GN&C Lessons Learned From Multiple Missions
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Flight Experience @ MAI

- 100+ years of Guidance, Navigation and Control (GN&C) design and flight experience at Maryland Aerospace Inc.
- 127 Attitude Determination and Control Subsystems (ADACS) built at MAI
- 31 ADACS units launched
- 12 recent ADACS units flown with returned telemetry, analyzed for hardware performance

CubeSat/NanoSat ADACS

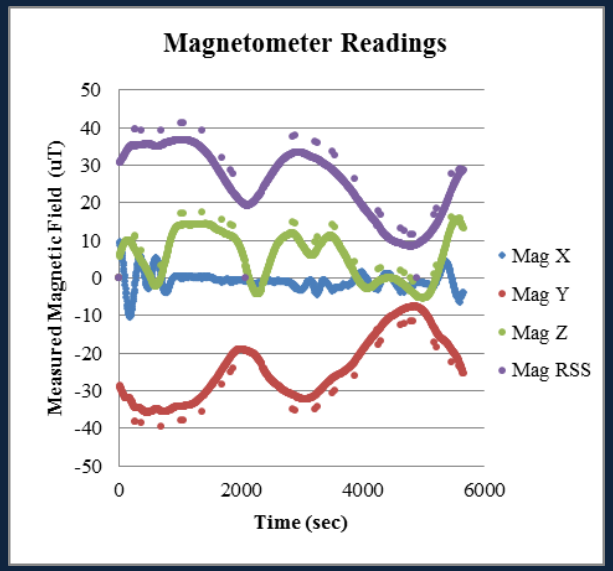
- Very challenging system
  - ADACS needs to do almost everything large, traditional space vehicles do
  - Similar hardware needs, goals of similar performance
  - Similar software requirements
  - Everything except (for now) redundancy
- Low volume, low mass, low cost ADACS are required for these missions
- Expectations are very high for performance and reliability
- Higher and higher performance desires without significant cost increases

Recent ADACS Experience

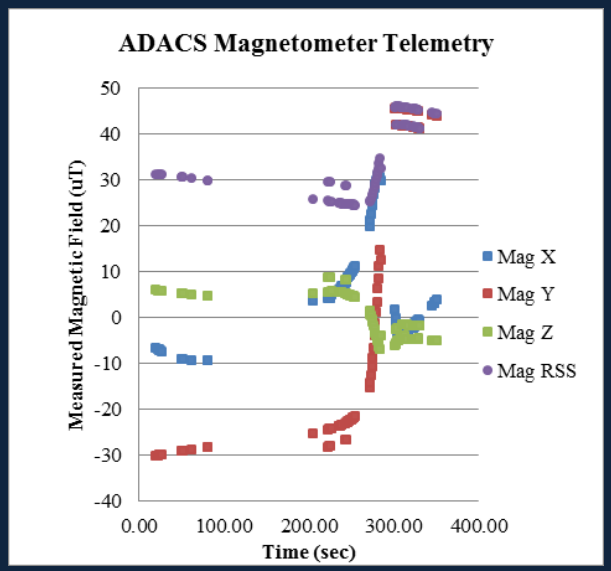
- 12 units flown with telemetry feedback to MAI in last 3 years
  - Many more coming in the next year
  - No failures, but lots of anomalous performance
- Several other missions have gone through integration and test and provided feedback to hardware performance
- Ideal hardware performance rarely matches "real world" test or on-orbit data
  - Idealistic testing also needs to be scrutinized

Magnetometer Experience

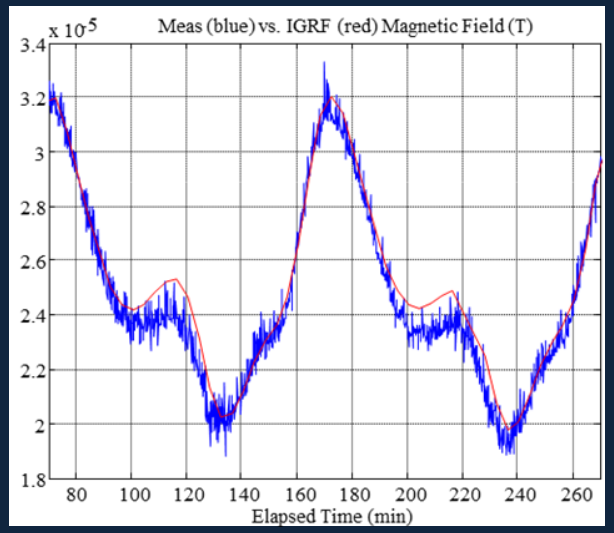
- Magnetometer can see jumps and biases from residual magnetic fields
  - Vehicles are very small, may not be able to place the magnetometer where it isn't affected
  - Need to calibrate for scale factor, bias of local fields



Jumps from short term equipment (comms)



Improper scale factor and bias calibration shown from vehicle slew



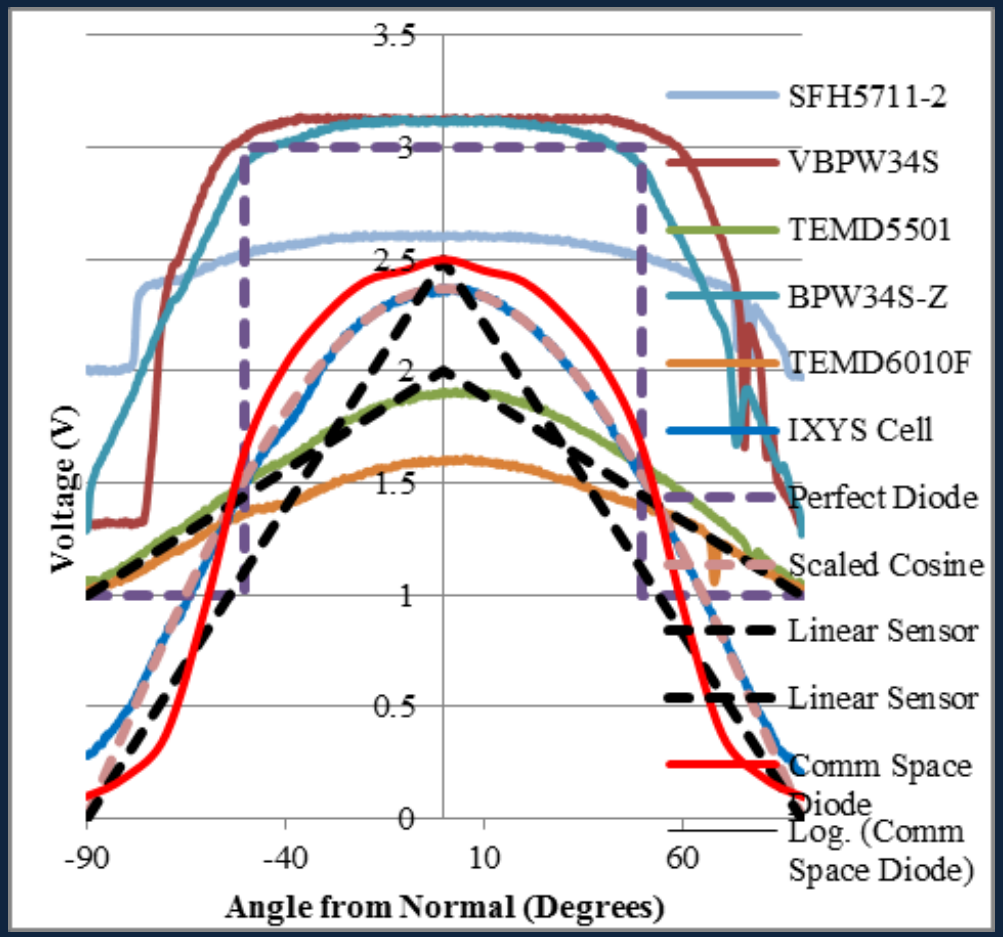
Noise, jumps and actual vs. modeled field

Sun Sensor Experience

- Sun sensors for a number of missions used as a primary attitude knowledge, vs. traditional use of a sun pointing support function
  - Reliance of accuracy over spherical coverage typical
- Many Cubesat builders not angling sensors to avoid deployed appendages or shadowing of sensors
- Combination of sensors should be done with “intelligence” of knowledge, not averaging of groups of sensors
  - Avoid known problems based on previous cycle
- Variety of sensor types have varied performance

Sun Sensor Experience

- Not all "sun sensors" follow a predicted curve

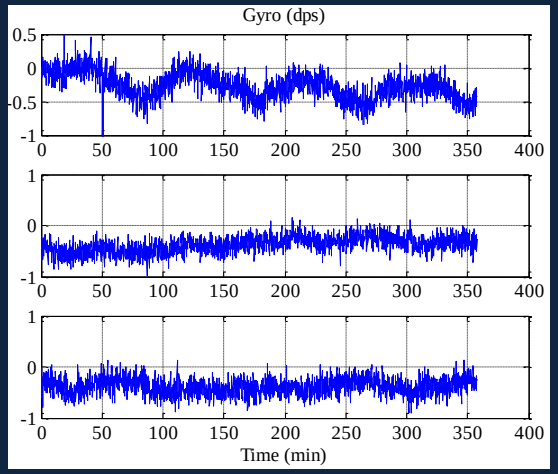


MAI Solar Test Results

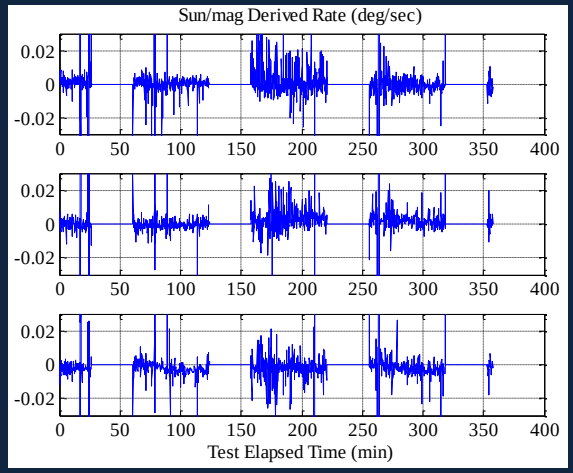
- IXYS Silicon PV cell matches a cosine curve very well (past 85 degrees)
  - GA cells may also perform well (not tested)
- Photodiodes have wide range of performance, but none match a well known curve
  - Some are not usable as an angle sensor (too flat)
  - Requires table-look-up calibration
  - Found to be more sensitive to reflections, Earth albedo

Gyroscopes

- Gyros traditionally used to propagate attitude when sensor data is unavailable
  - Drive toward very low noise, very low drift gyros
- MEMS gyros are not adequate for accurate pointing
- Fiber optic gyros are small and better performing, but have issues for CubeSats
  - Radiation darkening, power use (1W/axis for small gyros), size
  - Still do not approach larger space gyros

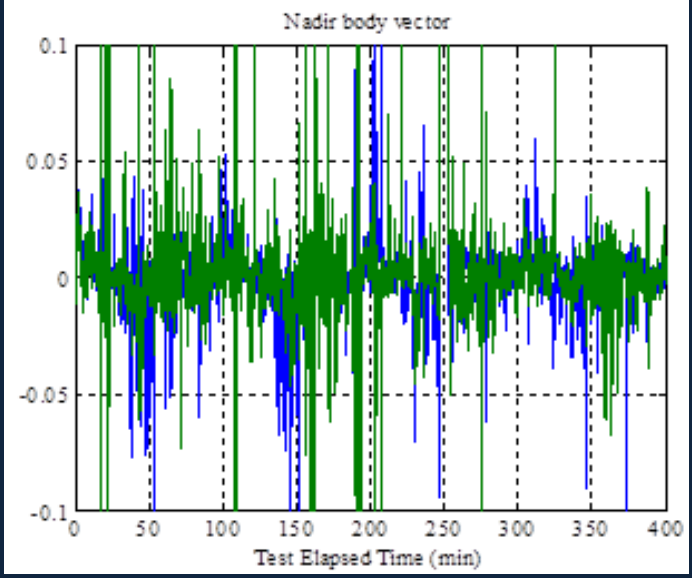


MEMS gyro noise and bias variation is 10x larger than sensor derived rate (unfiltered)



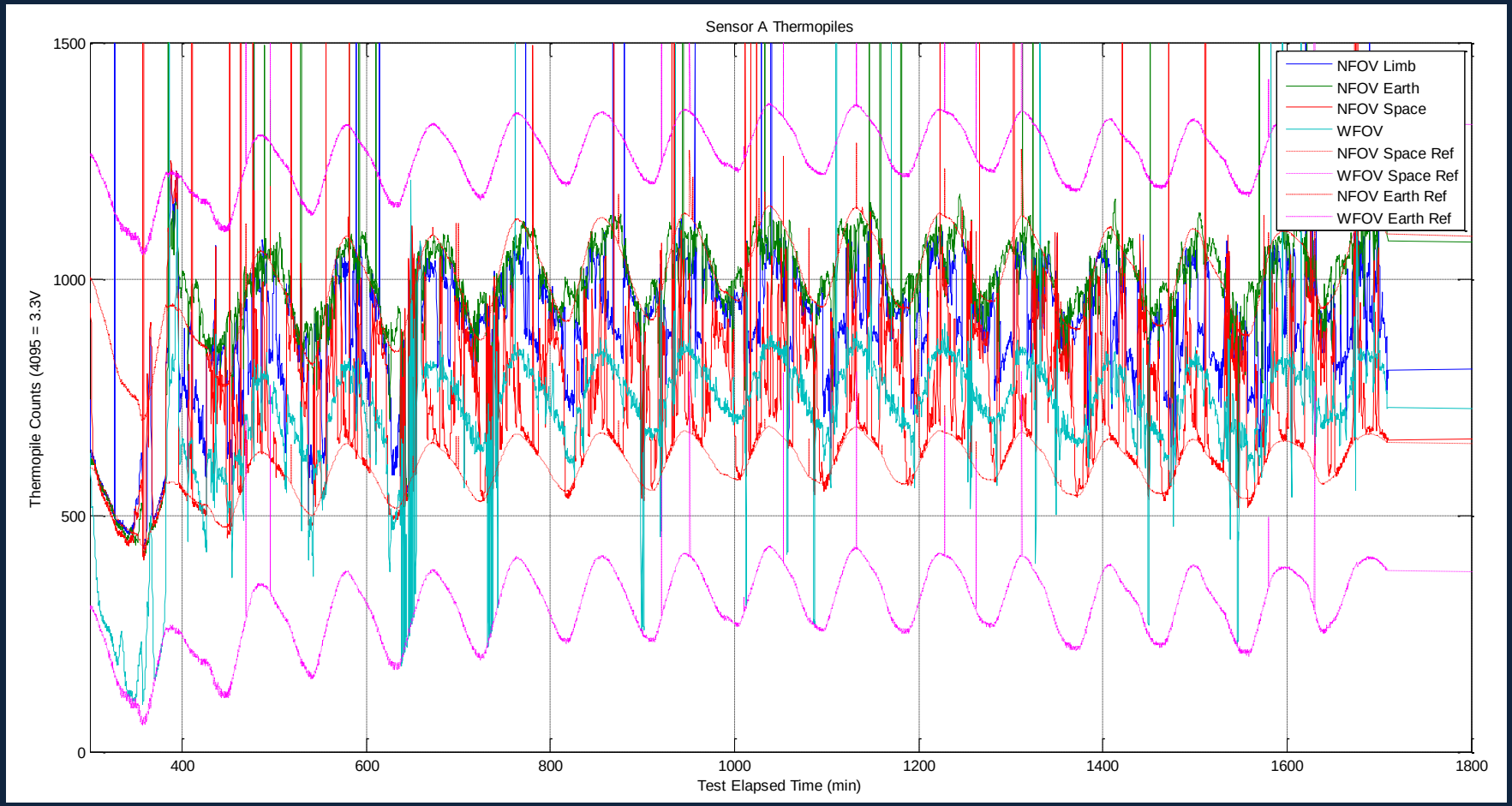
MAI Static IR Earth Sensor

- Early flights showed promise
- Recent flights have shown higher temperature sensitivity than expected
- MAI has worked through most issues with software, now performing well



Sensor noise ~0.5 deg
Pointing capability < 1 deg

MAI Static IR Earth Sensor



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Star Trackers

- Much of Cubesat industry re-learning star tracker issues developed over 2+ decades for traditional vehicles
- MAI has flight experience with a large number of “traditional” spacecraft trackers, and have taken lessons learned into consideration
  - Still expect we will find old and new minor issues
- Stay Tuned …