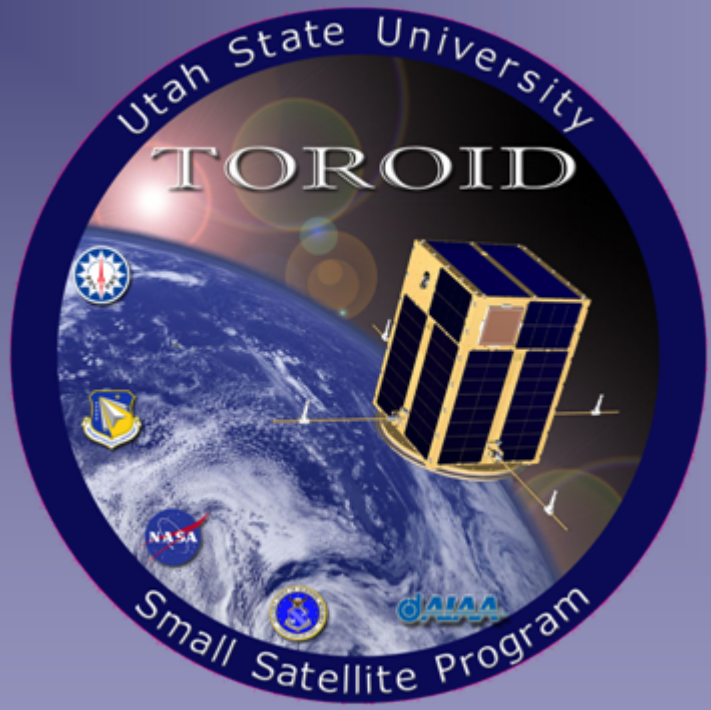
Magnetic Attitude Control for Small Satellites with Orbit-Independent Missions and Modest Pointing Constraints



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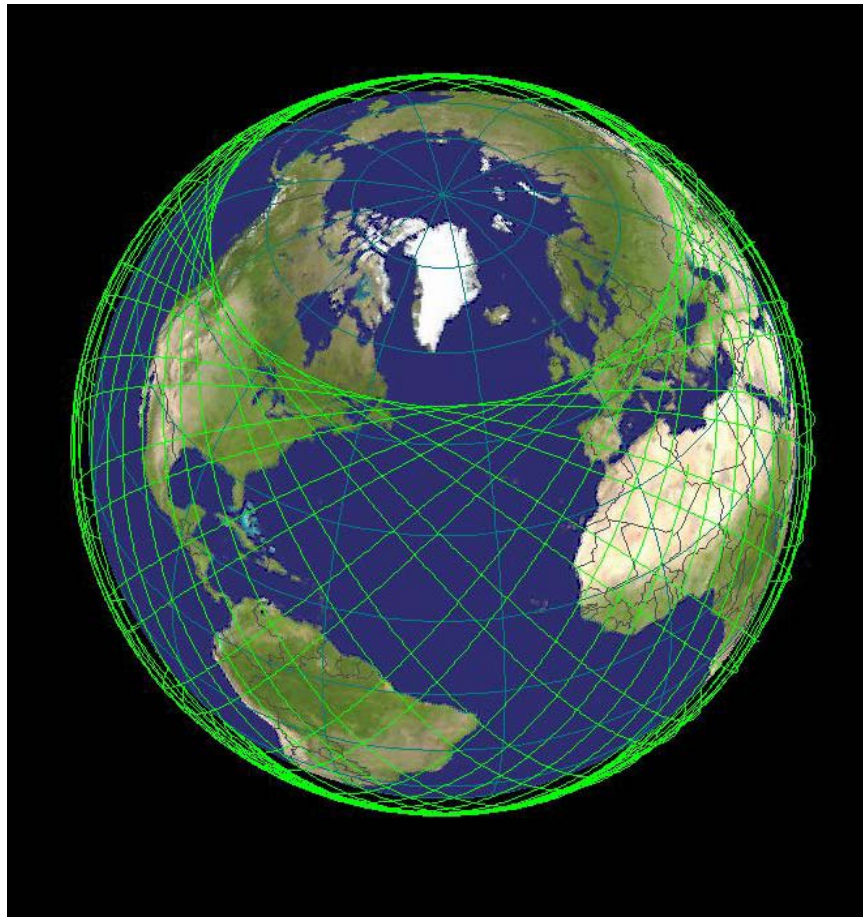
Conference on Small Satellites

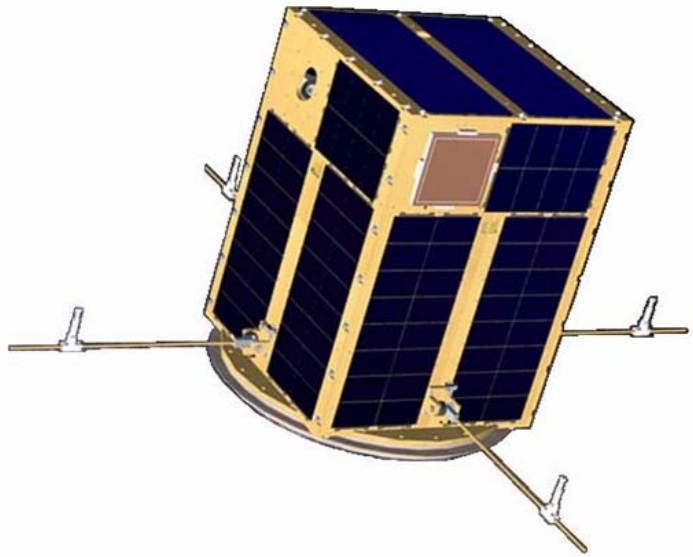
Overview

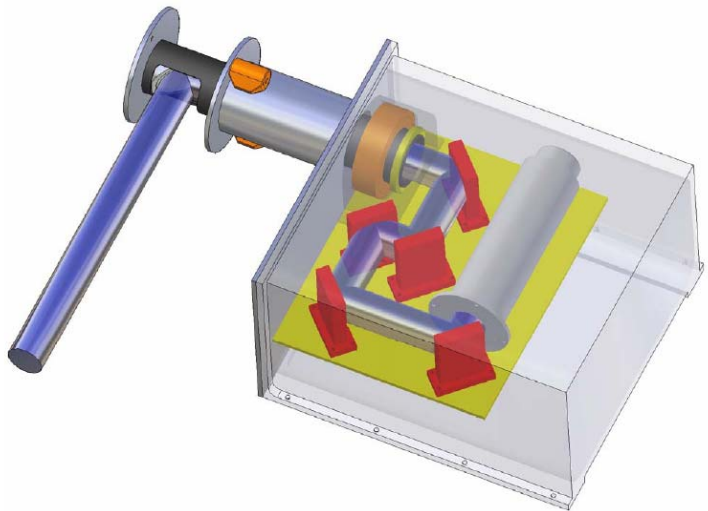
- Initial Motivation
- Magnetic Attitude Control
- Gain Scheduling Technique
- Further Motivation
- Expansion of the Gain Scheduling Technique
- Results
- Future Work



Initial Motivation

- USU TOROID Satellite
  - Low-latitude measurements of the ionosphere
  - Requires magnetic attitude control algorithm that is effective both with and without momentum bias
  - No guaranteed orbit

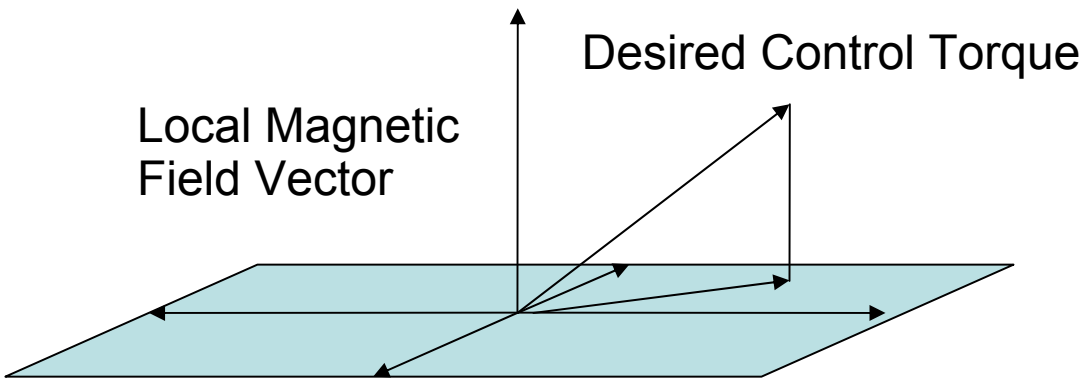




Magnetic Attitude Control

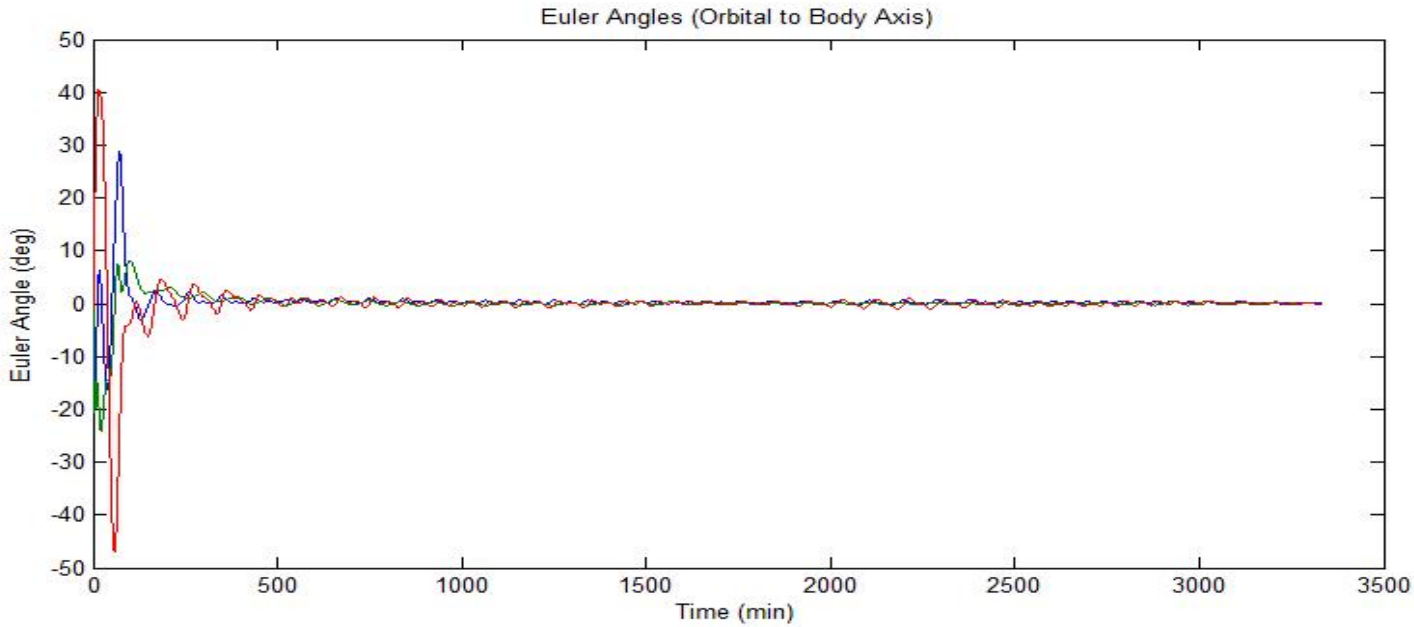
- Torque Coils
  - Rotate satellite using magnetic moments (like a compass pointing north)
- Restrictions:
  - The torques that can be generated are, by definition, in the plane perpendicular to the local magnetic field vector
  - The desired torque usually is not!
  - System is only controllable over time

$$\overline{T} = \overline{b}(t) \times \overline{M}$$



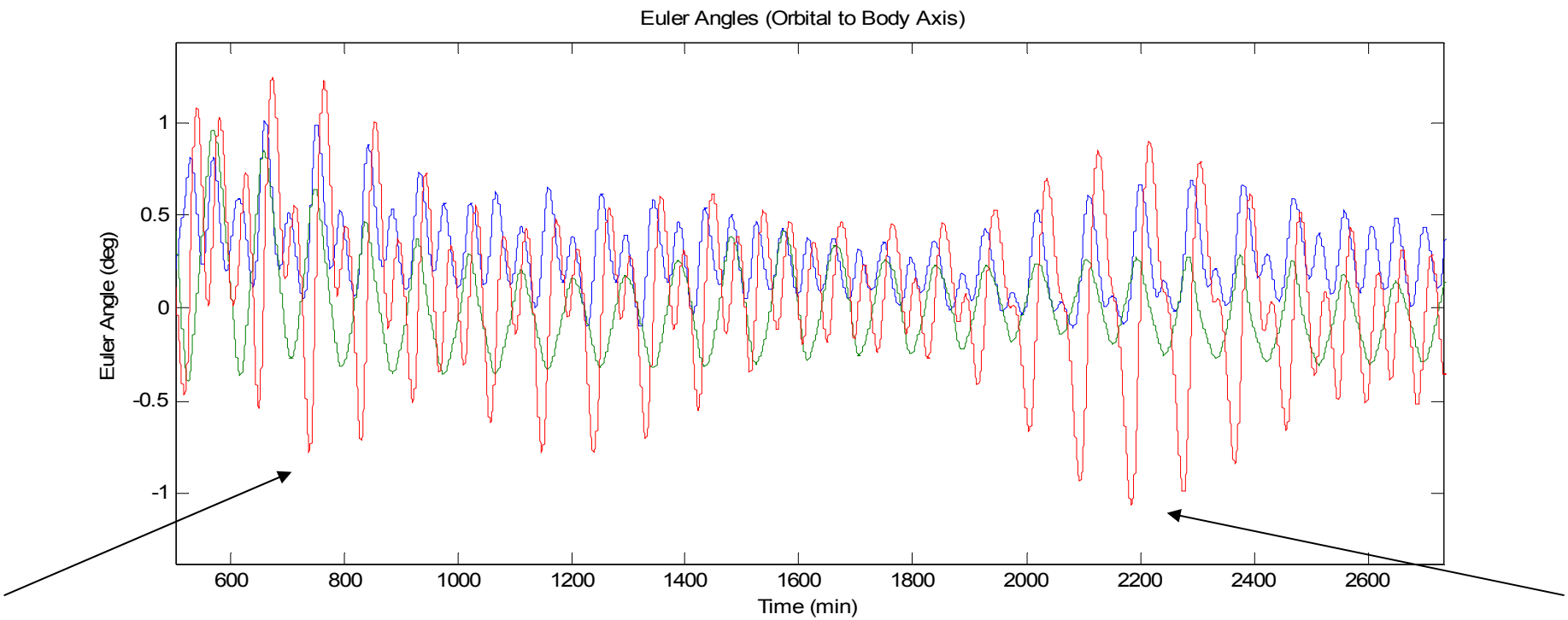
Development: Original Design

- Original design: typical LQ regulator
  - Results typical of similar studies
  - Accuracy significantly increases with momentum bias
  - Works best when tuned for known inclination



Development: Magnetic Inclination and Performance

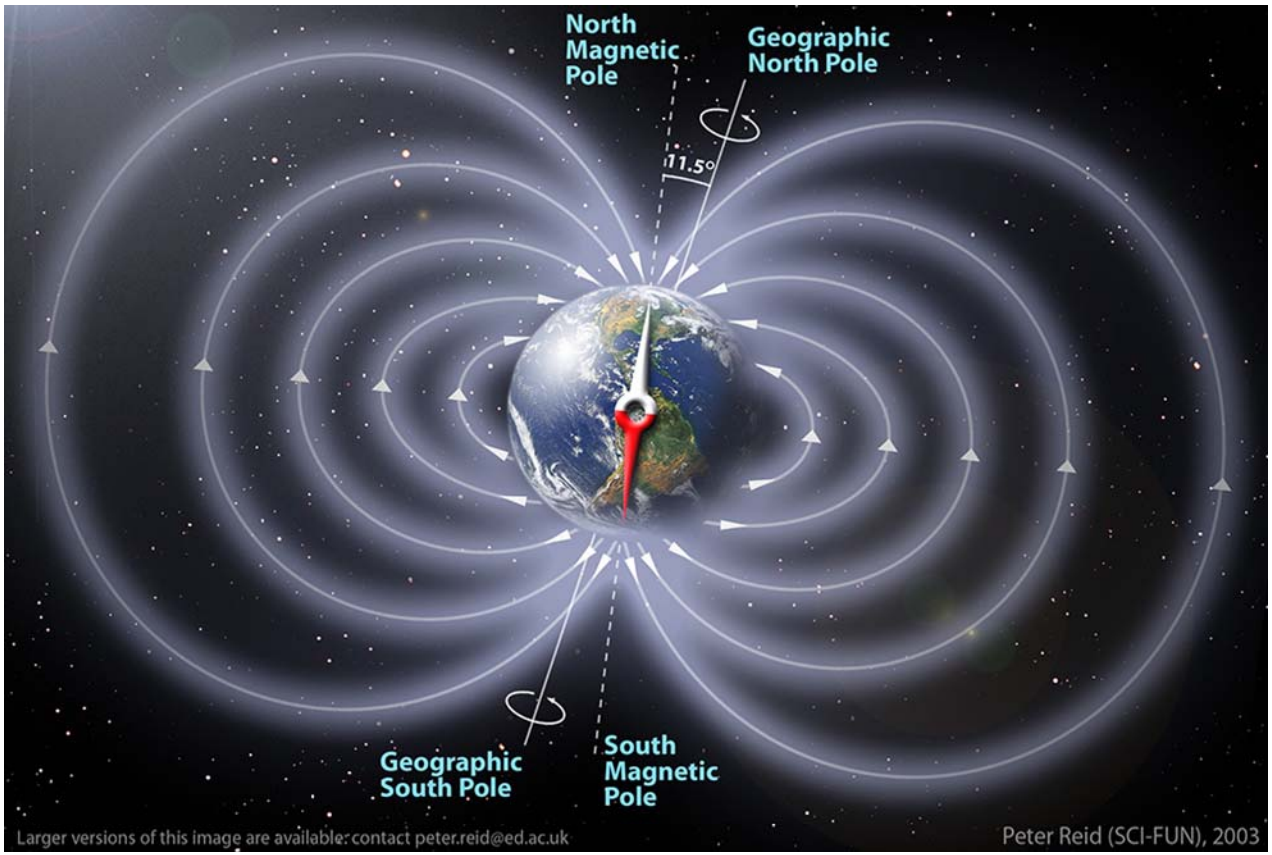
- A closer look at the results:
  - Decreased performance at 24 hour (1440 minute) intervals
  - Corresponded with change in magnetic inclination



Development: Magnetic Inclination and Performance

- Why the decreased performance?
  - Does not necessarily correspond with lower inclination
  - Adjustments in the weighting parameters may change *when* the decreased performance will happen, but it still happens
- The best performance happens at the magnetic inclination for which the controller is best tuned

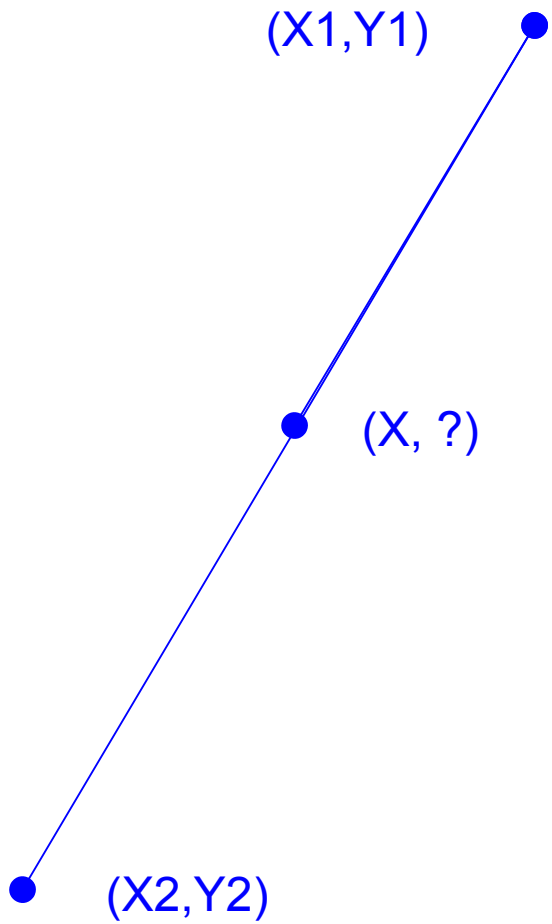
The Earth's Magnetic Field



- Rotates with the Earth
  - Over time the magnetic inclination changes 23° in inertial space

Development: Magnetic Inclination Gain Scheduling

- Magnetic inclination dependant gain scheduling
  - Linear interpolation between max and min values
  - Virtually eliminates periodic decreases in performance
  - Potential for use in a range of inclinations

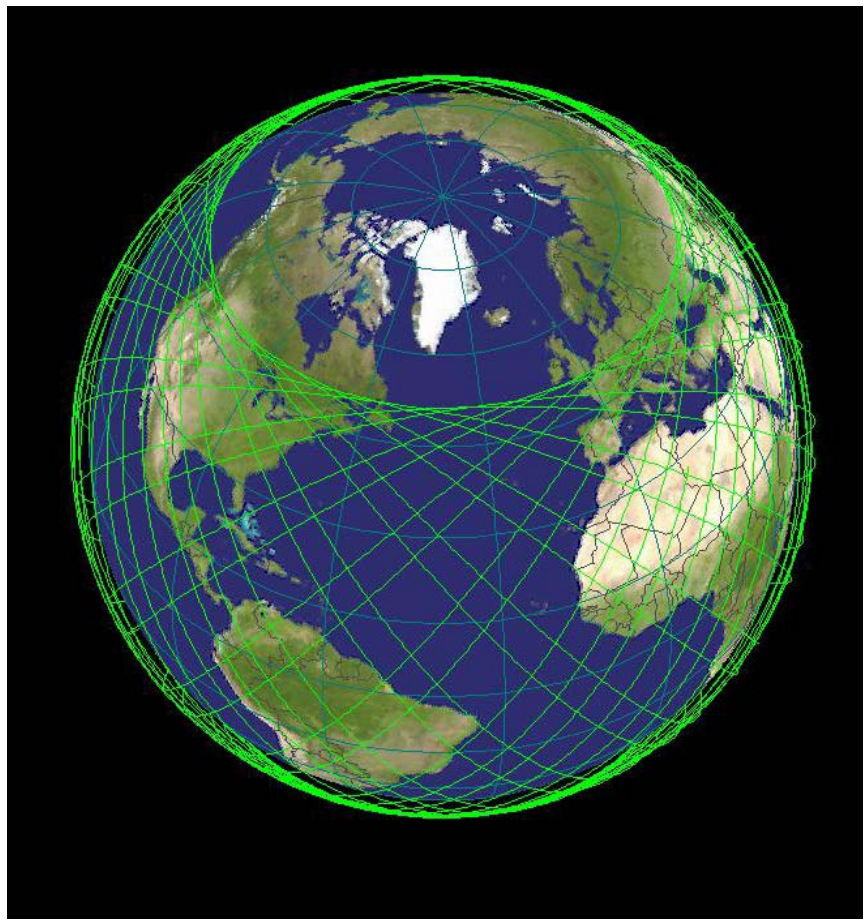


Further Motivation

- Technology Demonstrations
  - Rendezvous
  - Relative Navigation
  - Space testing of cameras or other equipment
- Atmospheric Measurements
  - Constellations with a large number of small satellites
- Piggyback Satellites
  - Small satellites with flexible missions

Earth-Fixed Analysis

- In order to expand the gain scheduling:
  - Fix earth in space so that the magnetic field does not change over time
  - Find best values for high and low magnetic inclination
  - Verify by simulation at regular intervals



Results

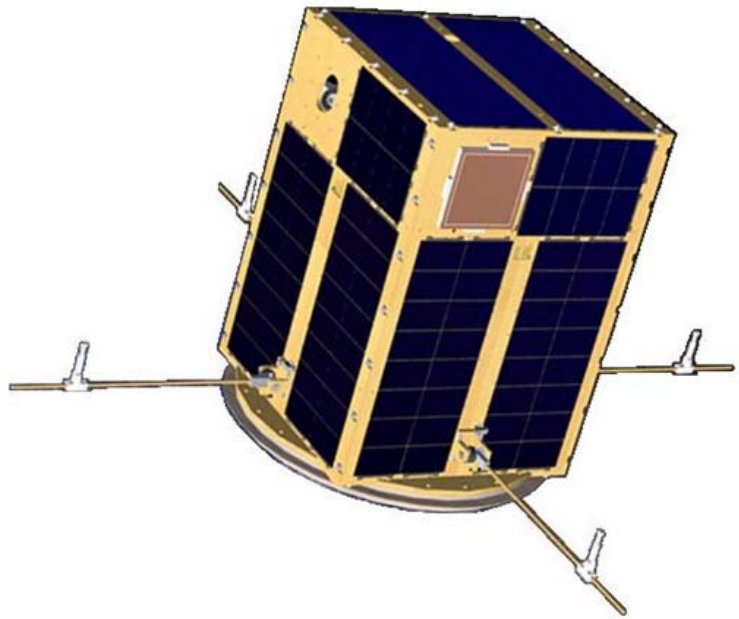
- Attitude Control
  - Accurate to 5° (3σ) or better over entire range
  - Accurate to 0.6° (3σ) or better over entire range in the presence of 0.02 Nms internal momentum bias
  - Accuracy improves with more momentum bias
- Range
  - 39° to 90° magnetic inclination
  - Corresponds to 40.5° to 90° inclination
  - Other orbit parameters do not affect performance

Limitations

- Sensitivity to disturbance torques
  - Magnetic dipole knowledge may need as accurate as 0.01 Am^2 (requires continuous monitoring and estimation)
  - May not work at low altitudes (below 400 km)
- The general solution still is not as accurate as an LQ regulator that is tuned to a particular orbit

Future Work

- For TOROID
  - Magnetic interference testing
  - Residual magnetic dipole estimation
- Magnetic attitude control in general
  - Further work in improving the general case



Question and Answer

- Questions?