Effective Hardware-in-the-loop CubeSat Attitude Control Verification and Test

Craig Clark, and Dr. Simone Chesi

ADCS System

Attitude Determination & Control Subsystem (ADCS)

- Single board ADCS solution
- Handles complete ADCS tasks
  - Limited interaction from OBC required
  - Ability to receive telemetry from ADCS
- Easily adaptable to different sensors and actuators
- Low power, low mass, low volume, low cost and high performances

ADCS System

Complete ADCS task runs on board

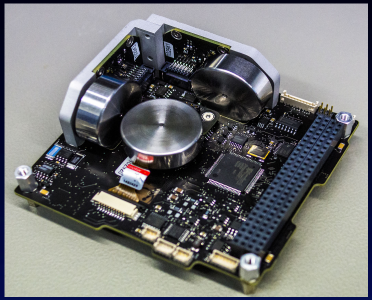
- I2C telemetry and telecommand

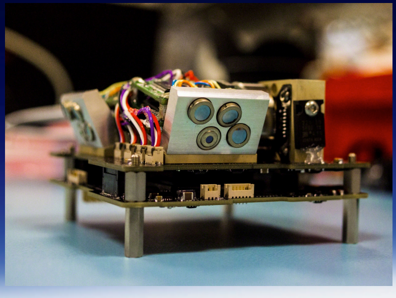
Sensors:

- Magnetometer
- Rate gyros
- Sun sensors
- Optional GPS
- Optional Star Tracker
- Optional Horizon Sensors

Actuators:

- Six magnetic torquers drivers
- Interface to 1/3-Axis Reaction Whe
Module





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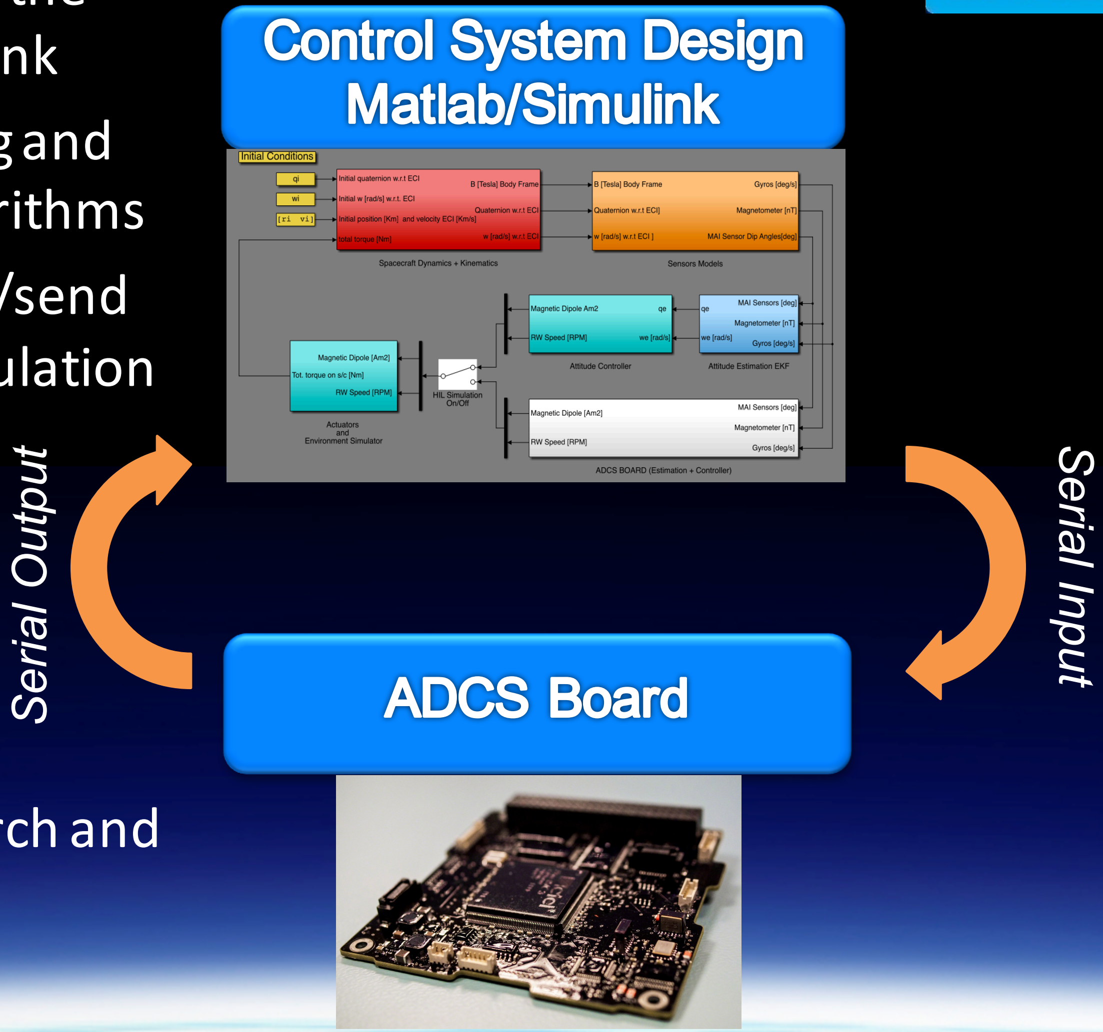
ADCS HIL Simulator: Software Design

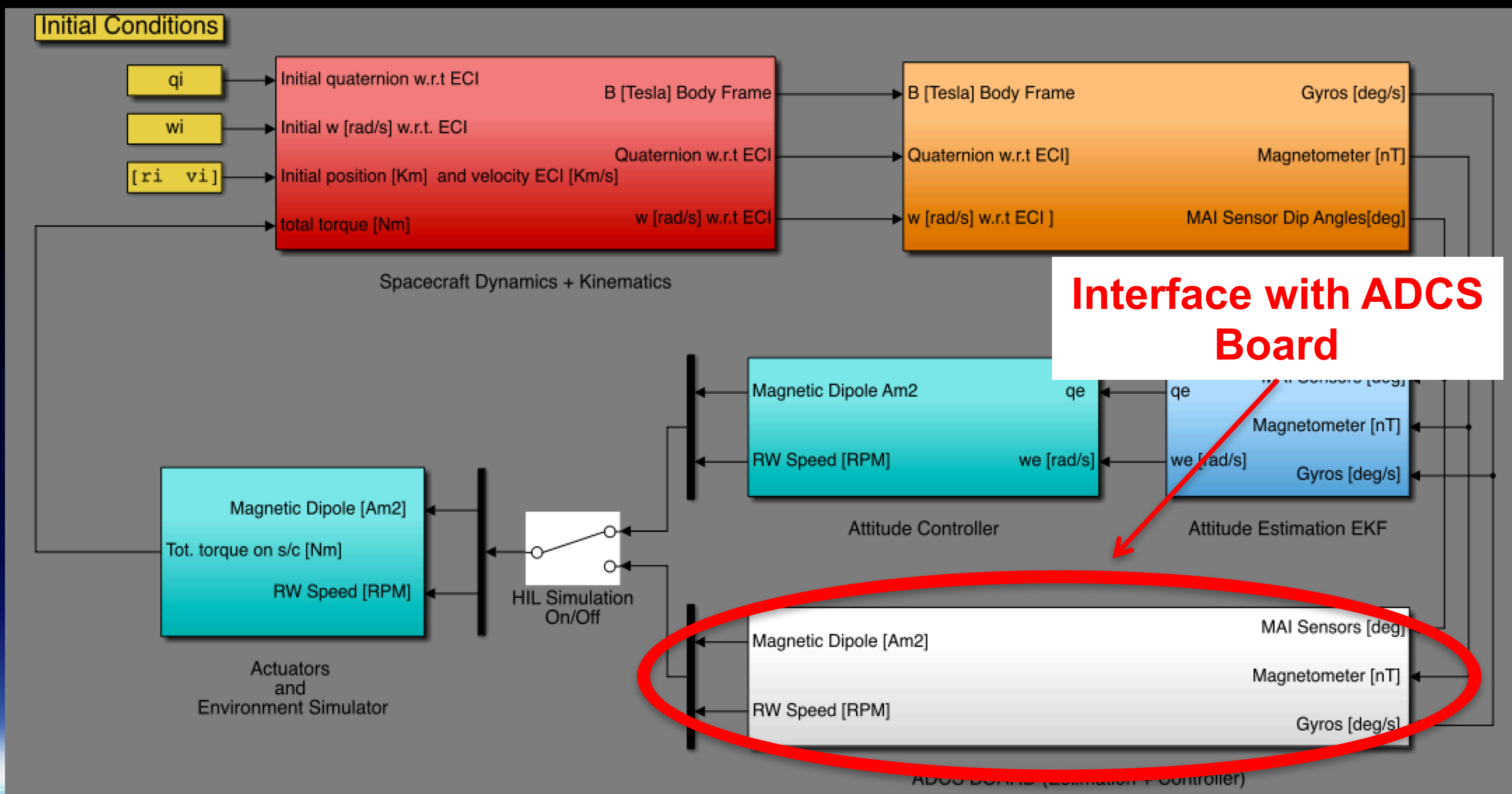
- ADCS on board software can be developed and tested in the loop with Matlab/Simulink
- Allows rapid prototyping and evaluation of ADCS algorithms
- The ADCS board receive/send input/output to the simulation by using serial interface



- Ideal for industry, research and education

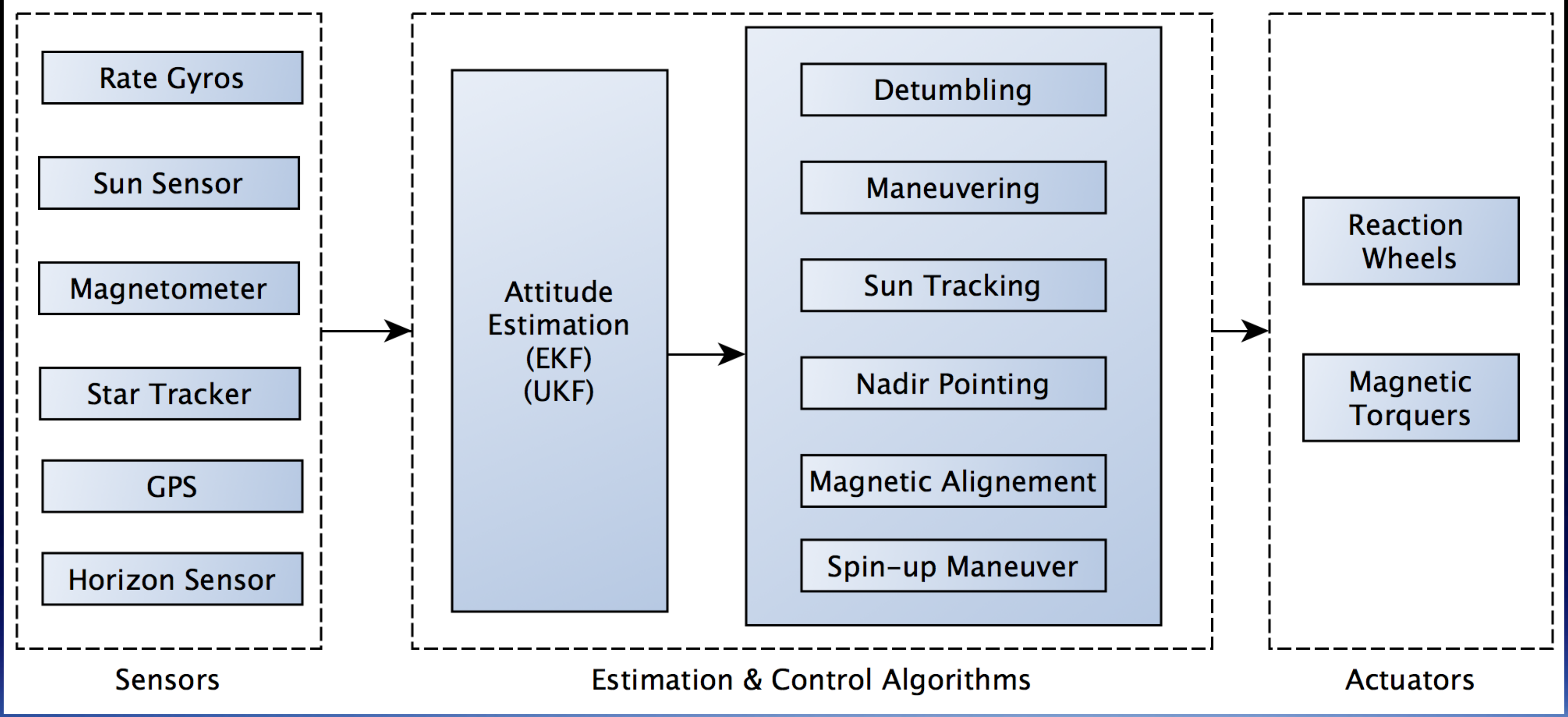
ADCS HIL Simulator: Simulink Interface

- Analysis and simulation of the mission using in-house 6DOF high fidelity Matlab/Simulink Model
- Sensors/Actuators output based on measured data from real HW



ADCS HIL Simulator: Softcore

- Softcore on ARM Cortex CPU implemented in FPGA fabric for radiation tolerance
- Runs a stand alone C program



ADCS HIL Simulator: Nadir Pointing Mission

Mission Requirement

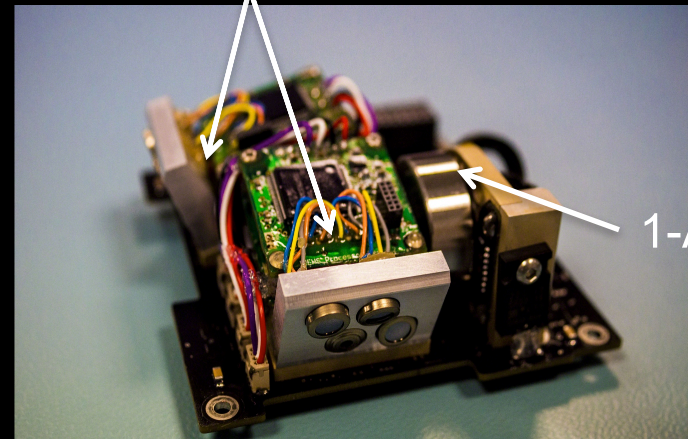
- Nadir Pointing over North Pole
- Pointing Accuracy < 5 deg

Sensor

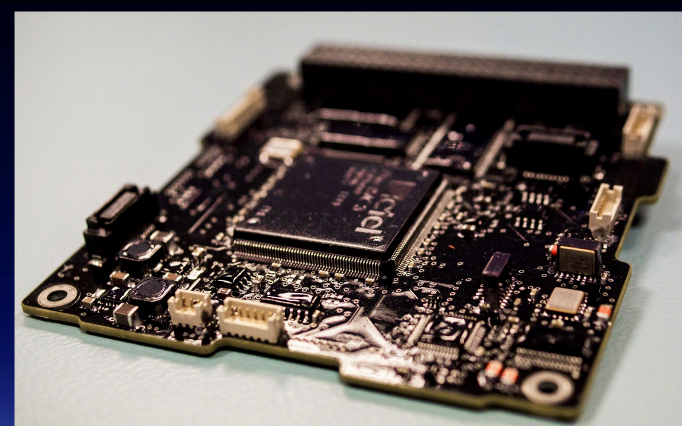
- GPS
- 2 Static Horizon Sensor
- 4 Coarse Sun Sensor
- 2-Magnetometer
- 3 Single Axis Gyros

Actuators

- 1-Axis RW — Gyroscopic Stabilization
- 3-Axis MTQ — Attitude Control



ADCS daughter Board with 2-Static Horizon Sensors and 1-Axis RW



ADCS Board

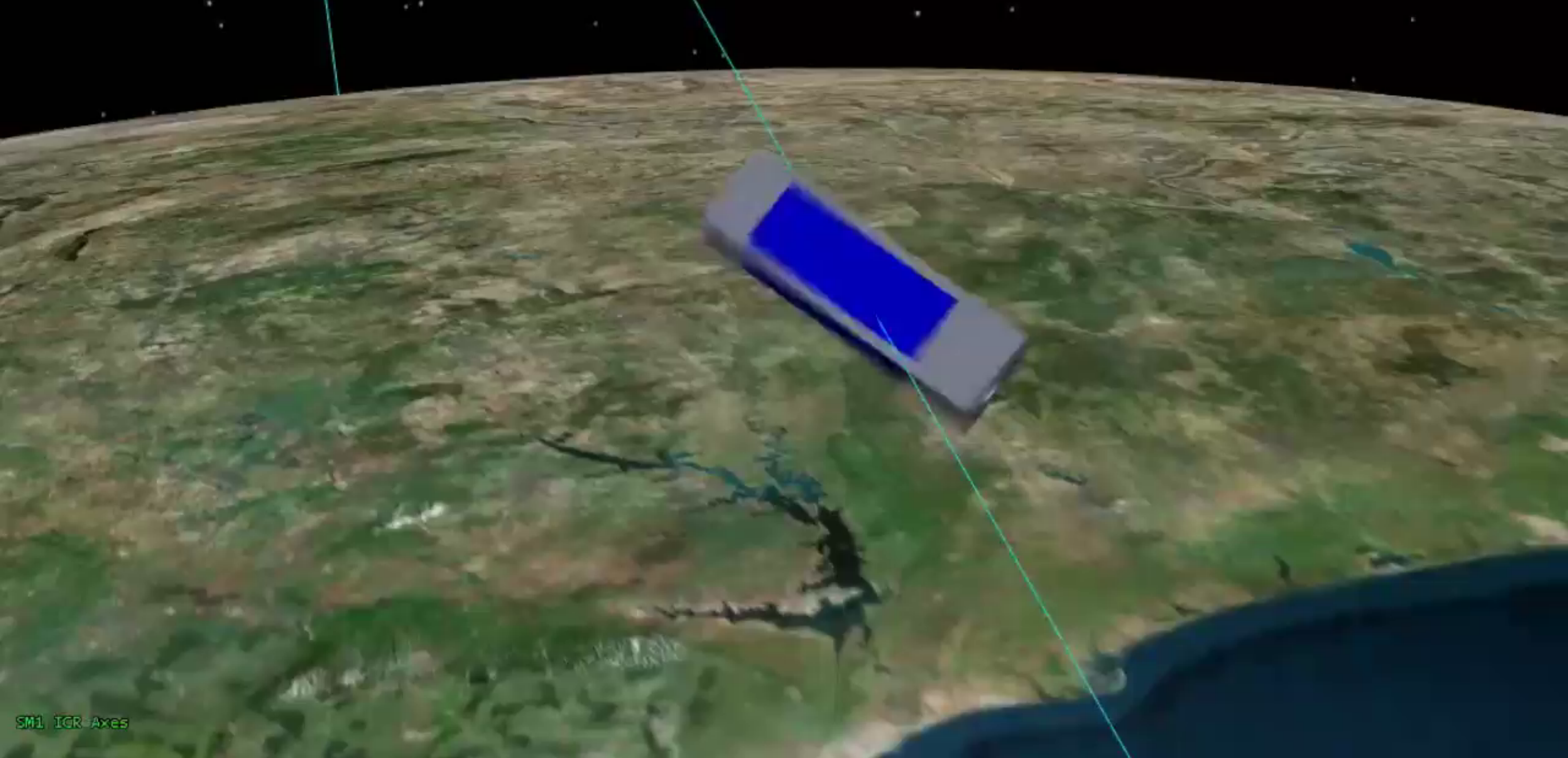
ADCS HIL Simulator: Nadir Pointing Mission

Orbit:

Semi-major axis = 6963 Km

eccentricity = 0

inclination = 97.7 deg



ADCS HIL Simulator: Nadir Pointing Mission

Detumbling: B-dot control Law

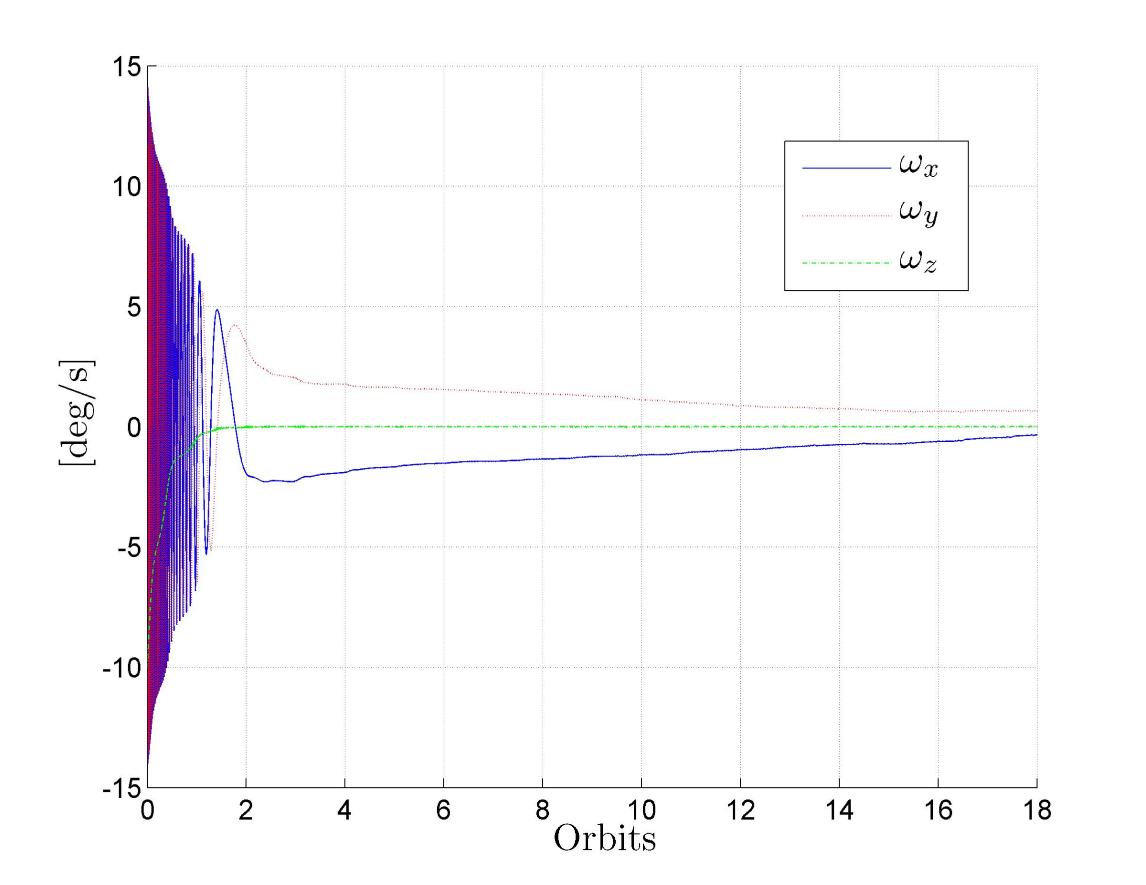
In this phase only MTM readings and MTQ are used

Initial Angular velocity

$\boldsymbol{\omega}_{sc} = [10, -10, 10] deg/s$

Final Angular velocity

$\boldsymbol{\omega}_{sc} = [0.34, 0.66, 0.08] deg/s$



ADCS HIL Simulator: Nadir Pointing Mission

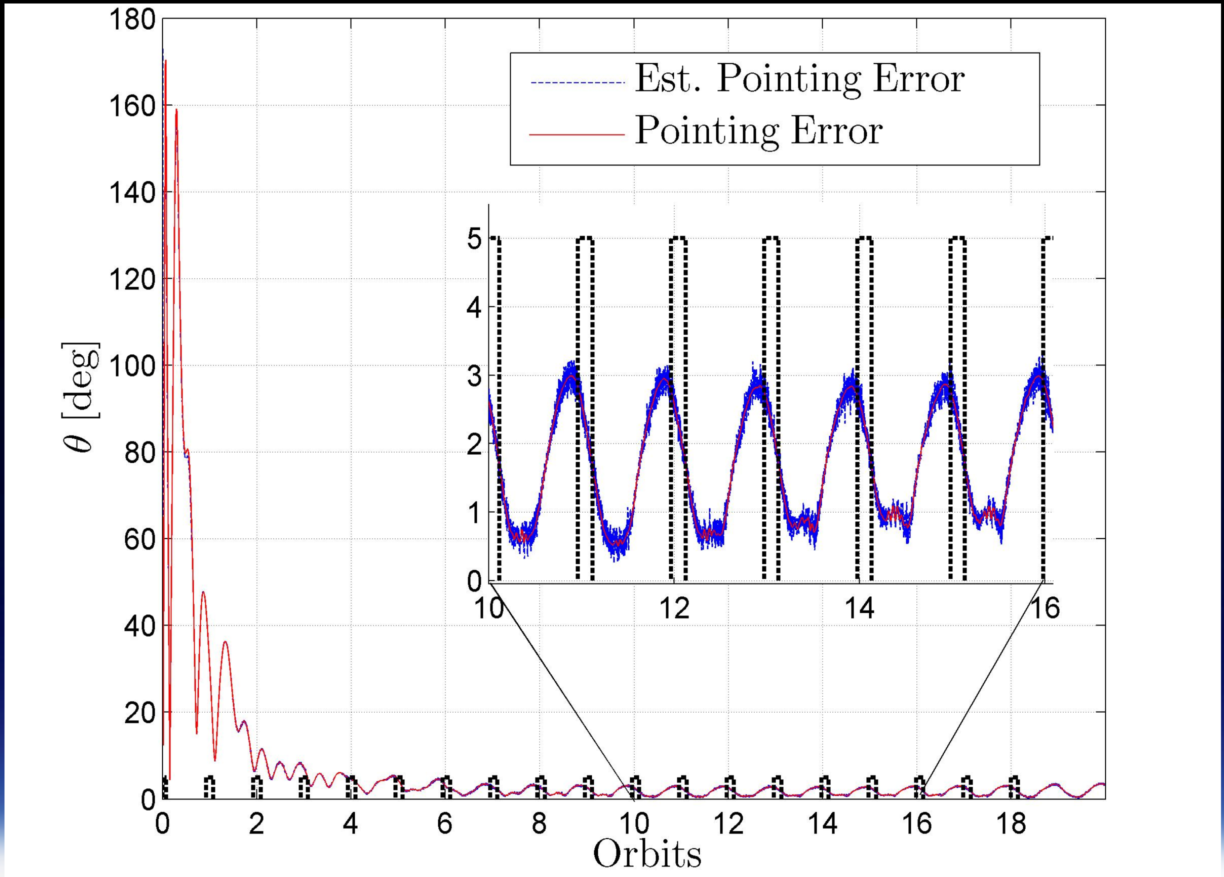
Nadir Pointing: The ADCS estimates the sc attitude using EKF with sensor fusion algorithm

Initial Pointing Error

$$\boldsymbol{\theta}_e = 175deg$$

Final Pointing Error

$$\boldsymbol{\theta}_e < 5deg$$



ADCS HIL Simulator: Sun Pointing

Mission Requirements

- Sun Pointing < 1 deg
- Maneuver speed > 2deg/s

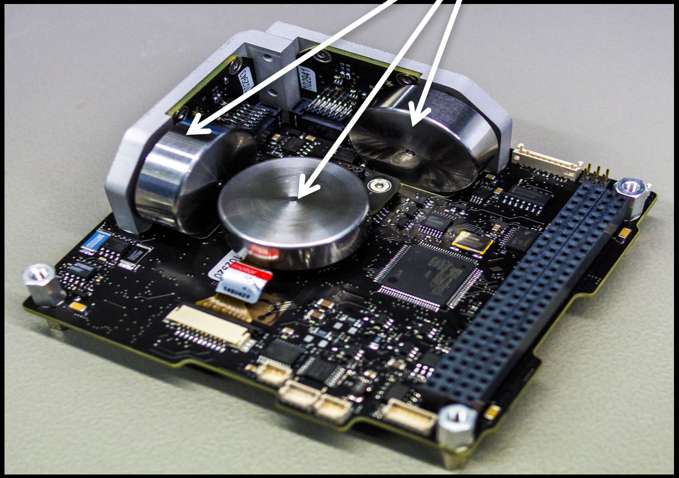
Sensor

- GPS
- 1 Fine Sun Sensor
- 1 Star Tracker
- 4 Coarse Sun Sensor
- 2-Magnetometer
- 3 Single Axis Gyros

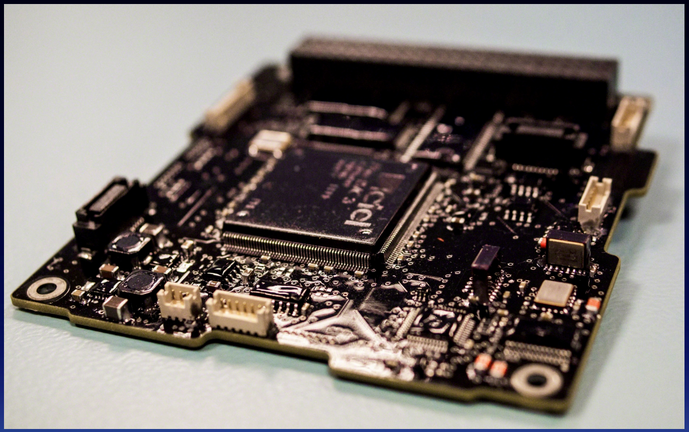
Actuators

- 3-Axis RWs — Attitude Control
- 3-Axis MTQ — RW Momentum Management

3-Axis RWs



3-Axis RWs daughter board



ADCS Board

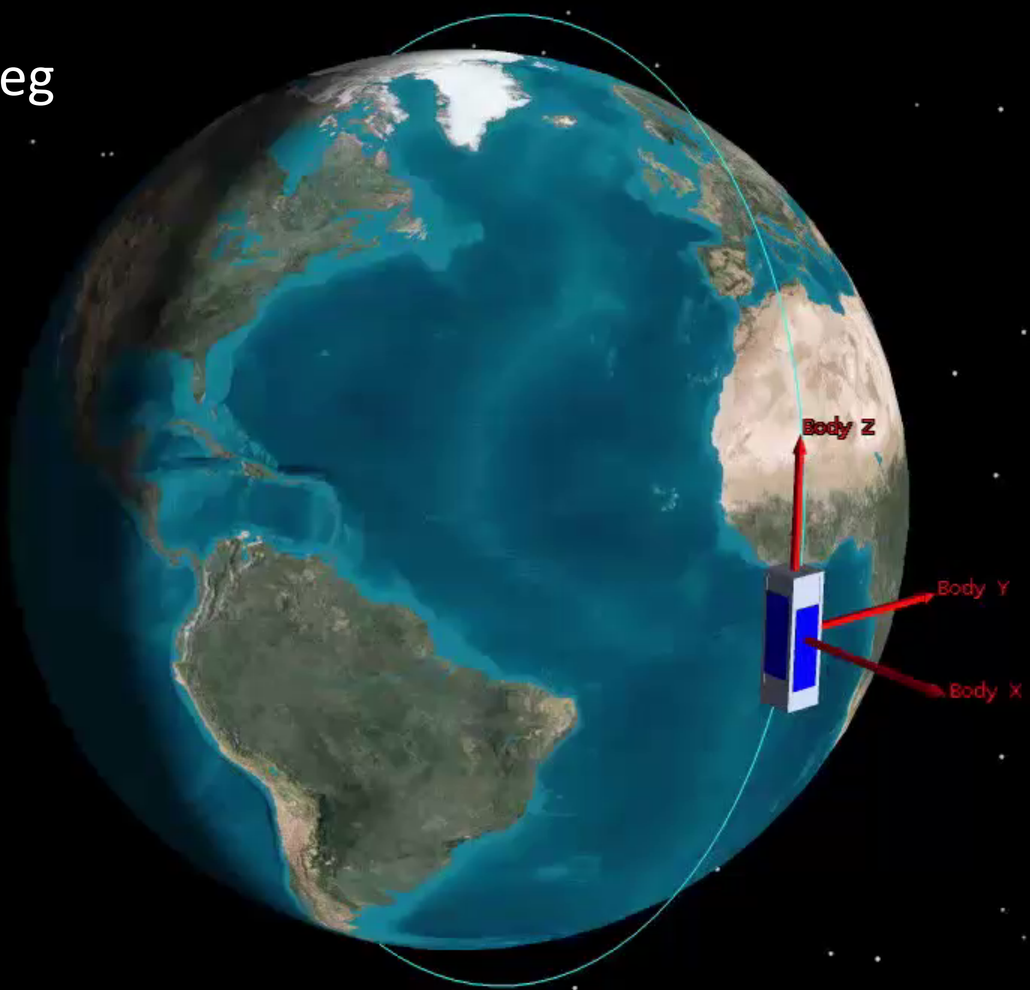
ADCS HIL Simulator: Sun Pointing

Orbit:

Semi-major axis = 7078 Km

eccentricity = 0

inclination = 79 deg



ADCS HIL Simulator: Sun Pointing

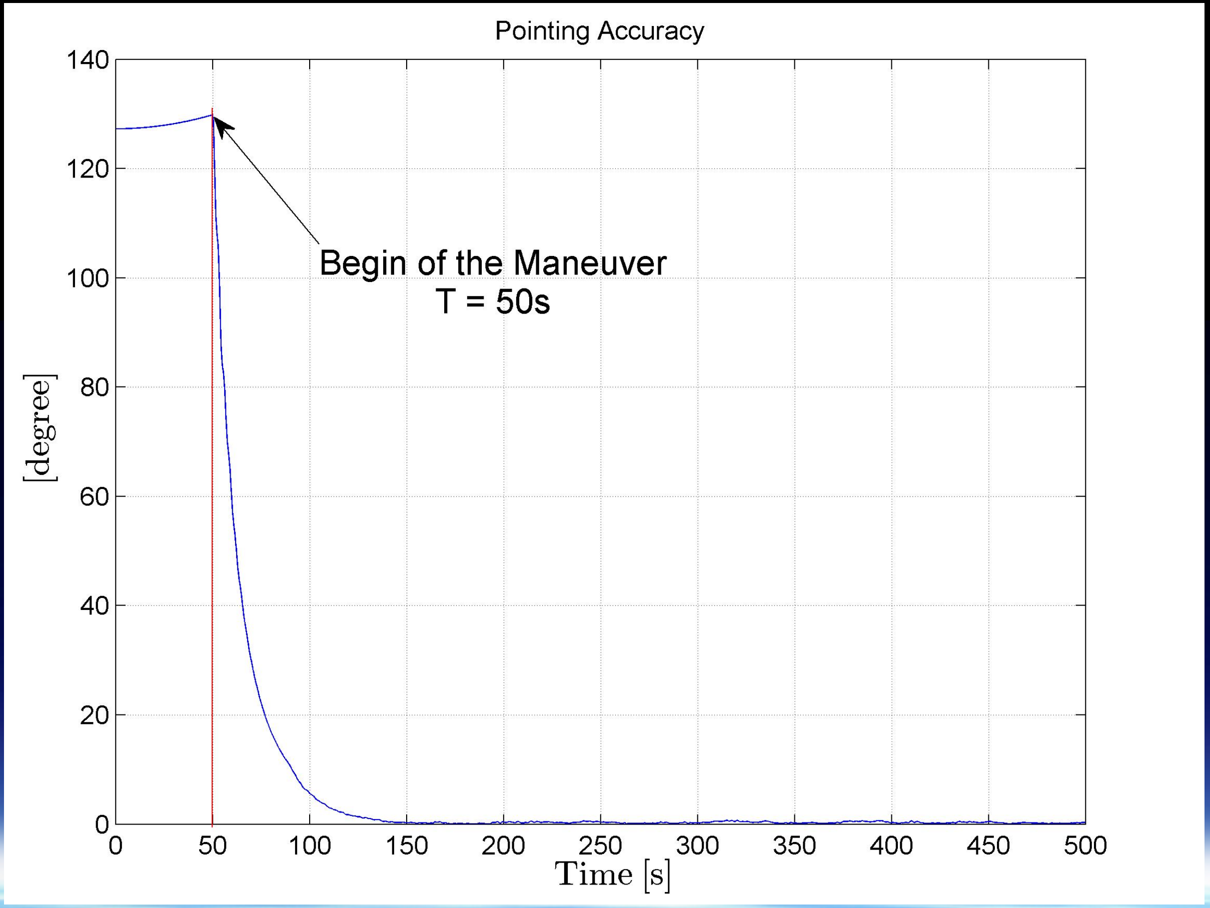
Sun Pointing Maneuver: Attitude estimation using EKF with sensor fusion algorithm. Attitude control using 3-Axis RWs and MTQ for momentum management

Initial Pointing Error

$\boldsymbol{\theta}_e = 130.89deg$

Final Pointing Error

$\boldsymbol{\theta}_e < 1deg$



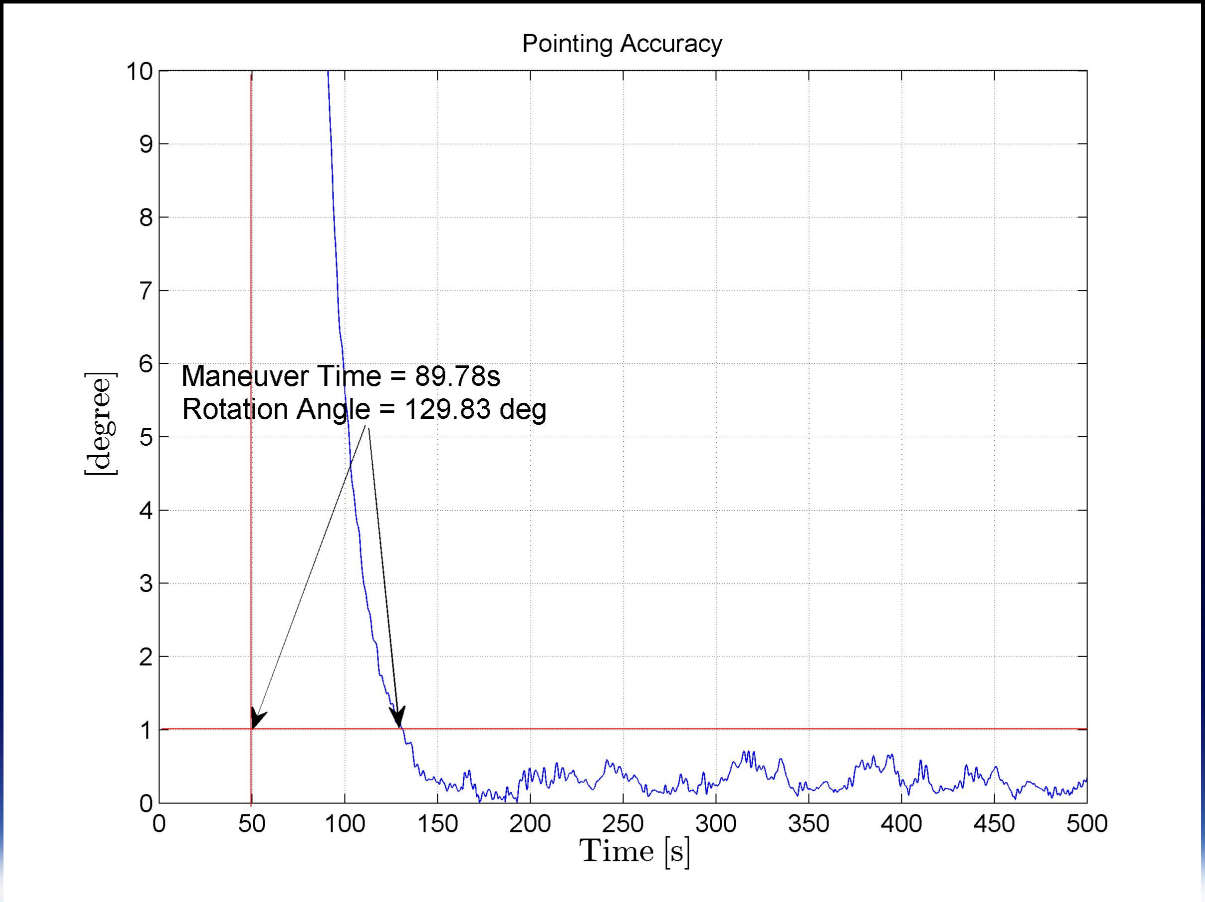
ADCS HIL Simulator: Sun Pointing

Sun Pointing Maneuver: The system perform an eigenaxis rotation using quaternion based feedback control law

Rotation angle ≈ 130 deg

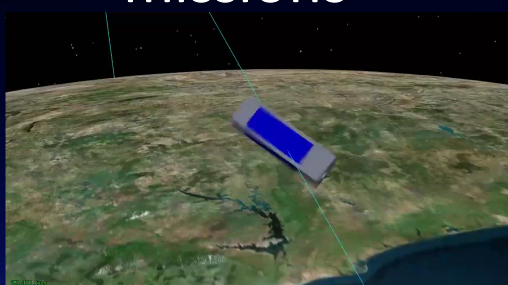
Maneuver time < 90 s

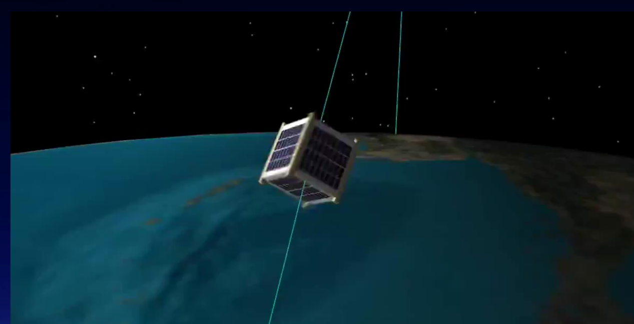
Pointing accuracy < 1deg

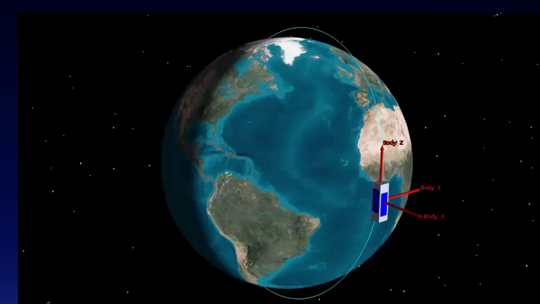


ADCS Customization

- ADCS algorithms can be developed and tested to increase mission reliability
- Additional control modes can be developed and included based on the specific mission requirements
- Additional sensors and actuators can be interfaced
- ADCS Software can be easily adapted to various missions







- The ADCS board can be reprogrammed in flight

THANK YOU

ADCS HIL Simulator: Advantages

There are several advantages in using the ADCS hardware-in-the loop simulator w.r.t. simulations only:

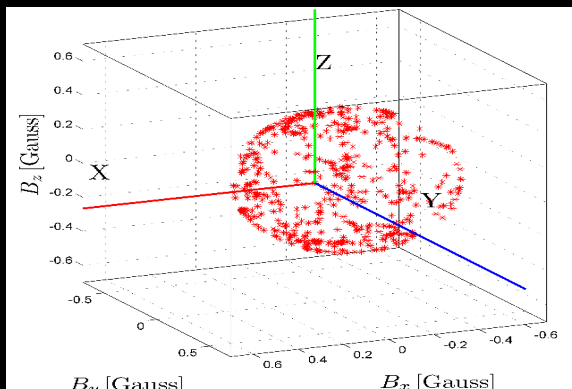
- Easily ADCS software debug and improvement
- Analysis and development of sensor calibrations algorithm

Analysis of interference effects of unmodelled dynamics such as:

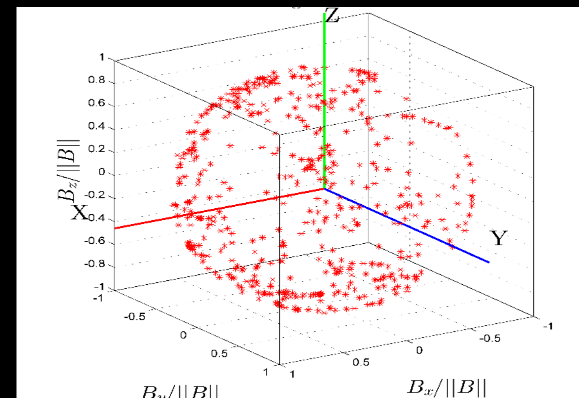
- Interference between magnetorquer actuation and magnetic readings (ON/OFF actuation)
- Effect of RW vibration w.r.t. angular velocity on system sensor to optimize ADCS design
- Actuators response (e.g. zero crossing effect, magnetic coils discharging, etc.)

ADCS HIL Simulation – Magnetometers Calibration

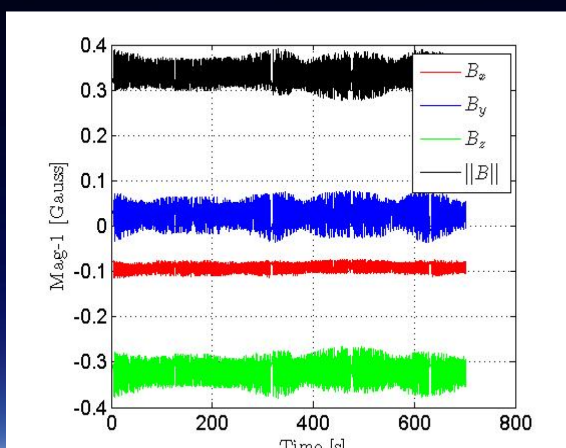
Performance analysis of calibration procedure to remove effect of bias, misalignment, scaling factor and compensate noise

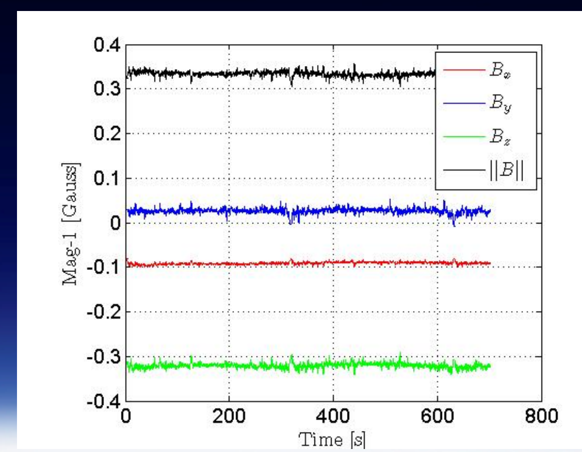


Before calibration



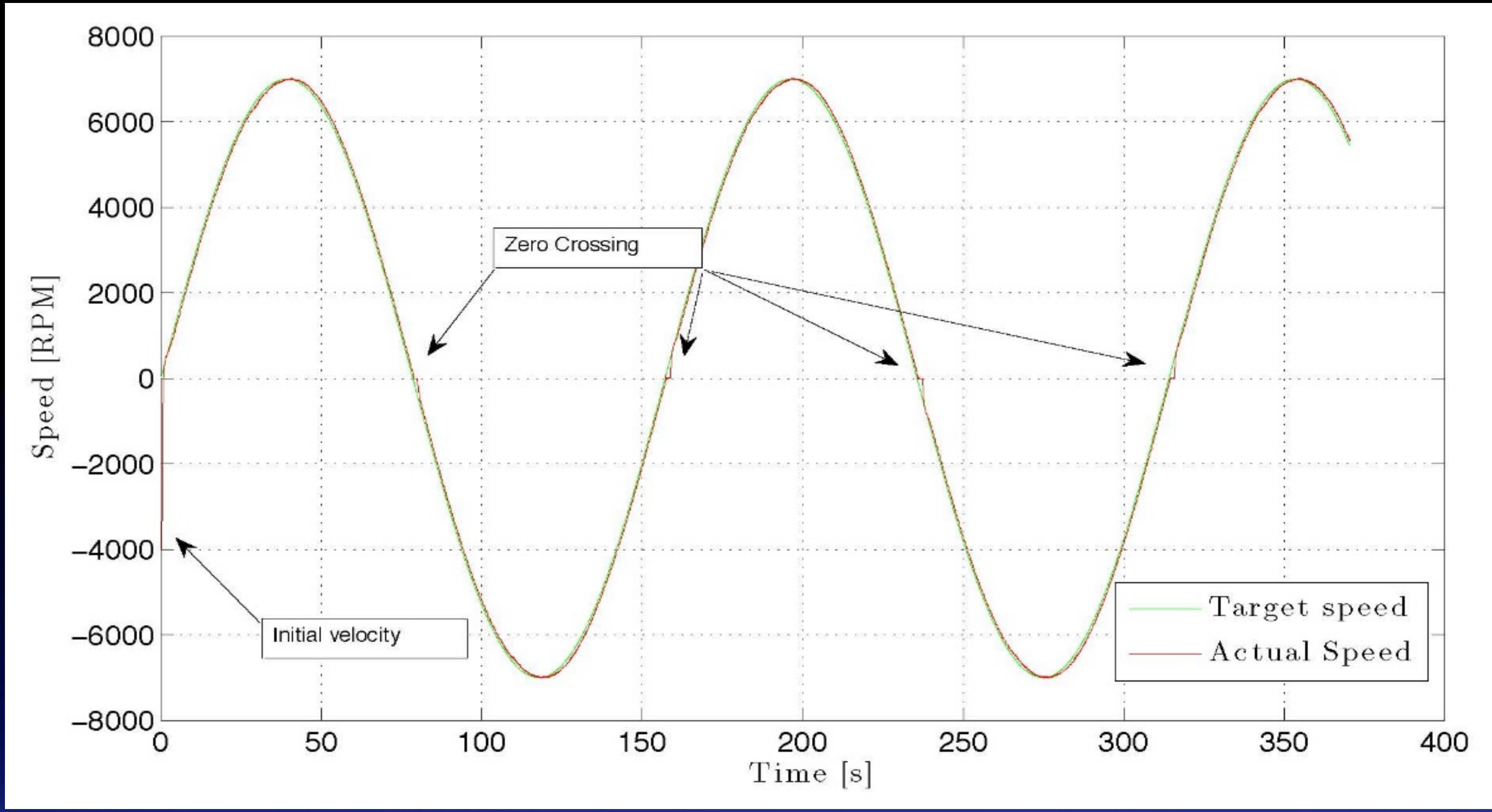
After calibration





ADCS HIL Simulation – RW Characterization

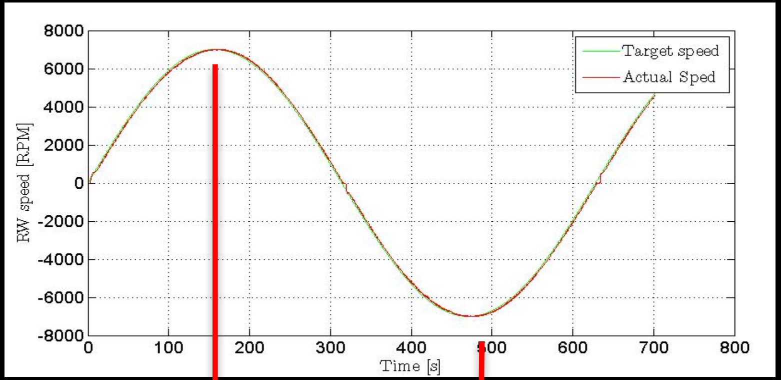
Analysis of zero-crossing effect on system performance



ADCS HIL Simulation – Sensor Interferences

Analysis of the cross-interference between actuators and sensors to drive ADCS design

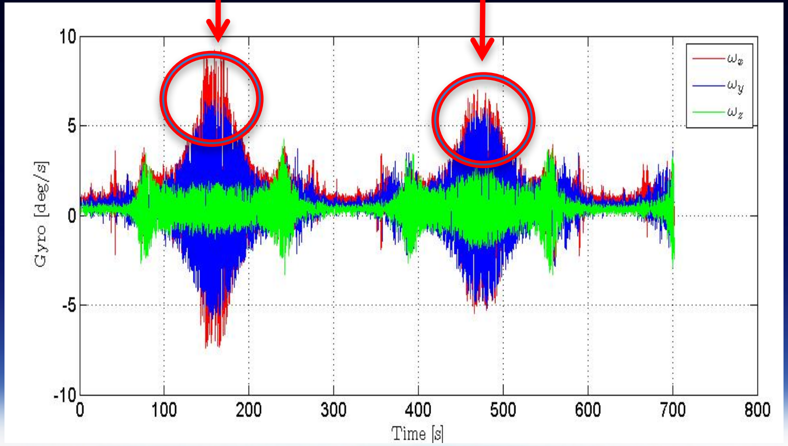
High RW speed causes jitter that can interfere with gyros readings and reduce mission accuracy



RW Speed

Interferences

These effect can be easily analyse and compensate by ad-hoc ADCS design



Gyros output

ADCS HIL – Softcore Architecture