Mini/MEMs Tri-Axis Sensor System (MTASS)

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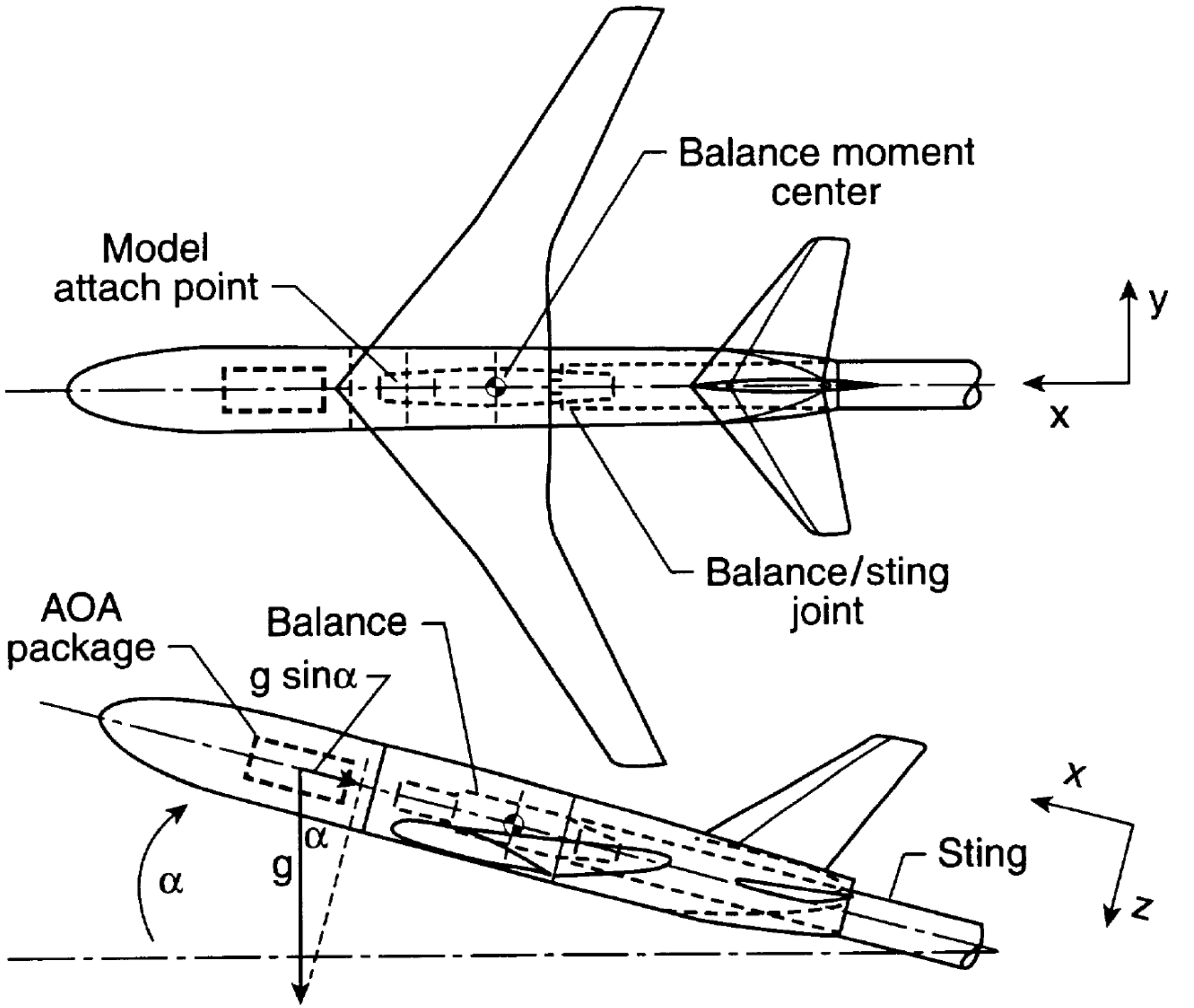
January 9, 2023

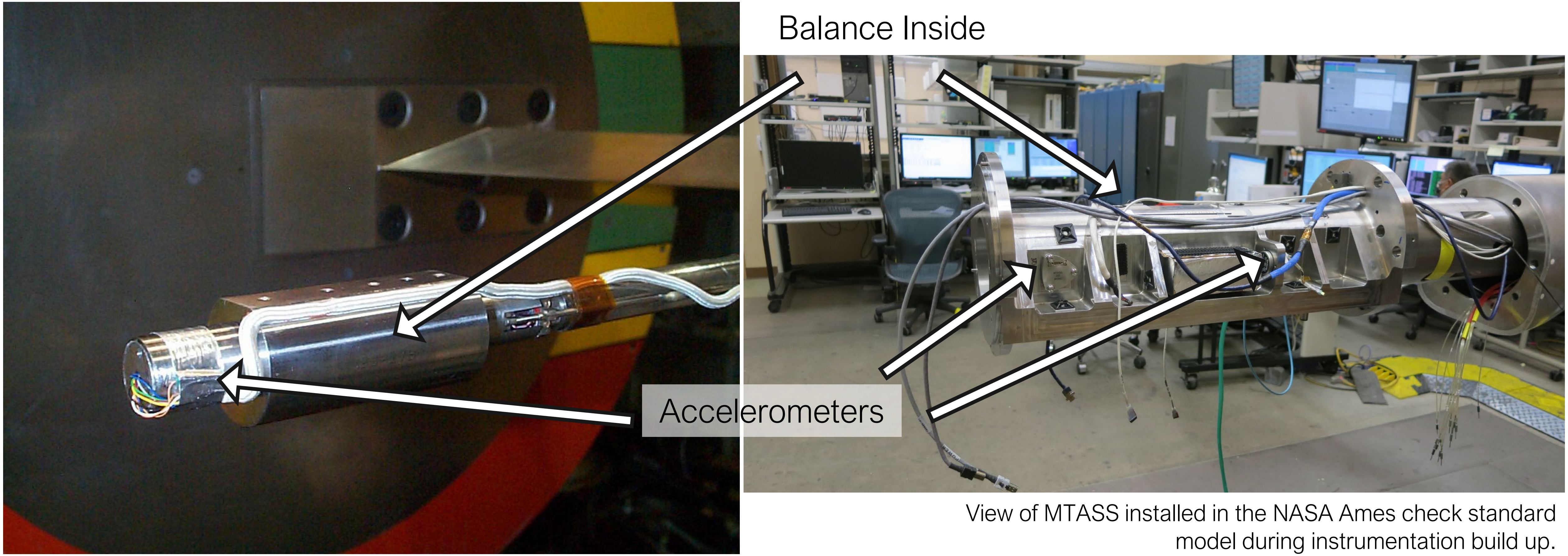
AIAA SciTech 2024
Orlando, FL

Force and Angle Measurement

- **Force and angle are two principal measurements used to evaluate aerodynamic performance**
  - Basic Lift: $L = \frac{1}{2}\rho V^2 A C_{L_\alpha}\alpha$
- **Six-component force balance provide direct model load measurement**
- **Angle is measured using a variety of methods:**
  - Onboard Accelerometers
  - Support structure angle measurement (Accelerometers, potentiometers, LVDTs, etc.)
  - Photogrammetry



Force and Angle Measurement Examples

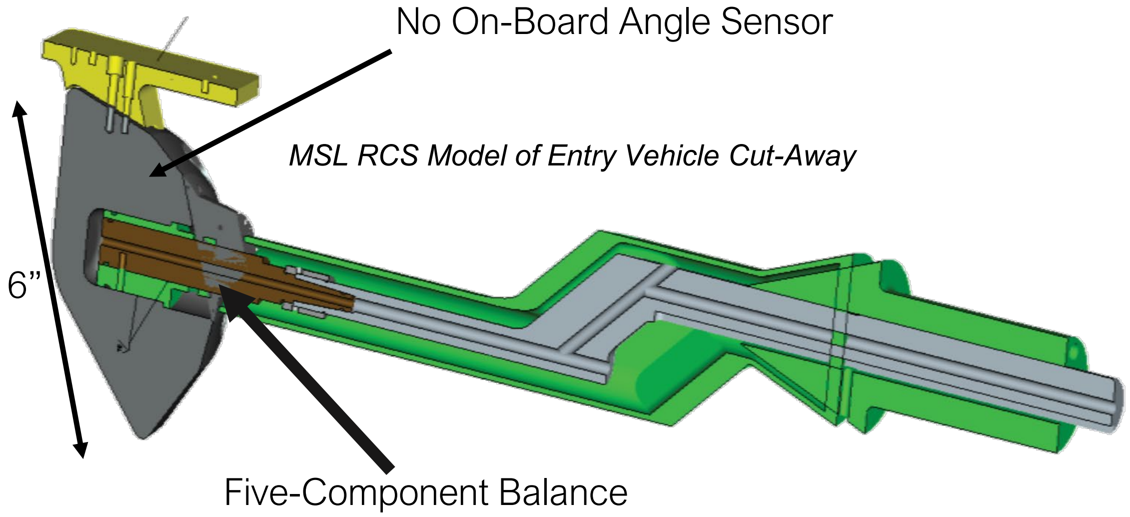


Accelerometer and Force measurement installed in 31-inch Mach 10 Wind Tunnel.

View of MTASS installed in the NASA Ames check standard model during instrumentation build up.

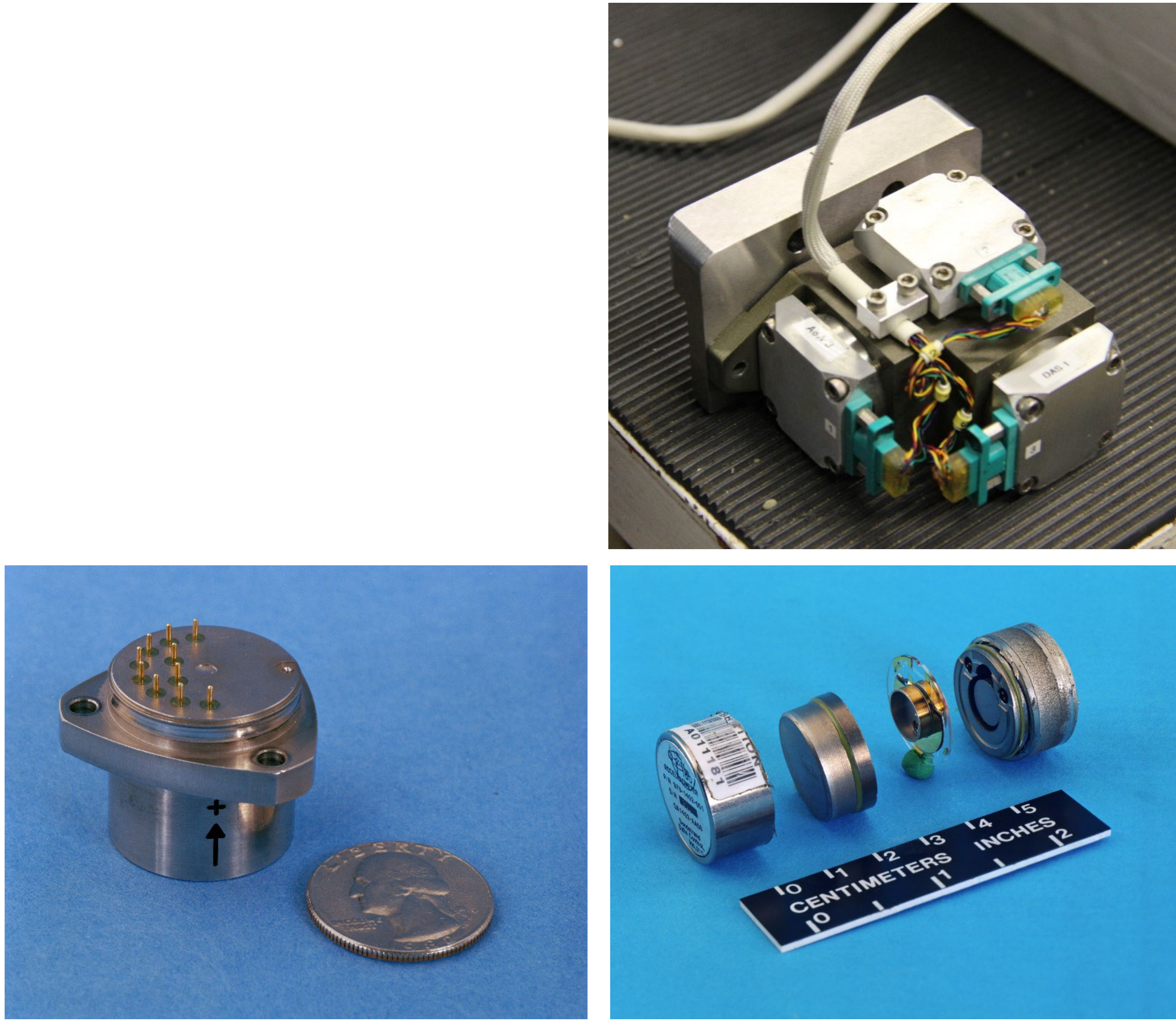
MTASS Project Overview

- **Create a family of reduced volume model attitude packages**
  - Current sensors provide challenges with small models (supersonic, hypersonic)
- **Tri-axis capability to allow flexibility usage**
  - Pitch and roll measurement on-board
  - Flexible positioning
- **Lower cost of assembled unit**
- **No additional signal conditioning required**
  - Current accelerometers require additional rack mount components



Current State of Art

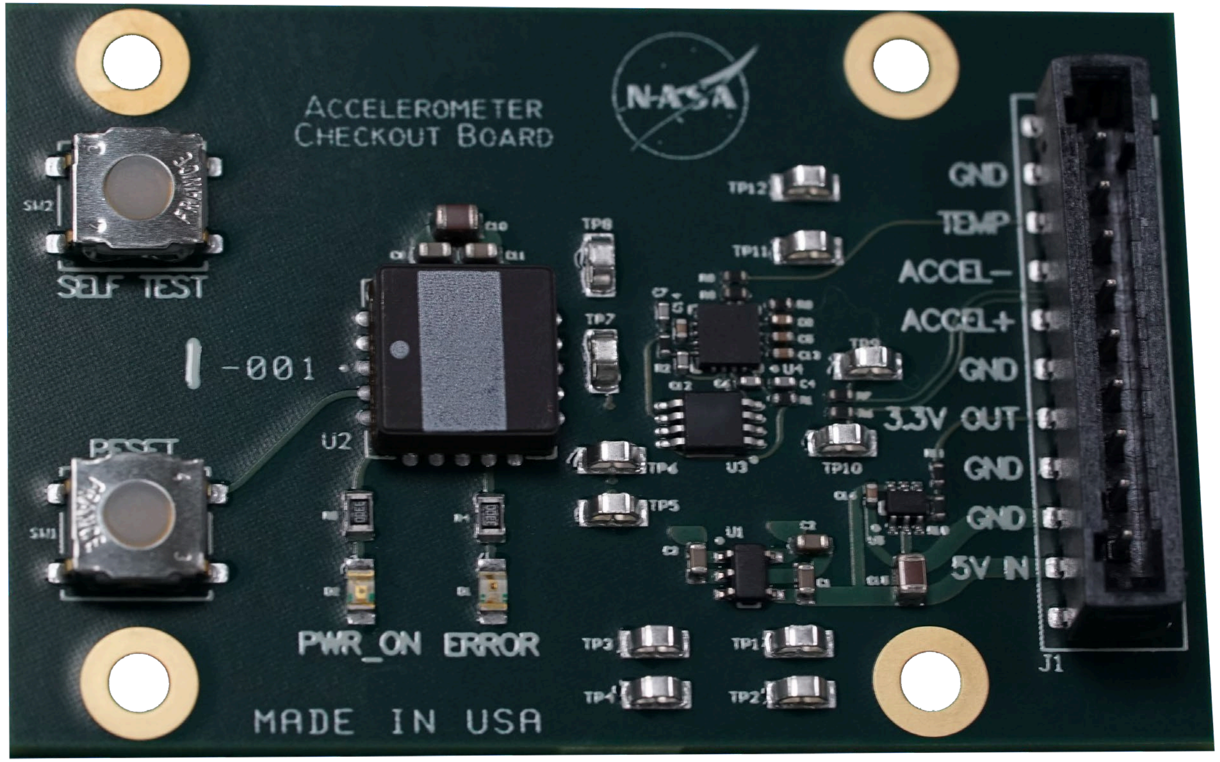
- **Internal seismic mass on spring**
  - Mass deflection proportional to acceleration
  - Acceleration = Sine of Angle
- **Q-Flex uses a quartz spring**
  - Long term stability
  - Low bias shifts
  - Low temperature sensitivity
- **Tri-axis accelerometer package capable of measuring pitch and roll angles**
  - Typically used for model setup and as a transfer standard
  - Gravity reference does not allow estimation of yaw angle



Tri-axis head (top) and Q-Flex sensor with cutaway (bottom).

MEMs Sensor and Checkout Board

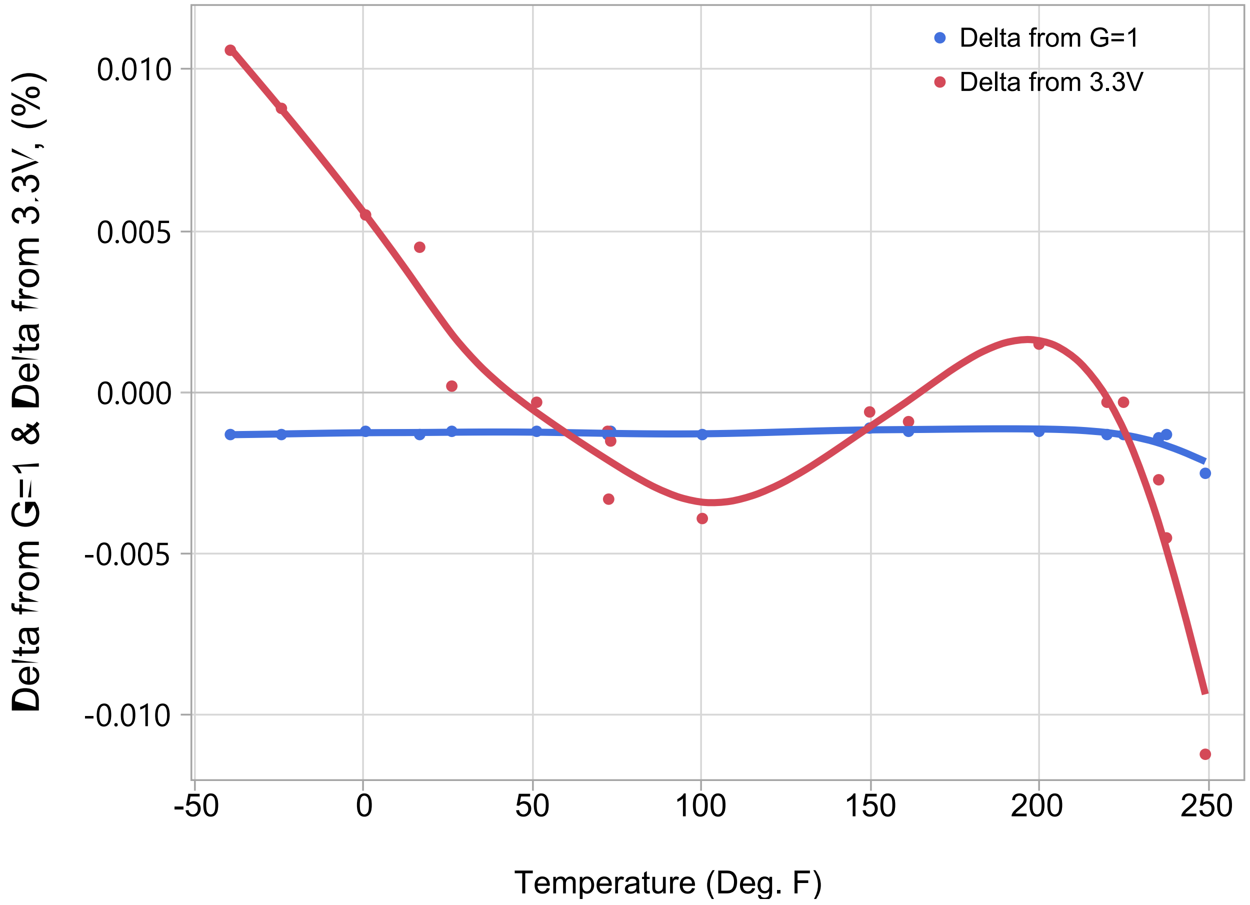
- **High-end, single-axis, accelerometer (2g Specs)**
  - Long term bias and scale factor repeatability, 0.24 mg
  - Low in-run bias, 3 µg
  - Internal temperature sensor
  - 0.35-inch (8.9mm) edge length
- **Single sided PCB layout for ease of mounting to test fixtures**
- **Accelerometer-less PCB was be used to test performance and thermal stability of signal conditioning**



Single-axis evaluation board with MEMs accelerometer.

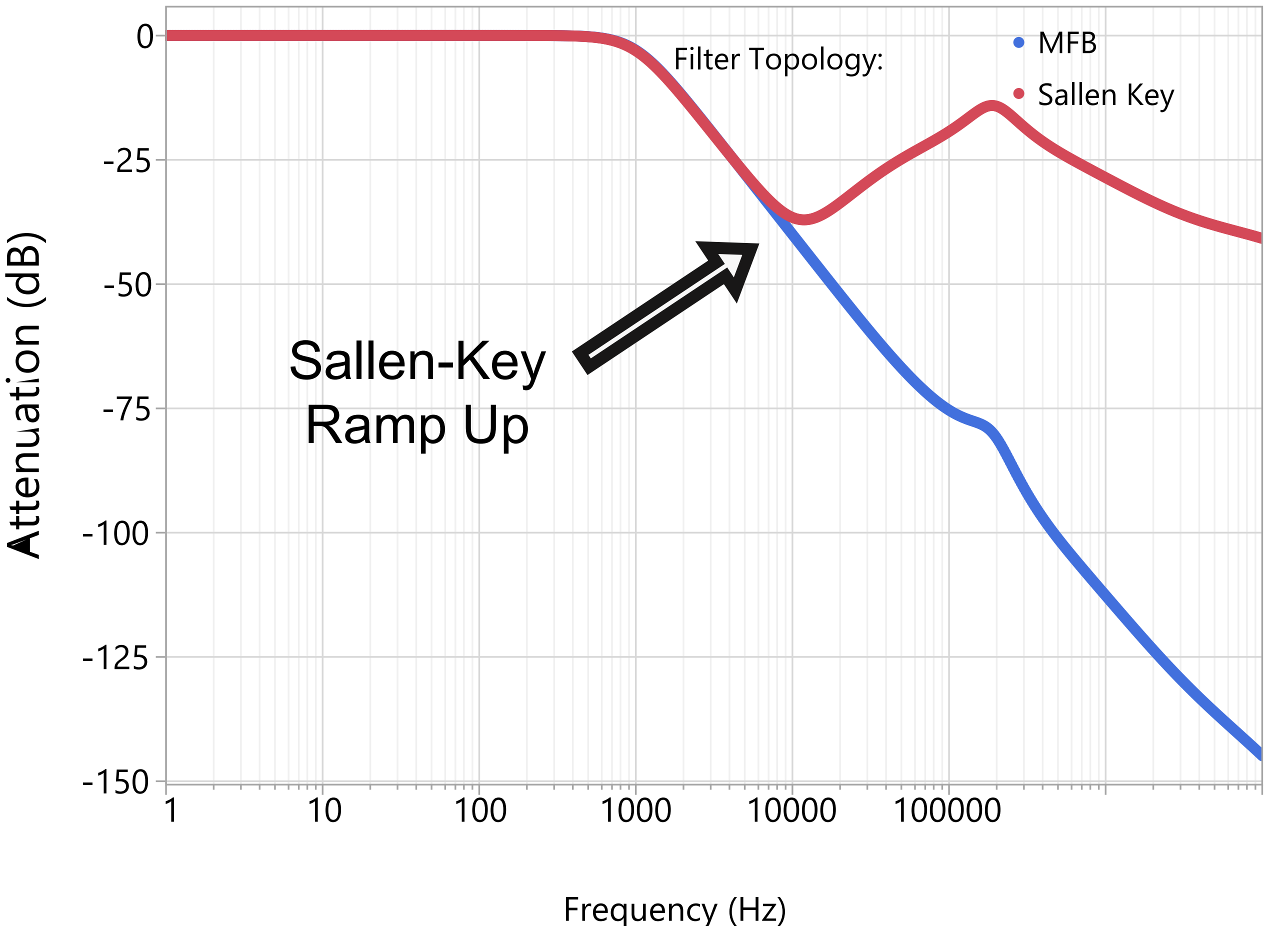
Electronic Stability

- **Accelerometer produces a differential acceleration output and single-ended temperature output**
- **Both outputs must be buffered for transmission along a cable due to low capacitive load driving capability**
- **Manufacturer stipulates that connected op-amps must have ultra-low bias current and the circuit must have 1MΩ input impedance at a minimum**
- **Acceleration output has 200kHz switching noise from a capacitance-to-voltage converter internal to the sensor package**



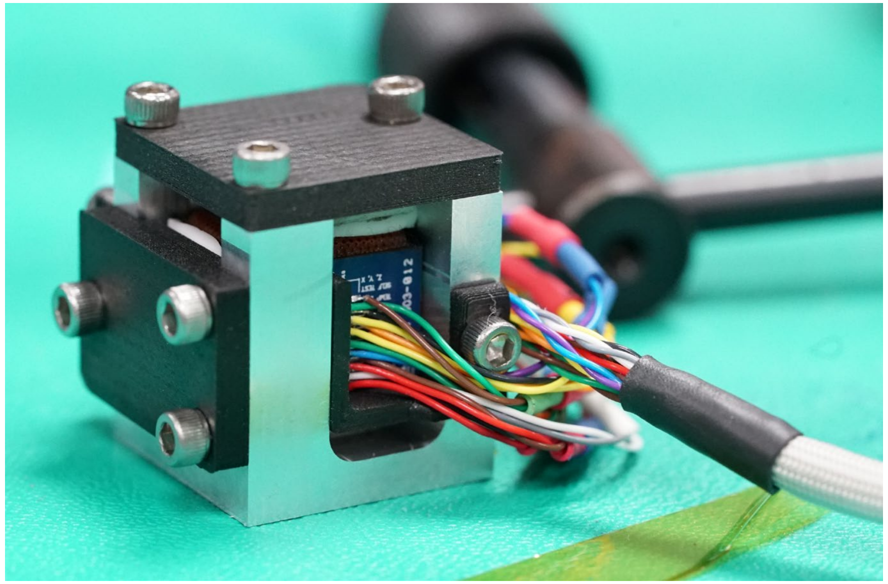
Filter Topology

- A 2-pole Multiple Feedback (MFB) topology filter with a 1kHz cutoff frequency was designed to filter and buffer the acceleration output
- MFB was chosen due the relatively high output impedance of ultra-low bias current op-amps, which would cause the attenuation of the filter to degrade above 100kHz and ramp back up
- A Sallen-Key topology filter would require a follow-on RC filter to counteract the ramp up, the resistance of which would interact with the input impedance of any connected DAQ device
- For the gain setting resistors of the MFB filter, a matched quad of 1MΩ was chosen to produce a stable gain of 1

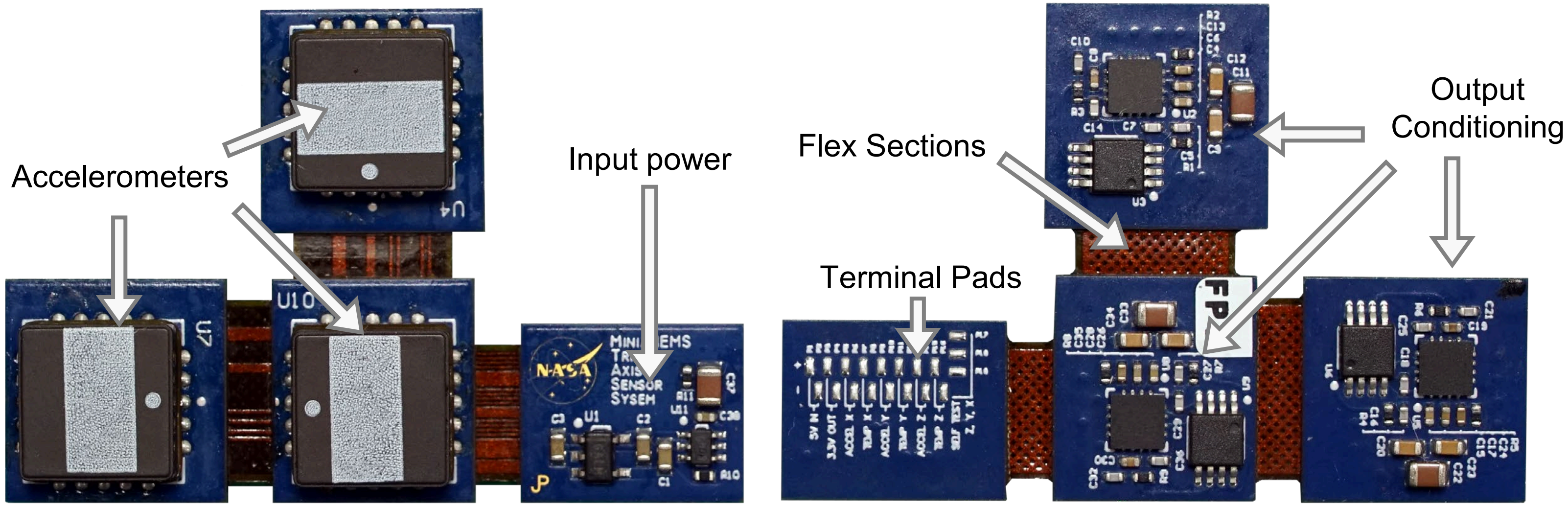


Tri-Axis Boards

- **Three single-axis sensors placed orthogonally to provide pitch and roll through 360°**
- **Folded PCB assembly approximately 0.6-inch cube.**
- **Supporting electronics on-board, no extra data-system requirements**
- **Initial results show good performance on the order of 0.01 Deg**



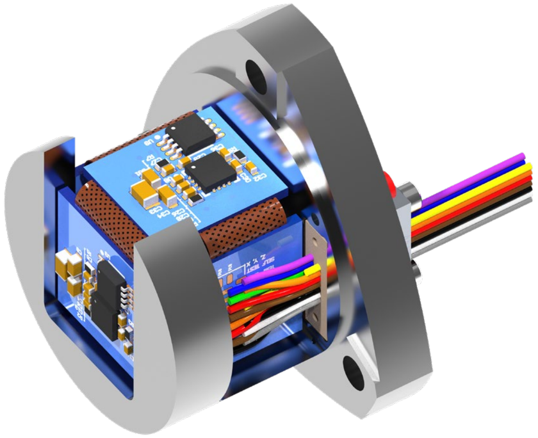
MTASS board in demonstration assembly.



Assembled MTASS layout and components.

Packaged Prototype Sensor

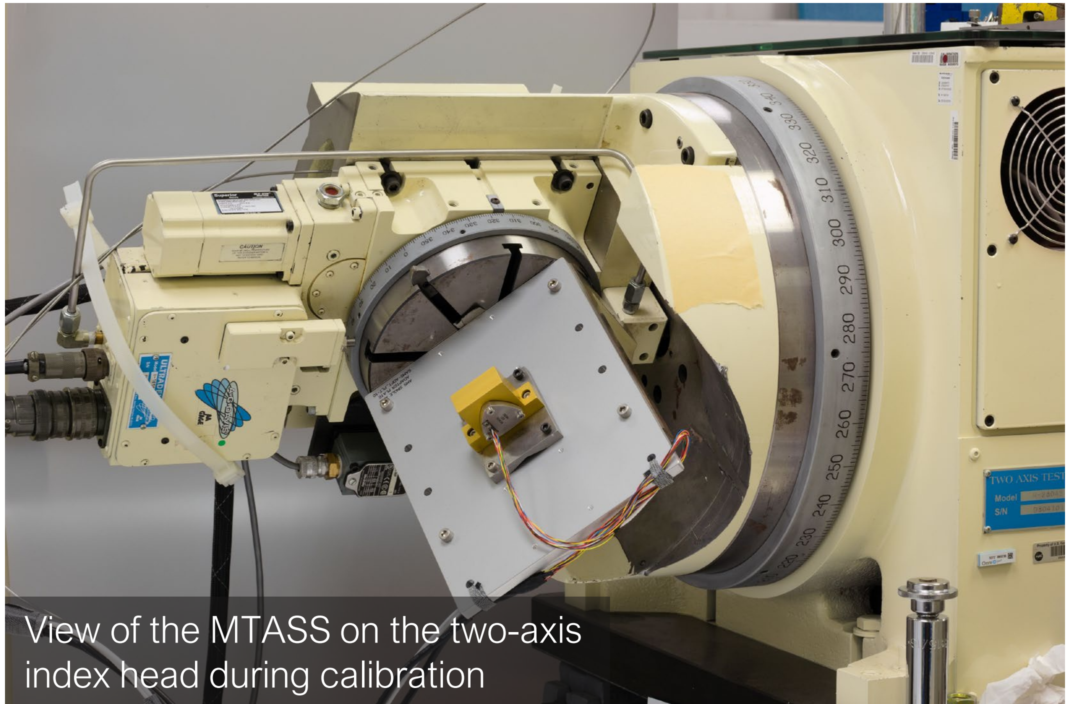
- **Mimics the packaging of a Honeywell Q-Flex**
  - Common interface in-use at NASA
  - Many current fixtures available for evaluation/calibration
  - 1-inch Diameter
  - 0.65-inch forward from foot pad (Ref. Q-Flex is 0.58”)
  - Same bolt pattern design.
- **Omnetics Nano-D 15 Pin**
  - 16 Conductors (Temperature leads expanded)
- **Assembly is fully potted to protect electronics**



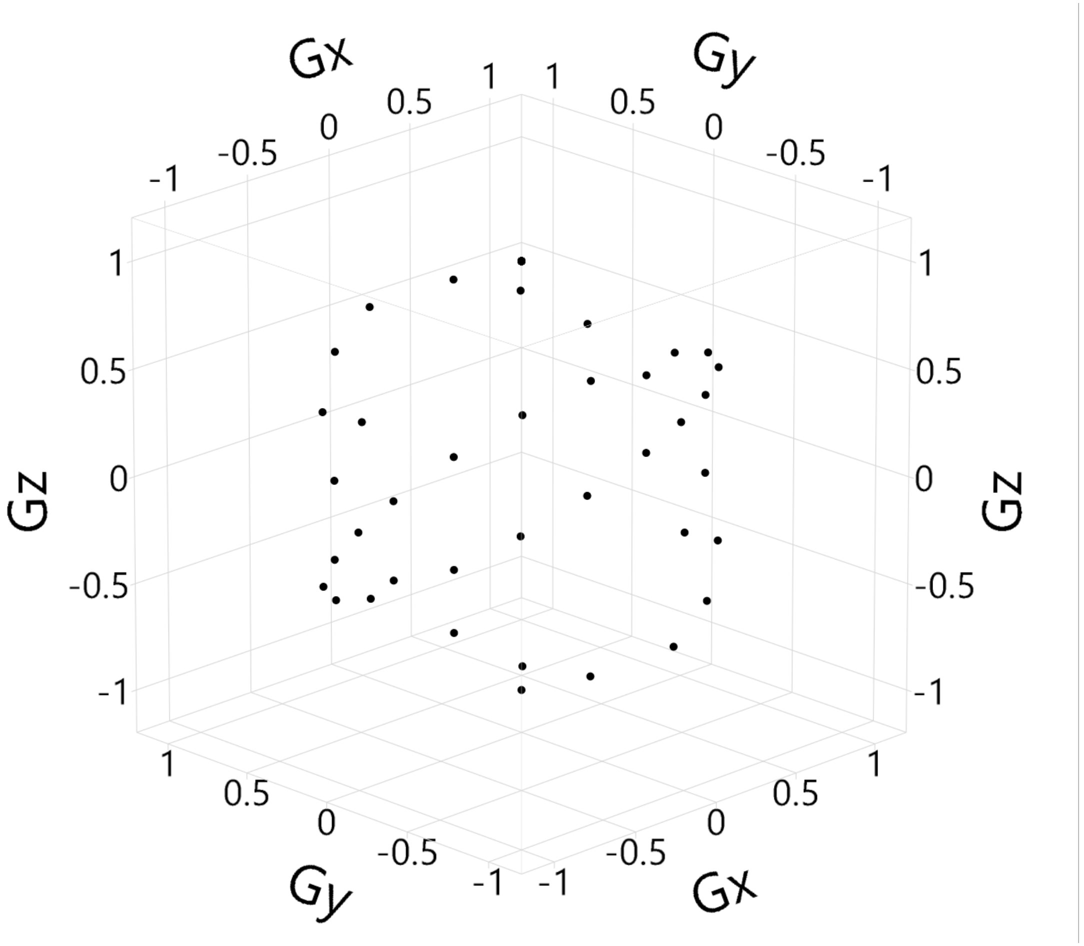
Partially fabricated (above) and completed (below) MTASS units.

Calibration Design

- **Calibration and Test Points**
  - Full scale points for model (±35° Pitch, 360 Roll)
  - Low angle confirmation points
    - Simulated tunnel use
    - ±15° Pitch at 0° &180° Roll



View of the MTASS on the two-axis index head during calibration



Calibration experimental design for MTASS.

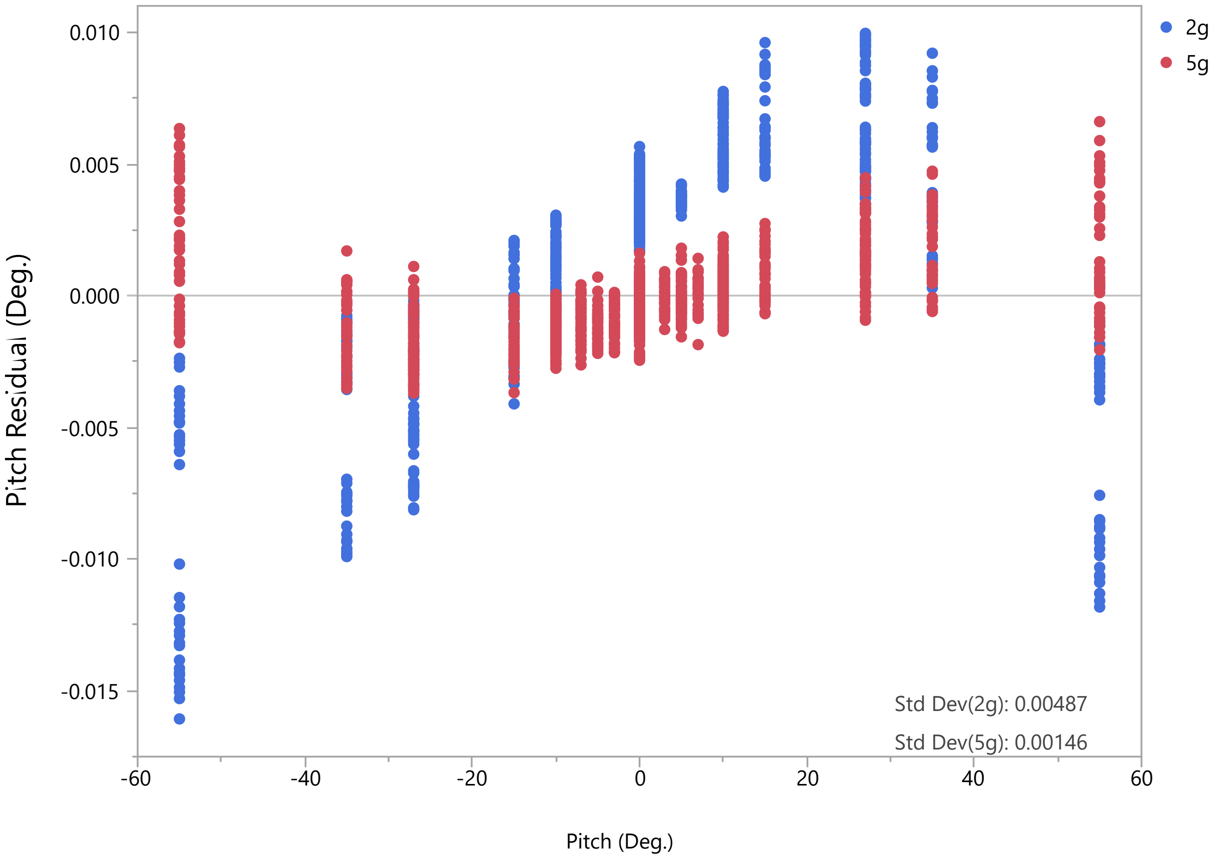
Calibration Model – Linear

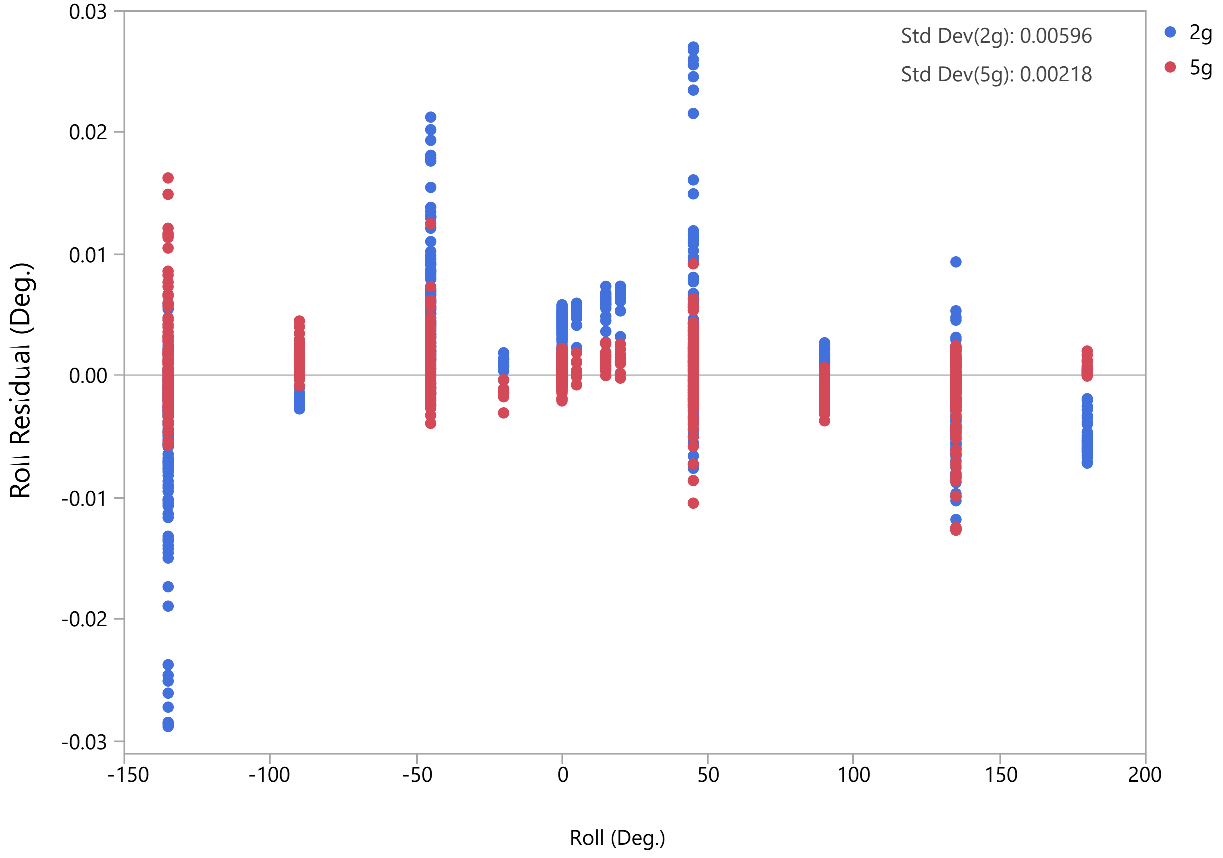
- **Linear model was fit between voltages and set gravity vector**
  - $\boldsymbol{v = \beta_0 + \sum_{i=1}^{k} \beta_i g_i + \epsilon}$
  - No temperature corrections

- **Angles were back computed using the following trigonometry functions:**
  - $\theta = \sin^{-1} g_x \, , \, \phi = \tan^{-1} \frac{g_y}{g_z}$

- **Calibration conducted over 3 days of continuous sampling**
  - 26 repeated run schedules
  - Calibration model build on off one run.

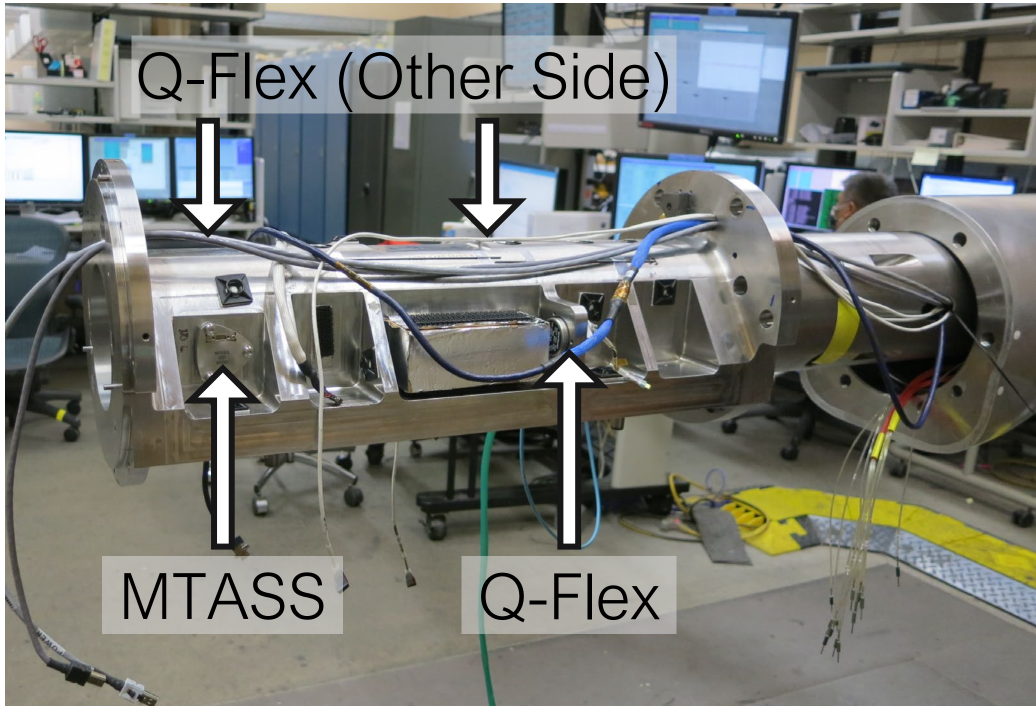
Calibration Results, Residuals Charts





Ames Check Standard Demonstration

- **Ames Unitary Plan Wind Tunnel Check Standard Model provides four Q-Flex locations**
  - Two pitch and two roll locations
  - redundant locations allow for low-risk demonstration opportunity
- **MTASS installed in secondary roll Q-Flex location, tri-axis format allows for any installation position**
- **No Temperature compensation was applied**
- **Wiring used during test was found to have a fabrication error, may have impacted data quality**
  - Loss of sensor signal requiring data system/sensor reset
  - Temperature outputs accidentally combined, unintentional feedback loop



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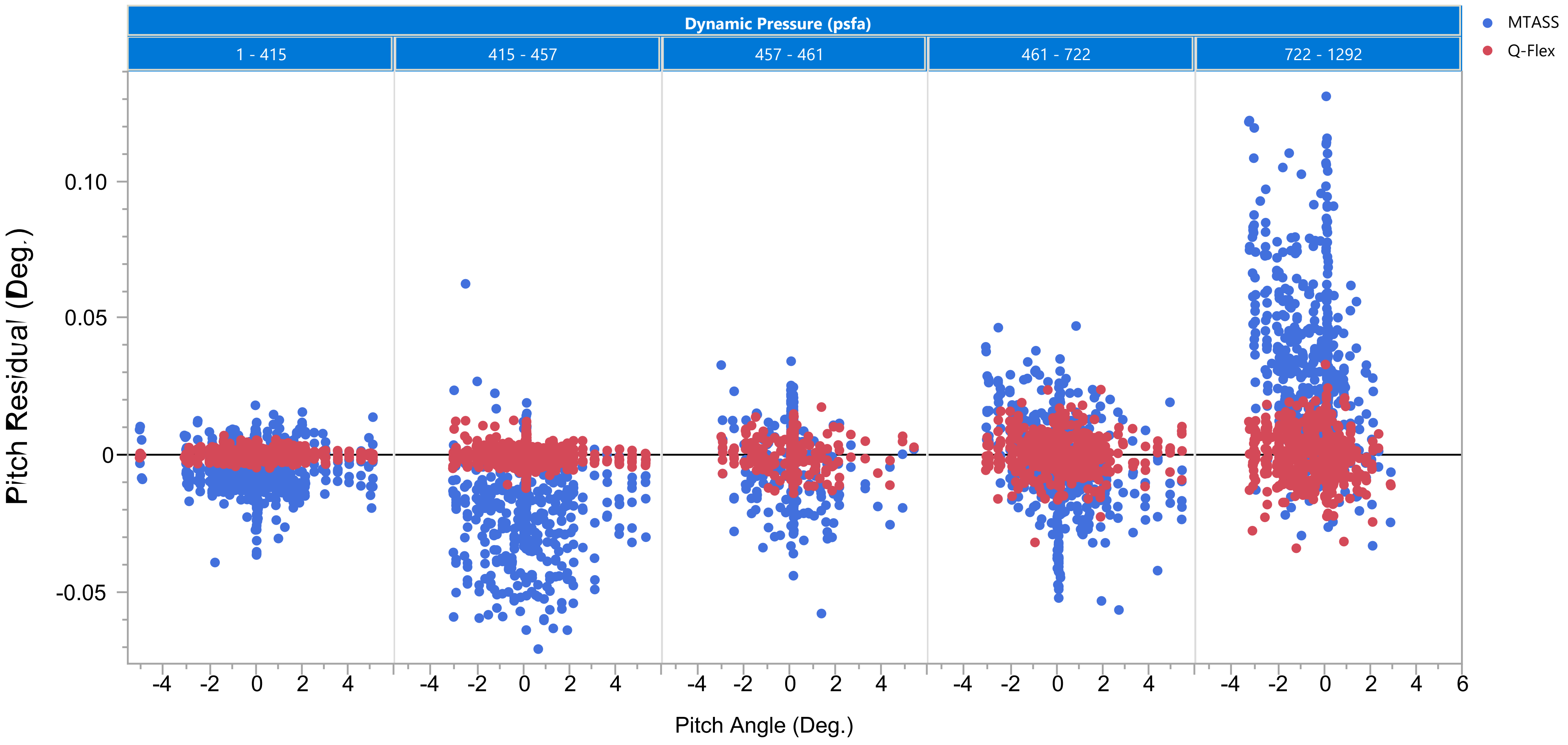
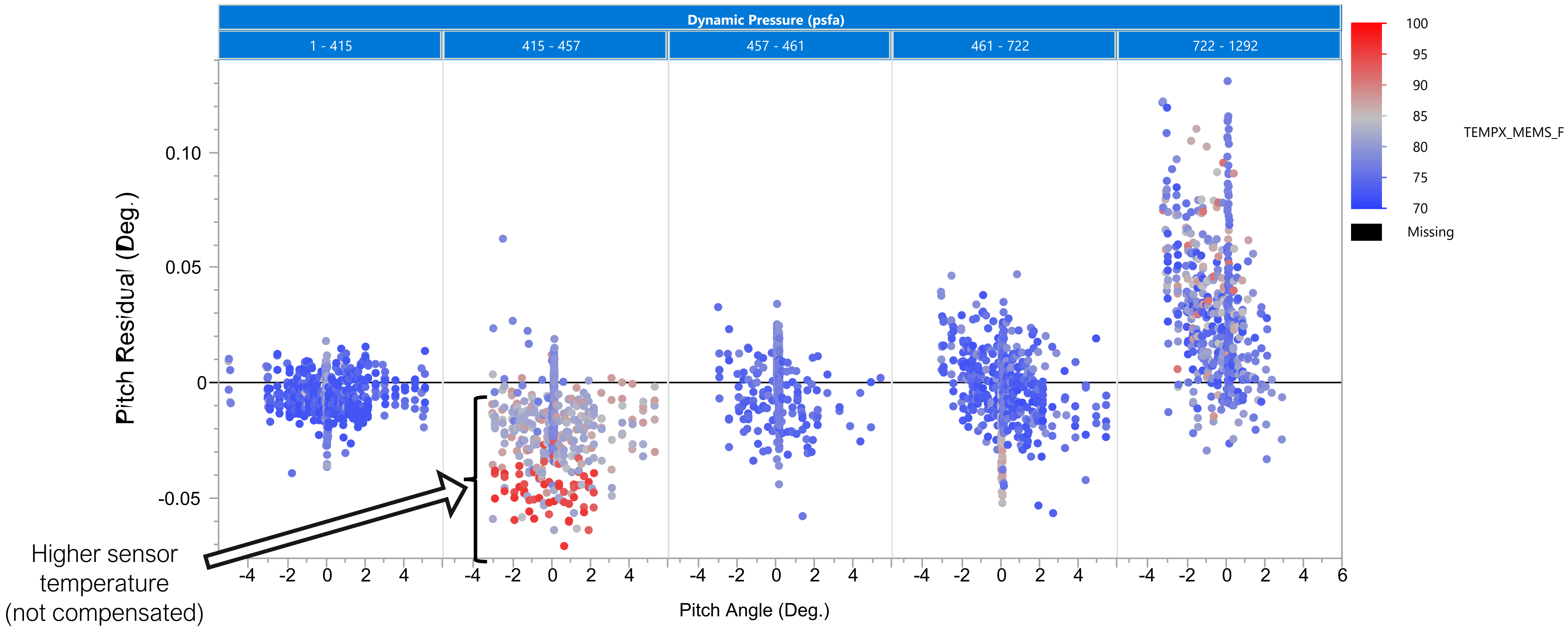
Ames Demonstration Results



Ames Demonstration Results (MTASS Only)



Summary

- **Accelerometers were integrated to form a tri-axis unit with a volume taken by a single axis Q-Flex**
- **Static calibrations demonstrated performance level meets requirements of aerodynamic ground testing**
- **Demonstration at Ames had promising results despite wiring issue**
- **Demonstration at AEDC Tunnel 9 results under review**
- **Future work:**
  - Temperature testing and compensation (Paper at IEEE Inertial 2024)
  - Dynamic evaluation and characterization
  - Long term stability and repeatability