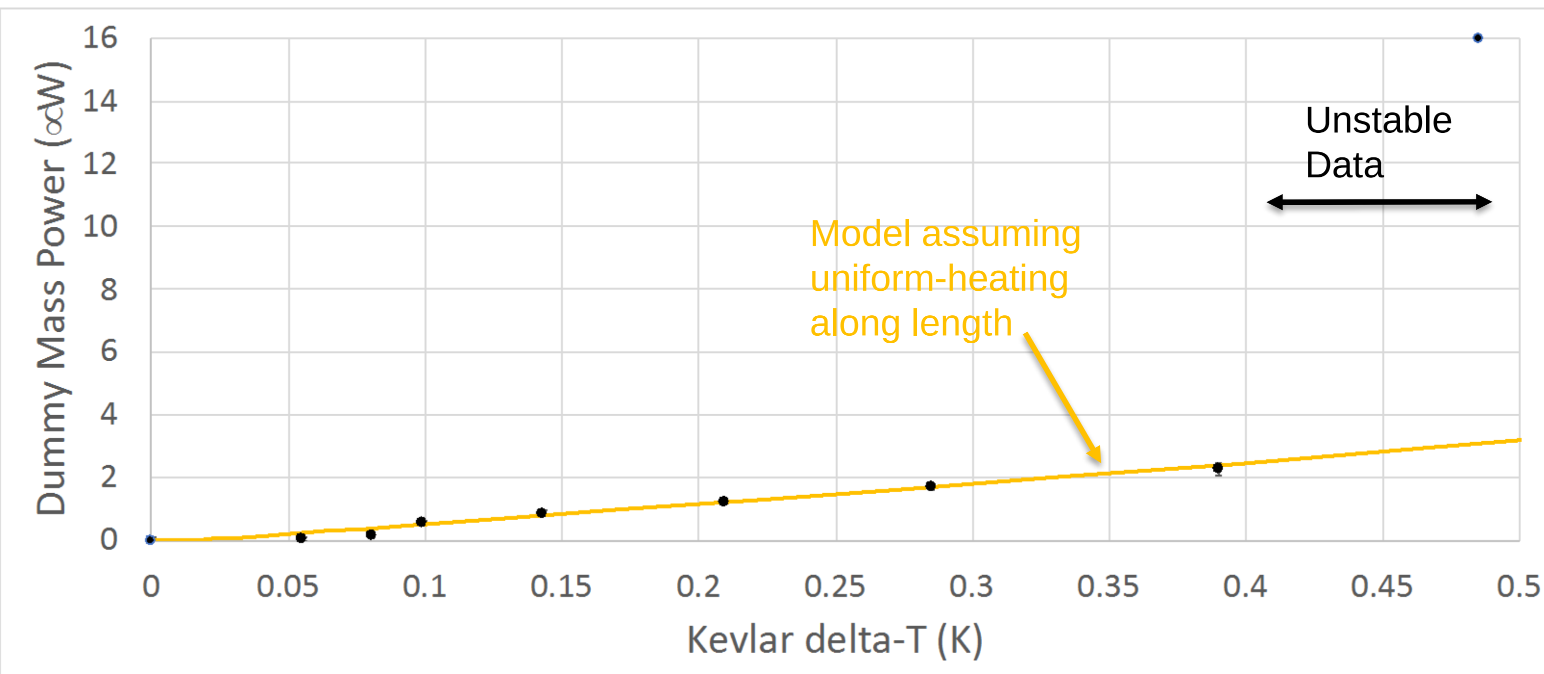
- We purchased 3-channel Attocube IDS3010 displacement sensor
- Fiber-optic system measures distance from sensor head to a reflecting surface @ 1MHz
- Mounted 3 heads on support frame aiming at retro-reflecting tape on dummy mass
- Began with one vertical and two horizontal displacement channels
- Applied vibrations with external transducer; measured motion of mass relative to frame



Test rig with Attocube position sensors

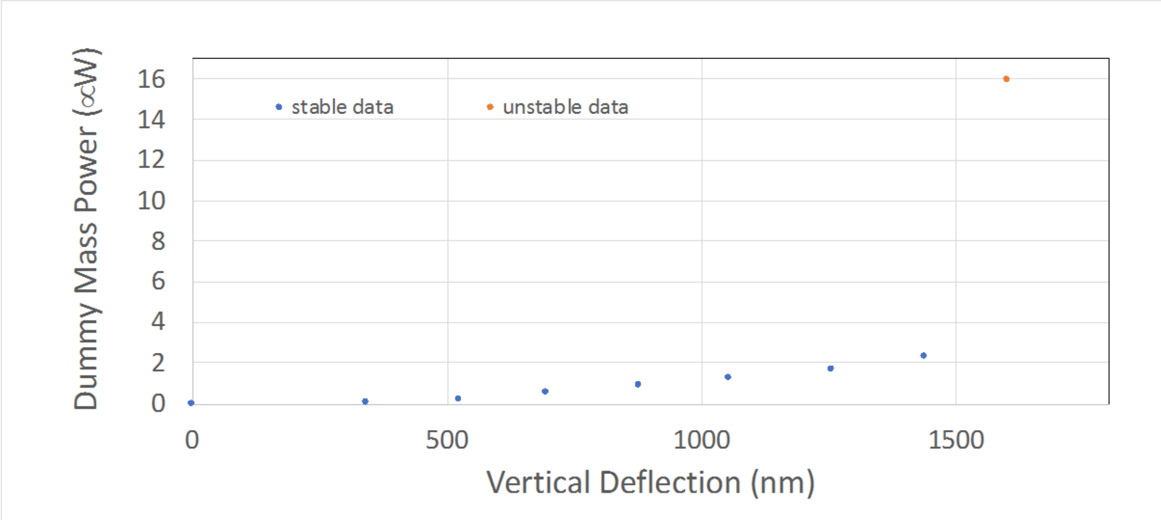
First Data Run

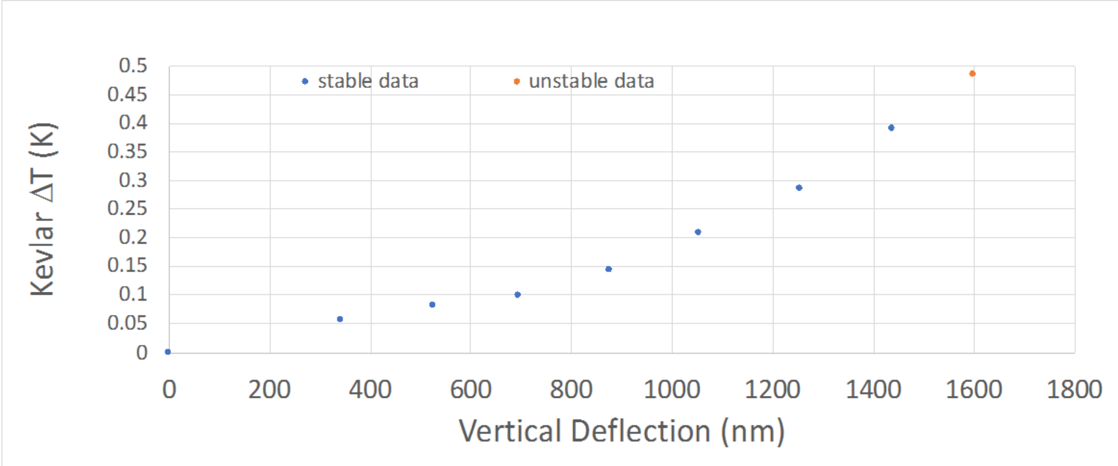
- Both horizontal reflectors fell off dummy mass on cooldown; vertical reflector survived
- Convenient to operate at 6 K; we ran Kevlar thermal model for that temperature
- Kevlar thermometer was calibrated *in-situ*
- Discovered a vibration mode at 128 Hz that gave a good signal for different amplitudes
- We measured ΔT(Kevlar) and dummy mass heating



Data vs. Vertical Deflection

- We calibrated the dummy mass vertical deflection for each data point
- Data suggest onset of "Belleville heating" at ~ 1500 nm deflection

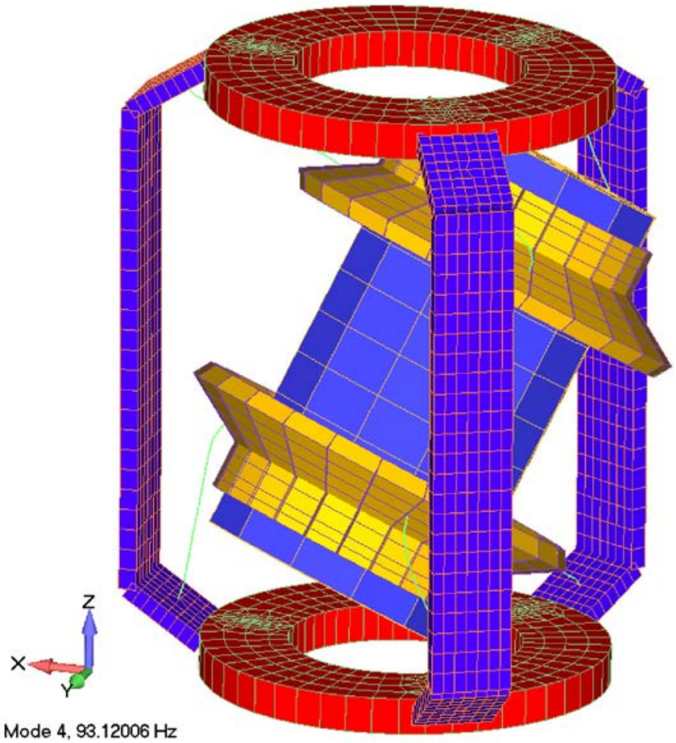




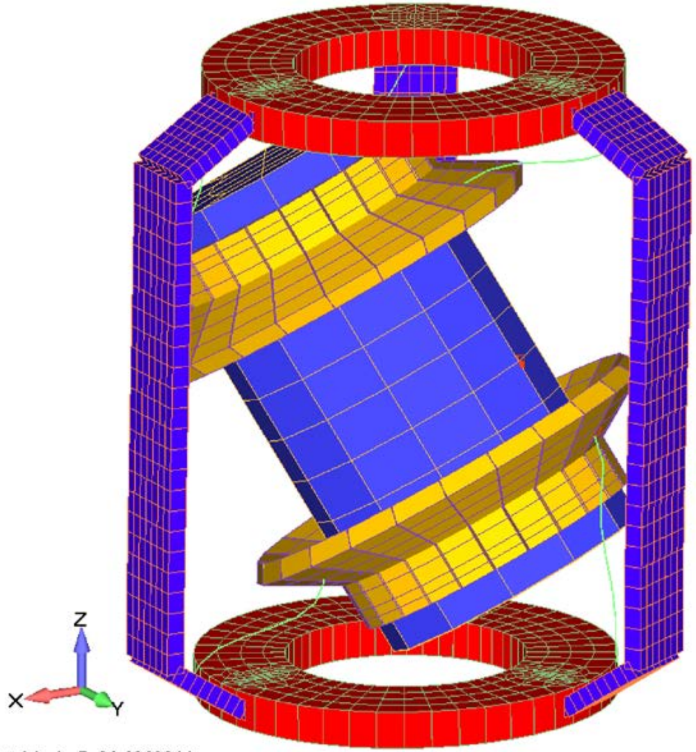
Structural Analysis

Cryogenics and Fluids Branch

- Analysis found dummy mass tilting modes at 94 Hz
  - Belleville/Kevlar stiffness uncertainties could explain 128 Hz mode seen

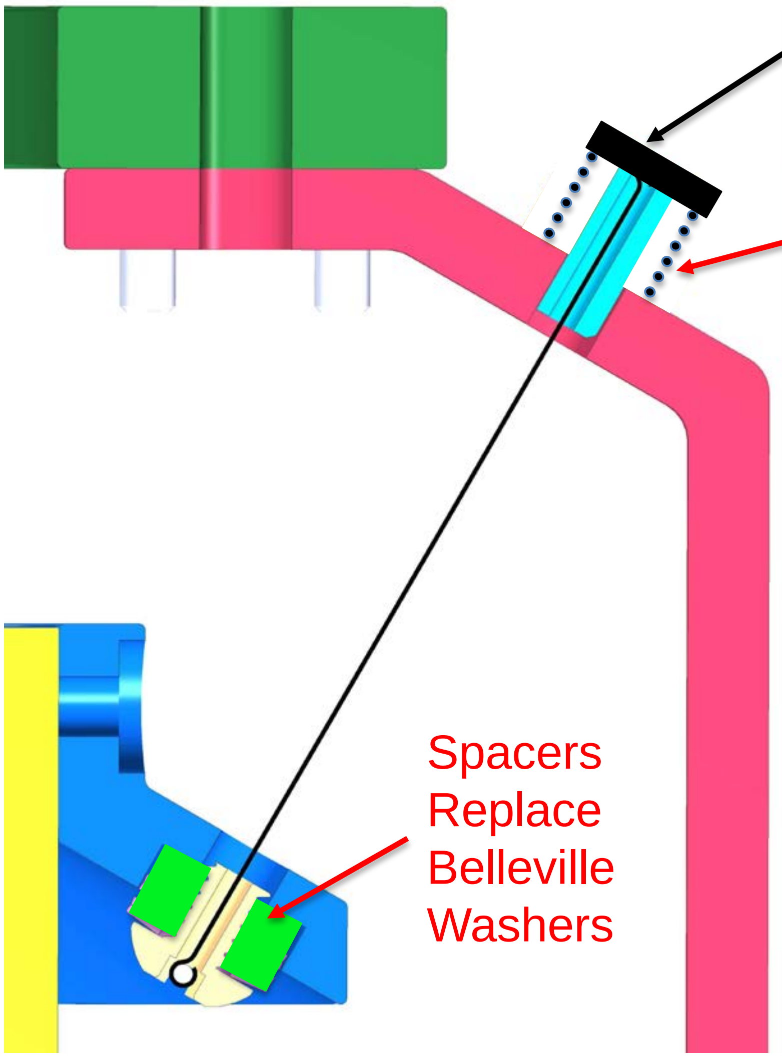


Output Set: Mode 4, 93.12006 Hz



Output Set: Mode 5, 94.43483 Hz

Modifications to Test Assembly

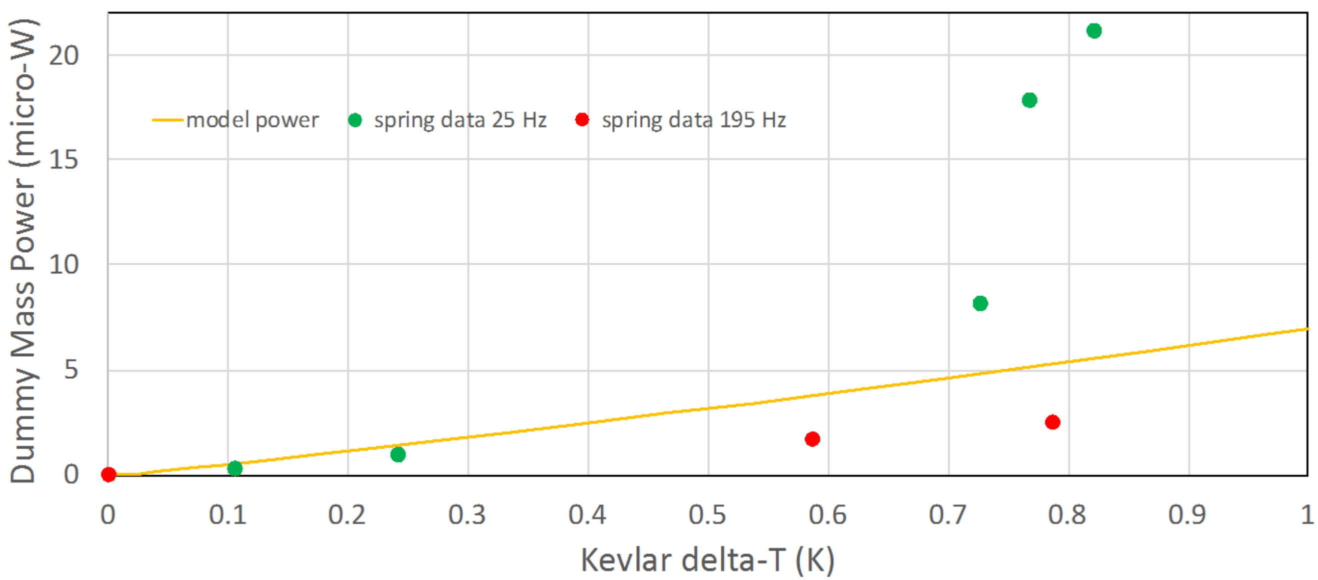


Also, epoxy was adde around edges of retro-reflecting tape dots

Second Data Run

Cryogenics and Fluids Branch

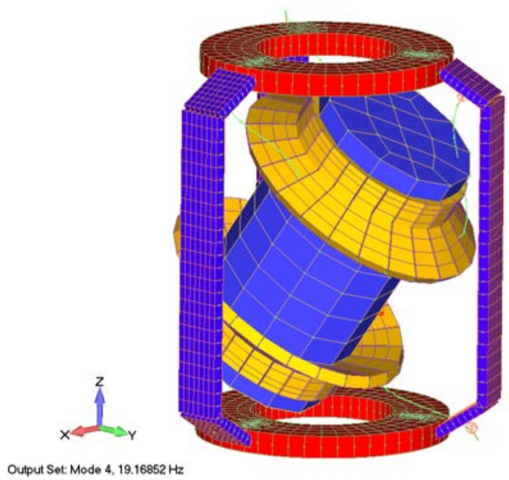
- Soft spring made data acquisition difficult:
  - Much larger deflection needed for same Kevlar motion
  - Springs shifting position?
- At 25 Hz we again saw onset of non-Kevlar heating; rattling spacer?
- At 195 Hz dummy mass power was ½ that predicted by uniform-heating model



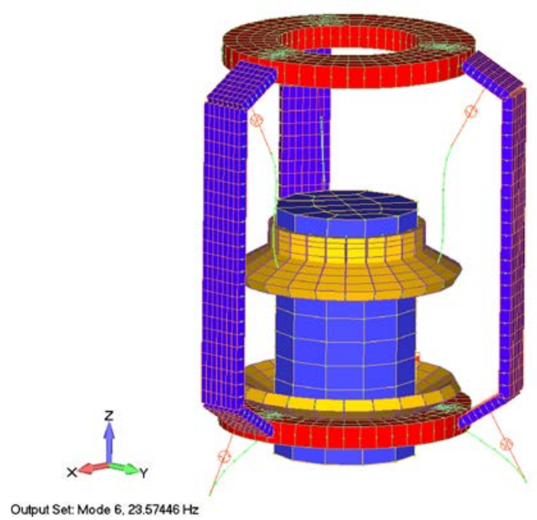
Soft Spring Modes near 25 Hz

Cryogenics and Fluids Branch

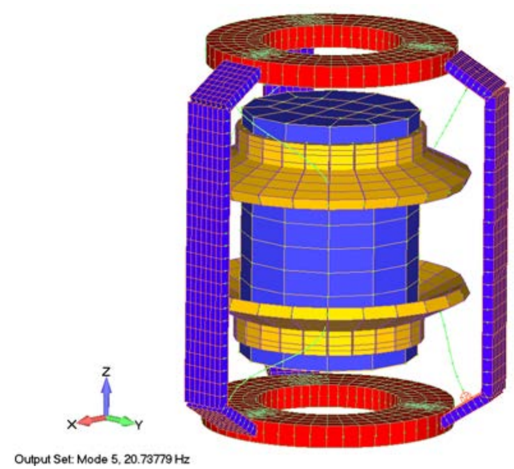
- Analysis found multiple modes near 25 Hz
- These modes involved all six Kevlar legs



Tilting Mode
19.1 Hz



Bouncing Mode
23.6 Hz

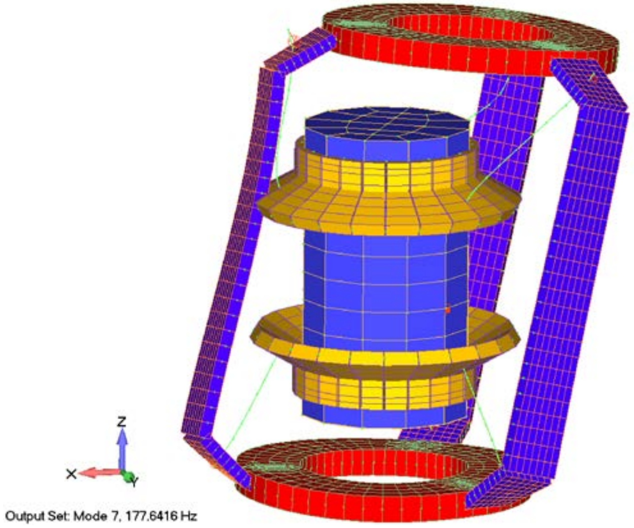


Rotating Mode
20.7 Hz

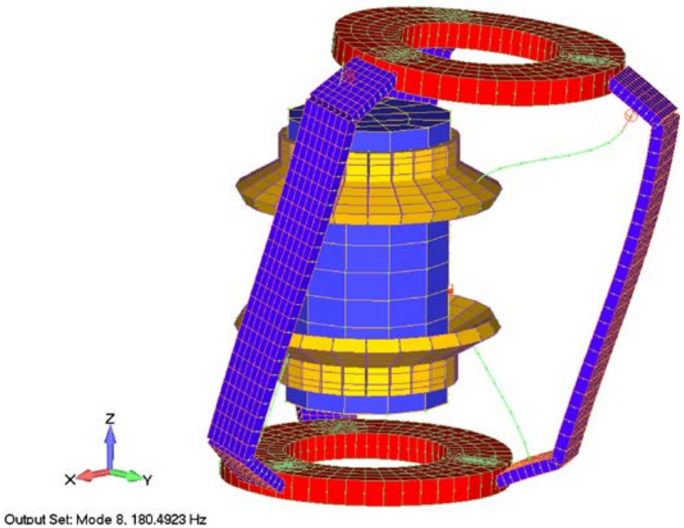
Soft Spring Modes near 195 Hz

Cryogenics and Fluids Branch

- Modes near 195 Hz had stationary dummy mass, tilting frame
- Kevlar thermometer was located near free (tilting) end of frame
- Explains why dummy mass power was 50% of model prediction



Frame bending in X direction
177 Hz



Frame bending in Y direction
180 Hz

Conclusion

- This work is a starting point for studying vibration-heating in suspensions
- We need to improve our retro-reflectors
- Data suggests that spacers and springs should have been epoxied in place
- Next step is to replace soft springs with designed-for-flight flexures