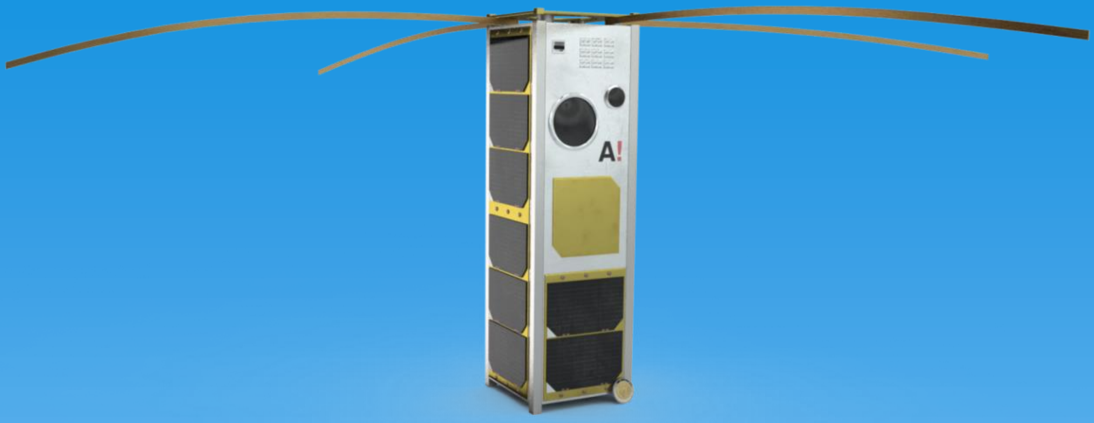

Attitude determination and control implementation for Aalto-1 plasma brake experiment

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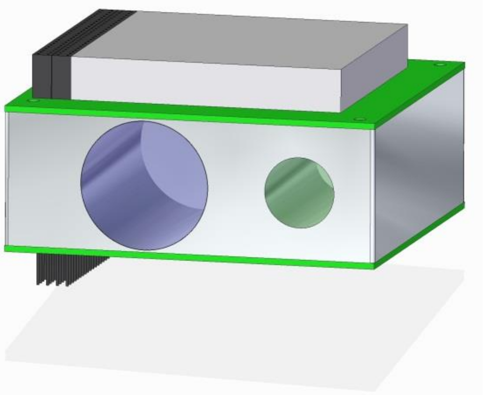
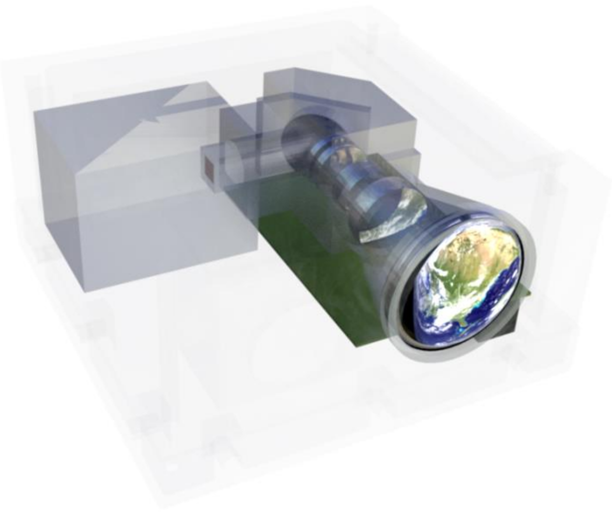
Aalto-1 – Introduction

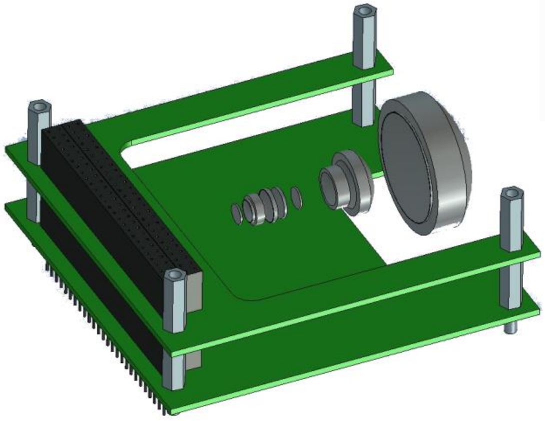
- Aalto-1, a student satellite project
  - started in the beginning of 2011
- Coordinated by Department of Radio Science and Engineering
- Participants
  - several departments of Aalto University,
  - Finnish Meteorological Institute (FMI)
  - VTT, Technical research center of Finland
  - Department of Physics, University of Helsinki (HY),
  - Department of Physics and Astronomy, University of Turku (UTU)

Aalto-1 – Payloads (1)

- Fabry-Perot Spectral Imager
  - Designed and developed by VTT

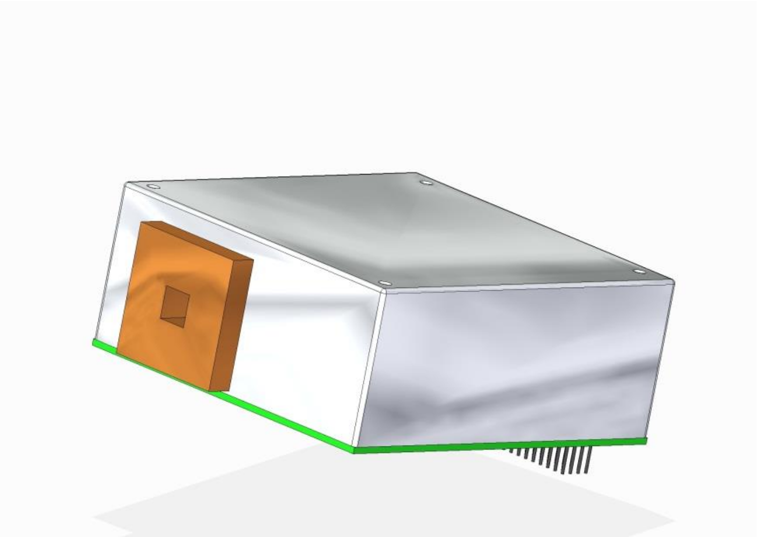






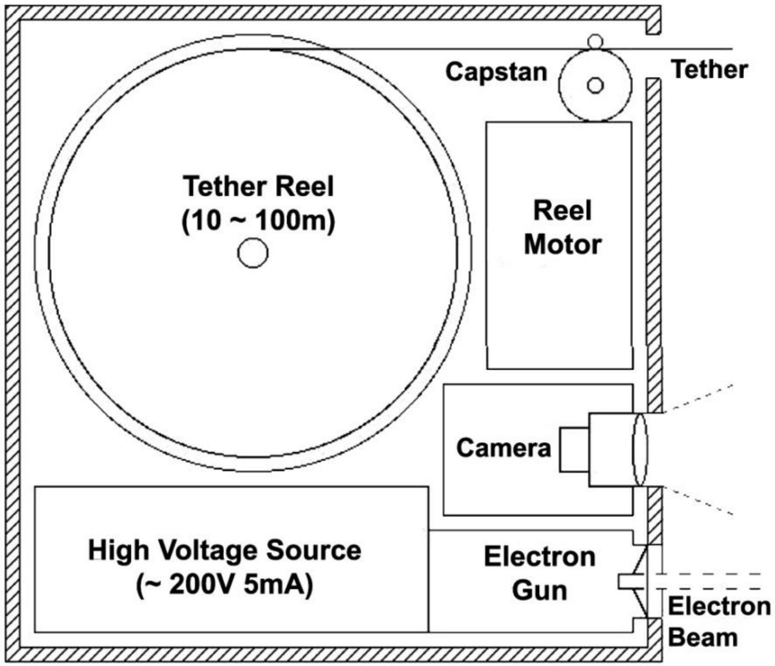
Aalto-1 – Payloads (2)

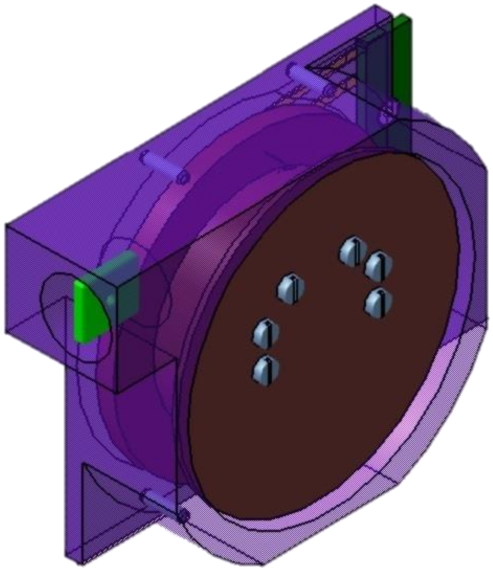
- Compact radiation monitor
  - Developed by University of Turku and University of Helsinki



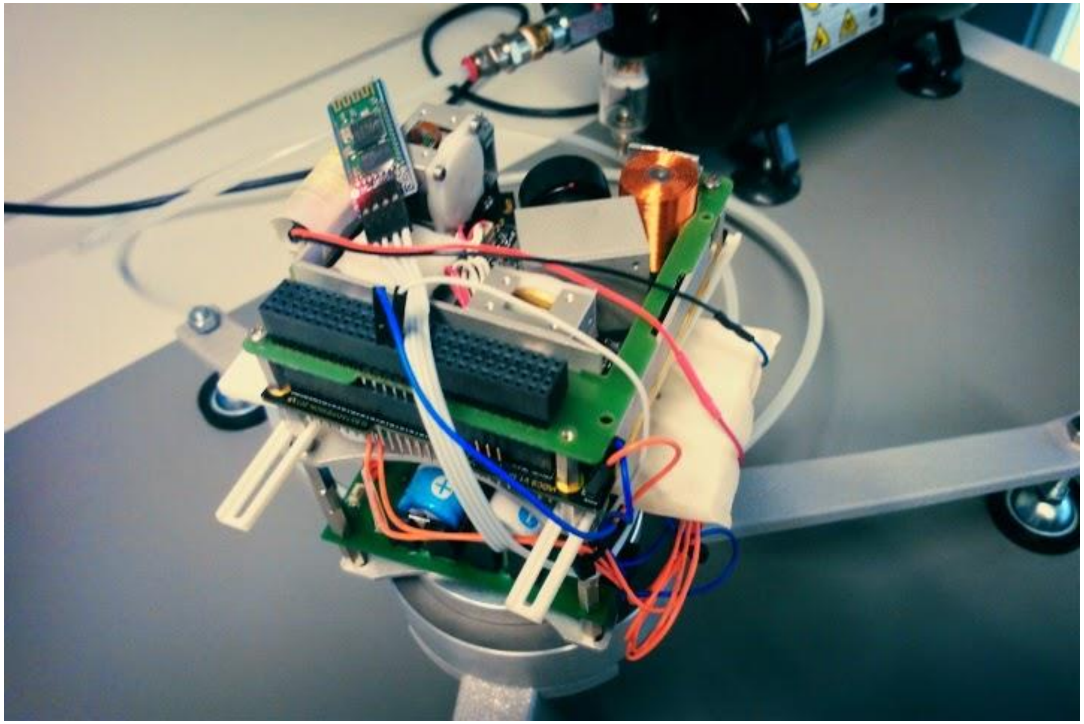
Aalto-1 – Payloads (3)

- Plasma Break Experiment





Aalto-1 ADCS



- ADCS on the air-bearing table at BST premises, Berlin

PBE – AIMS

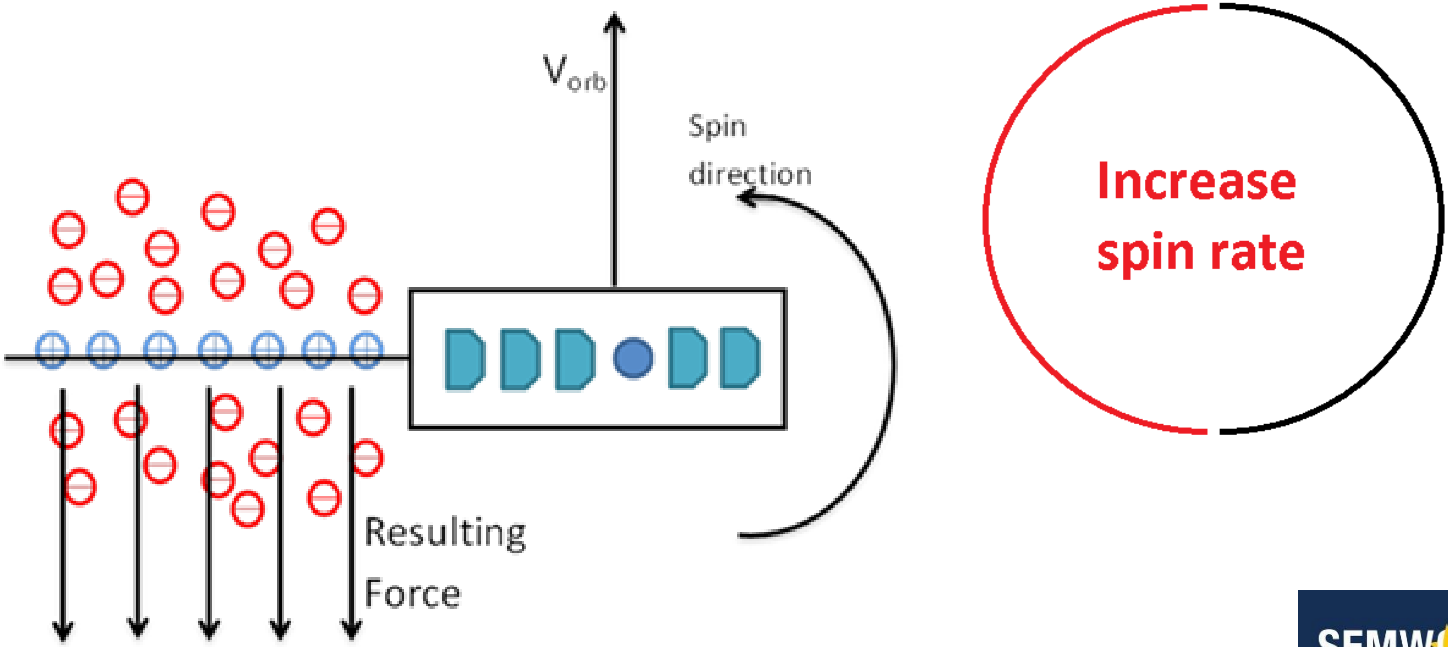
- The EPB experiment is intended
  - to demonstrate the deployment of a conductive thin, multiline tether,
  - to measure the electrostatic force exerted on the tether by the ionospheric plasma
    - measure the expected micro-Newton scale electrostatic force
  - to demonstrate the usefulness of the plasma brake as a satellite deorbiting device

PBE – Phases

- Spin-up to ~200 °/s starting from 3-axis stabilised attitude mode
- Tether reel-out using centrifugal force
  - 0.5 g end mass
  - 10 m, 100 m
- Tether charging

PBE – Phases

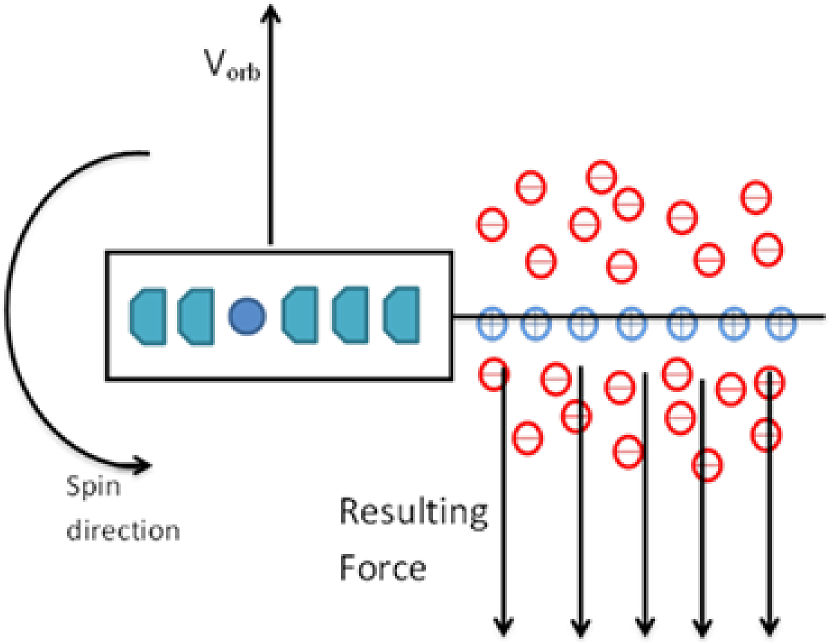
- the tether is charged always in the same direction during spin

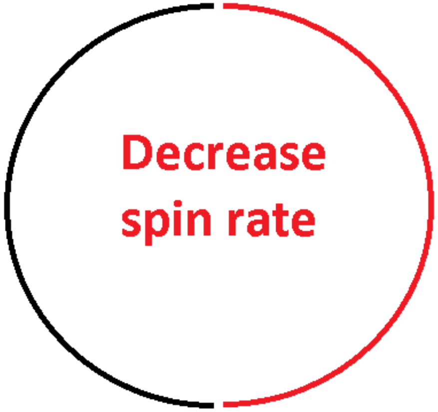


Increase spin rate

PBE – Phases

- the tether is charged always in the same direction during spin





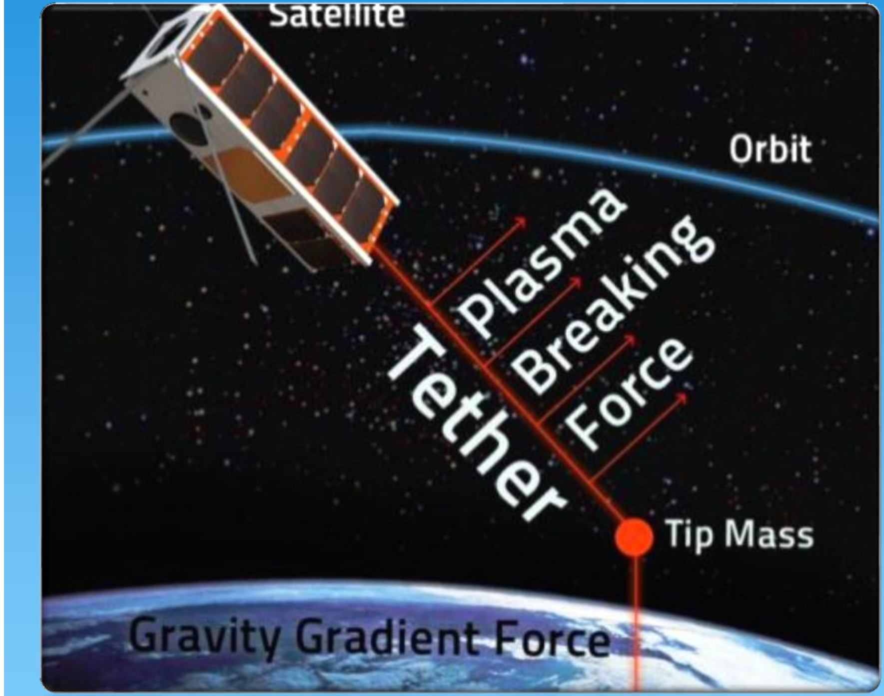
Decrease spin rate

PBE – Phases

- After several spins,
  - the effect would accumulate
  - Causing a detectable change in the system’s spin rate
  - can be used to quantify the force

Braking concept

- EPB will consist of a single gravity-stabilized tether
- Attempt to deorbit the satellite
- Force acting on the tether due to plasma-charged tether interactions slows down the orbital velocity



Attitude Dynamics Requirements for Aalto-1

- Spin axis aligned with inertial Z-axis
- Principal spin axis desired not to deviate from the closest body frame axis beyond ~10 degrees
- Angular velocity
  - Related to tether tension, required: 20 mN (min) to 25 mN (max) tension in the tether

Attitude estimation

- Fast spin mode
  - Star-tracker limitations
- Sensor limitations
  - Magnetometer, Sun-sensor, Gyro sampling frequencies
- Magnetometers, the most critical sensors
  - Bias and magnetic disturbances inside the satellite

Attitude estimation

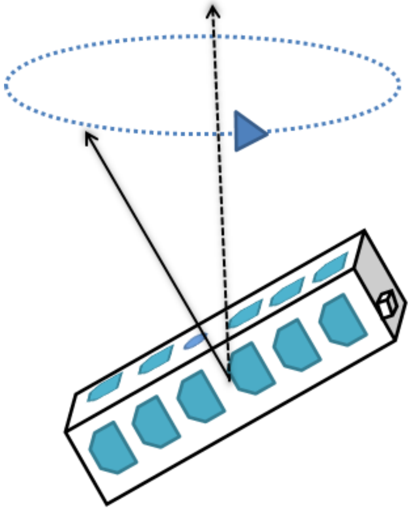
- Adaptive Unscented Kalman Filter (AUKF)
  - Magnetometer, Gyro bias estimation
- Adaptation of covariance matrices
  - Process noise covariance
  - Measurement noise covariance

Attitude control

- Purely magnetic control
- The spin-up phase starts with 3-axis stabilized attitude mode
- Spin axis has to be the major axis however…
  - Mass distribution
  - Limited control over C.G and mass distribution

Spin Control

- Spin controller required for
  - Spin axis and velocity control,
  - Precession control,
  - Nutation control.



Spin Control – the controller

- Spin controller

$$\mathbf{m} = \frac{-k}{||\mathbf{B}||^2}\left[\mathbf{B} \times \left(\tilde{\mathbf{h}} + k_1 e_h \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}^T + k_2 \mathbf{P}\omega\right)\right]$$

$$\tilde{\mathbf{h}} = \mathbf{h} - \mathbf{h}_d$$

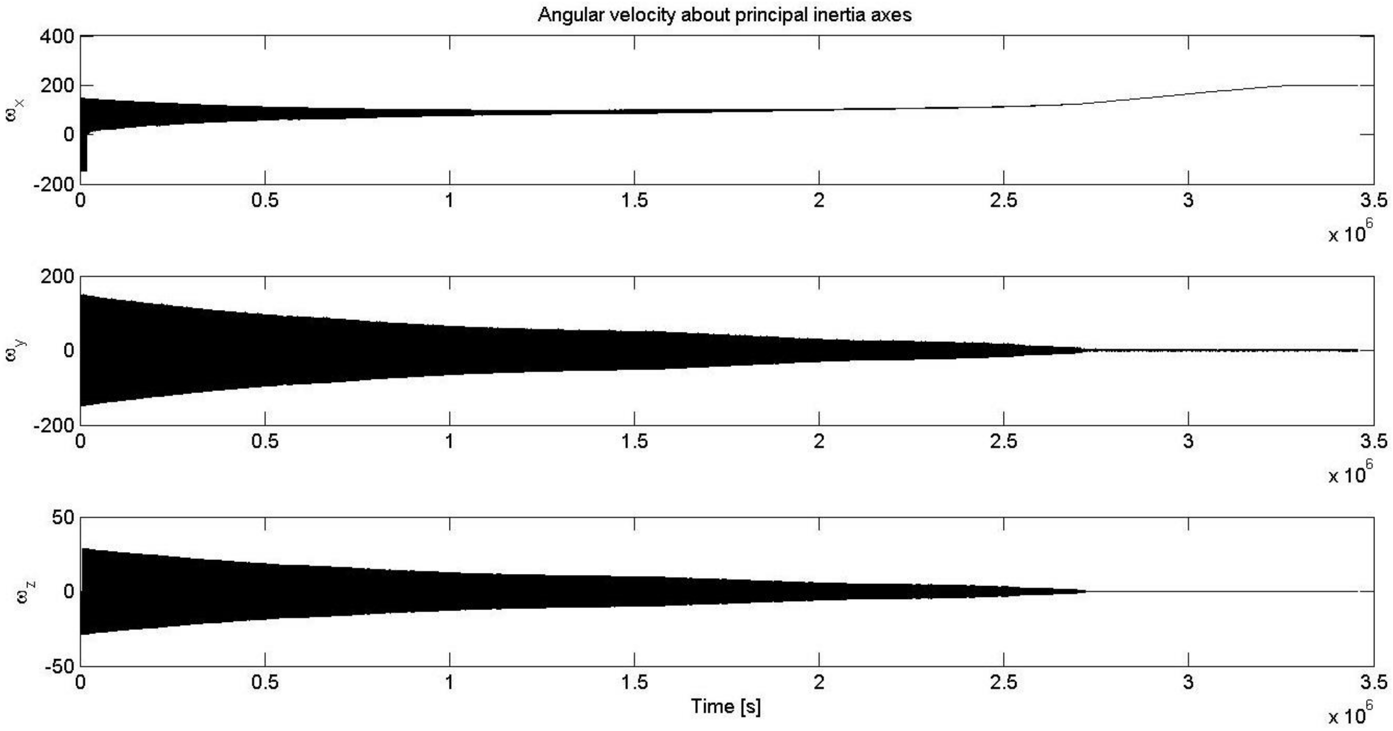
$$e_h = h_a - h_{da} \qquad \mathbf{P} = diag(1, 1, 0)$$

[1] **A fault-tolerant magnetic spin stabilizing controller for the JC2Sat-FF mission, Anton de Ruiter,** Acta Astronautica, Volume 68, Issues 1–2, January–February 2011, Pages 160–171

Spin Control – optimization

- Gain optimization (k, k_1, k_2)
  - High gain leads to saturation
  - Bang-bang control
    - Reduced steady state attitude stability
  - Low gain values
    - Slow response
    - More adept control
    - Higher steady state attitude stability

Spin Control – optimization



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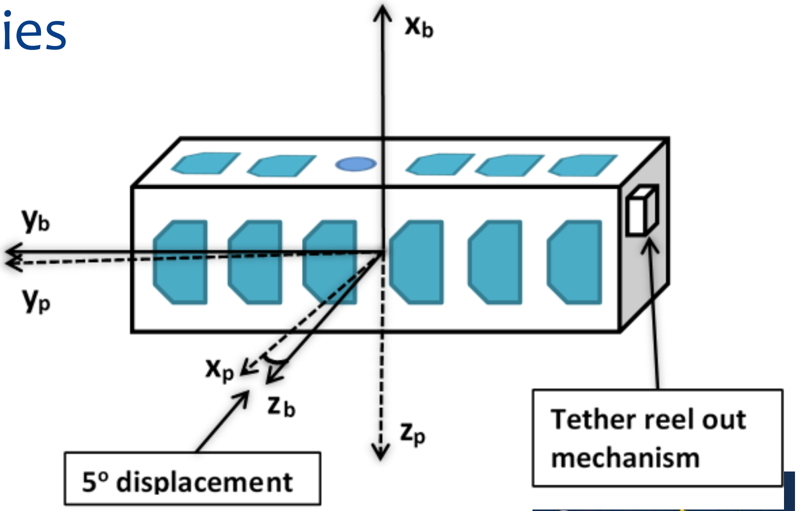
Spin Control – optimization

- Structure optimization
  - Inertia tensor
  - Well-aligned body and principal inertia reference frames
  - Subsystem relocation possibilities

- Internal magnetic field



Conclusion

- Main challenges
    - Increased attitude estimation frequency
    - Robust control
    - Residual, induced magnetic fields
    - Optimized mechanical design