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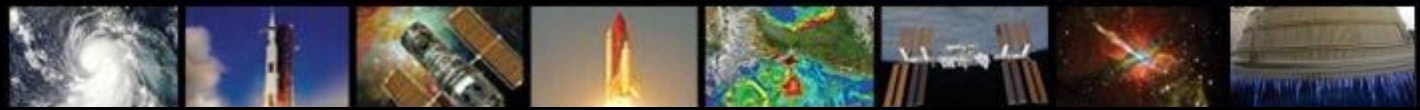

Pushing the Limits of Cubesat Attitude Control

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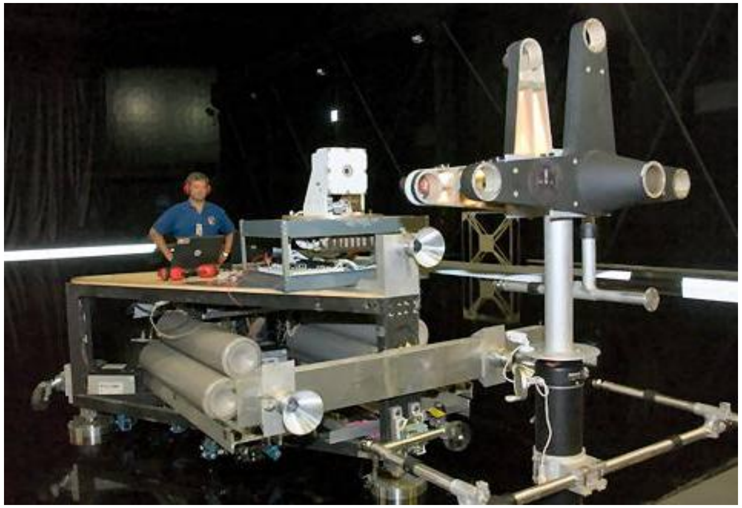
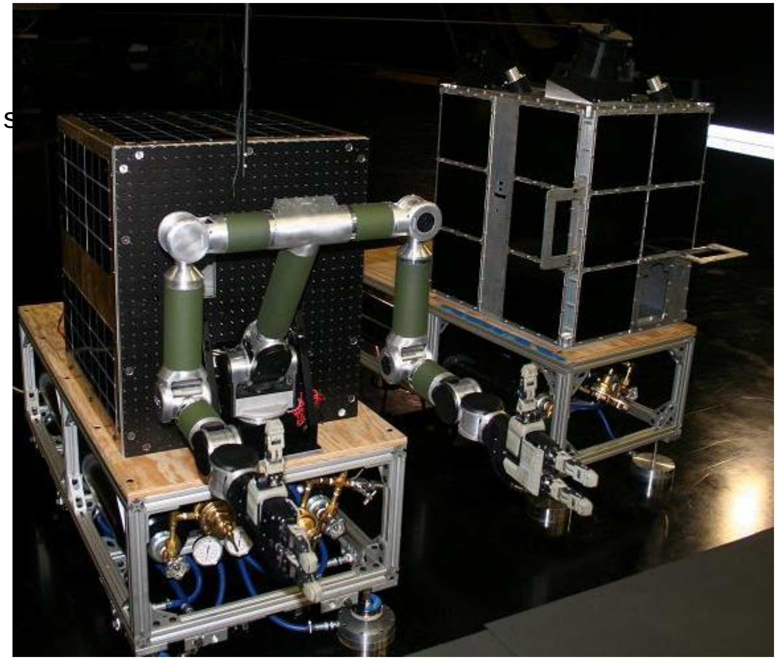
Introduction

- MSFC Overview
- Project Overview
- Cubesat Development
- Testing Results
- Lessons Learned
- Future Work
- Conclusions

MSFC Overview

- **AR&C Related Experience**
  - Video Guidance Sensor (VGS) & Advanced Video Guidance Sensor (AVGS)
  - Demonstration of Autonomous Rendezvous Technology (DART) – closed-loop
  - Orbital Express (OE) – open loop sensor suite testing
  - Hubble Servicing Mission 4 – Relative Navigation System
  - SpaceX DragonEye sensor testing using open-loop trajectories
- **Unique Facilities for Small Sat and AR&C Development**
  - SPRITE (Small Projects Rapid Integration & Test Environment) Lab
    - Provides hardware in the loop test capability for small satellites
    - Can be used to perform integration and software V&V
  - Flight Robotics Lab
    - Provides full scale, integrated simulation capability for the support of the design, development, integration, validation, and operation of orbital space vehicles (pico-sats through large satellites)
    - Centered around 44' x 86' precision air bearing floor
  - Contact Dynamics Simulation Lab
    - 6DOF Facility that enables real hardware simulation
    - Docking and contact dynamics for large spacecraft
  - Propulsion Research Laboratory
    - Ability to design, analyze, and hot fire small satellite propulsion s





Project Overview

- **Objective:** Raise Cubesat ACS with sub-degree pointing from TRL 2 to TRL 4

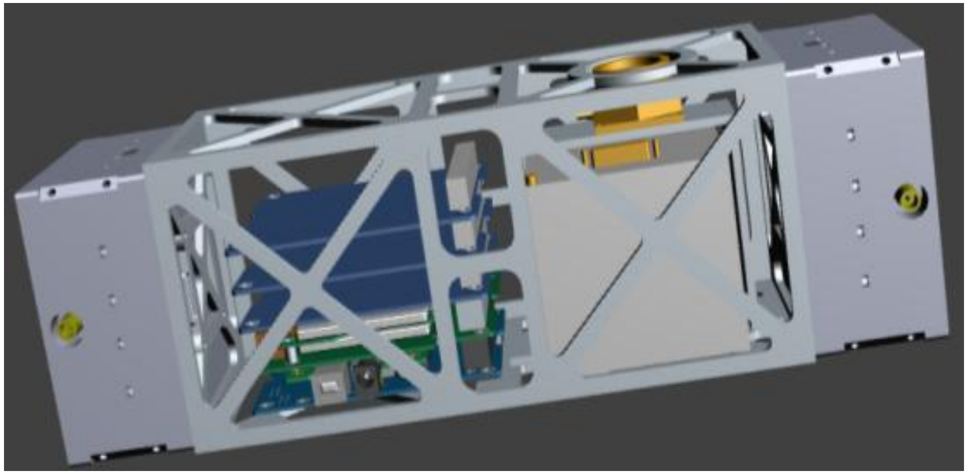
- **Why:**
  - Big exploration with small things!
  - Leverage existing MSFC AR&C experience, technologies, and infrastructure

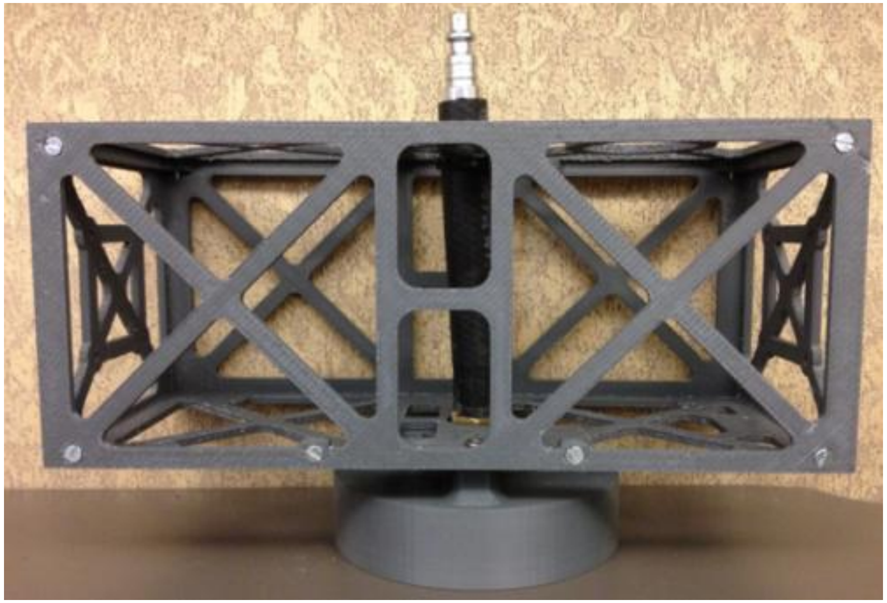
- **How:**
  - Find small, cost-effective hardware (gyros, mini-reaction wheels, micro-propulsion system, etc.)
  - Design and integrate 3U “Cubesat-like” breadboard in SPRITE Lab
  - Test and demonstrate ACS at Flat Floor in Flight Robotics Laboratory by floating cubesat on air bearing

- **Who:**
  - Small, young, multi-disciplinary team of engineers from MSFC Engineering
  - Propulsion provided by University of Arkansas

Cubesat Development

- **Designed a 3U cubesat-like breadboard with typical subsystems**
  - Mechanical, Avionics, GN&C, C&DH, Power, Propulsion
- **Took advantage of 3d printing capabilities for mechanical structure and air bearing**
- **Developed simple GN&C simulation with algorithms**
- **Integrated hardware and software in SPRITE Lab**





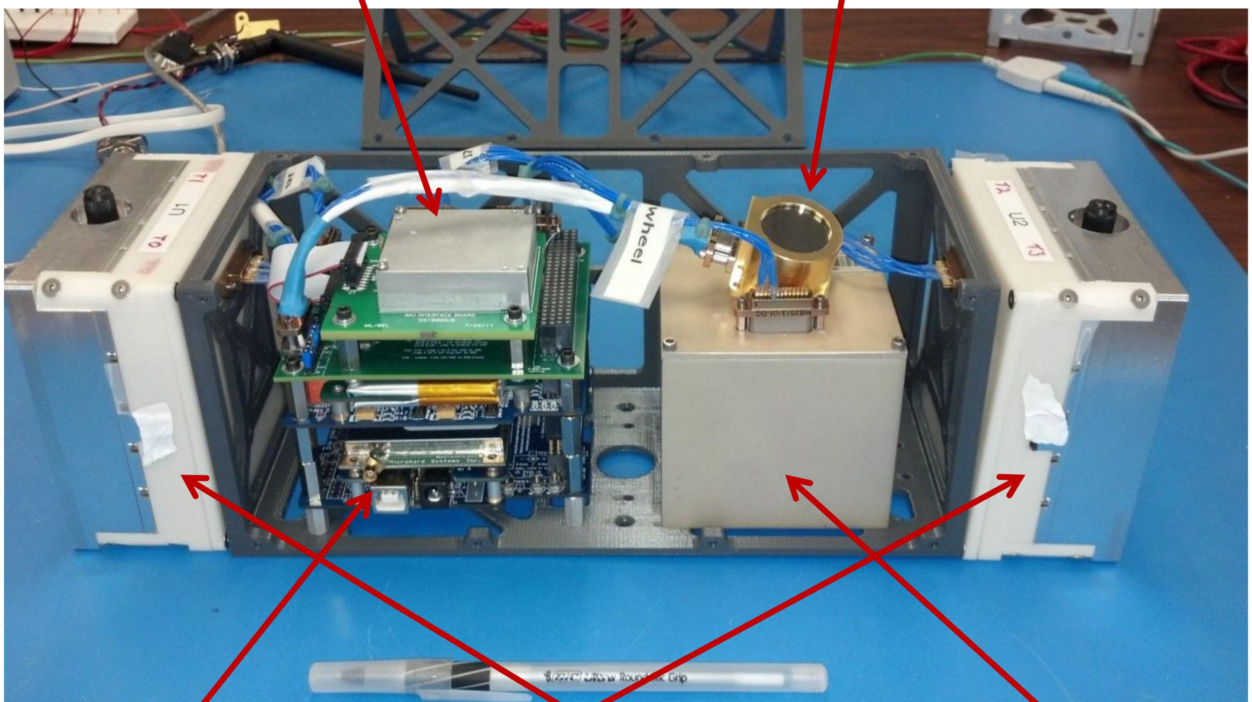
Hardware

- **Sensors**
  - Sinclair Digital Sun Sensor, accuracy +/- 0.1 deg
  - Analog Devices MEMS IMU (ADIS16488)
- **Actuators**
  - Micro Propulsion System, University of Arkansas
    - $C_3H_2F_6$ 1,1,1,3,3,3-hexafluoropropane (fire extinguishing agent)
    - 10-20 milliNewton thrust per thruster
    - 2 units (1/2 U ea.) providing Z axis roll control (+/- M_z)
  - 3 Axis Miniature Reaction Wheel (MAI-101)
- **Developed custom Avionics Breakout Board and connectors**
  - Provides power and comm interface between micro-processor and sensors/actuators
  - MSFC designed and built (ES42)
- **COTS Hardware**
  - Cubesat Kit motherboard and micro-controller (PSPM DSPIC 33 & PIC24)
  - Pumpkin Cubesat Kit EPS with battery
  - Microhard Wireless Modem (MHX920A)

Integrated Cubesat

MEMS IMU

Digital Sun Sensor
(Sinclair)



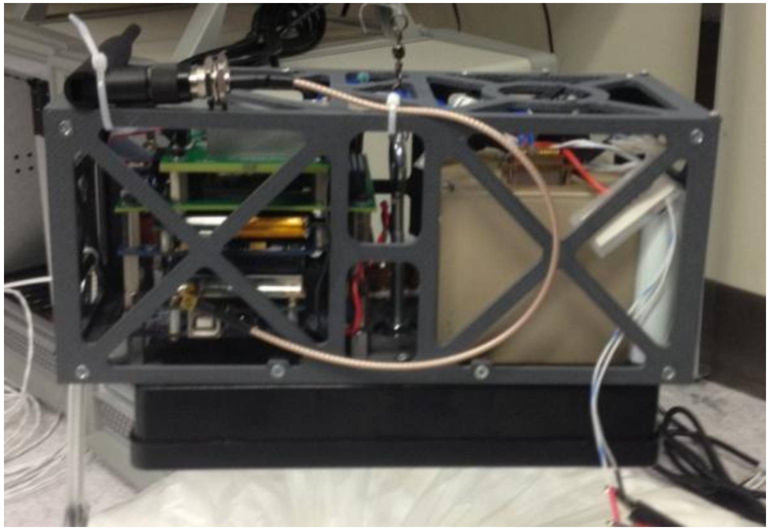
C&DH, Power boards

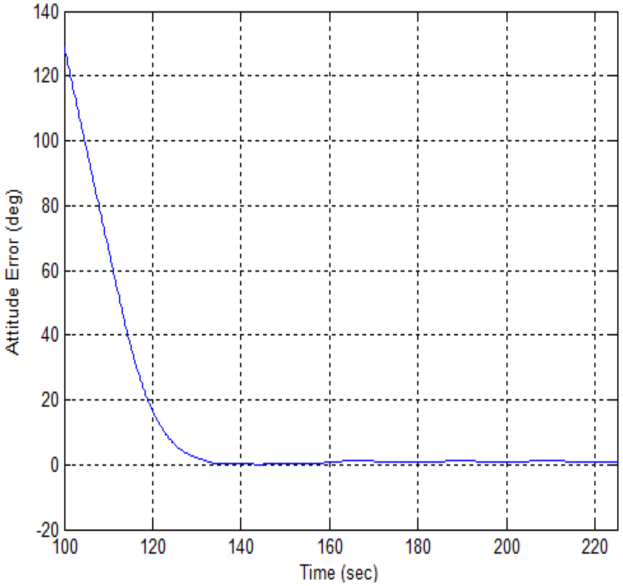
10 mN thruster modules
(University of Arkansas)

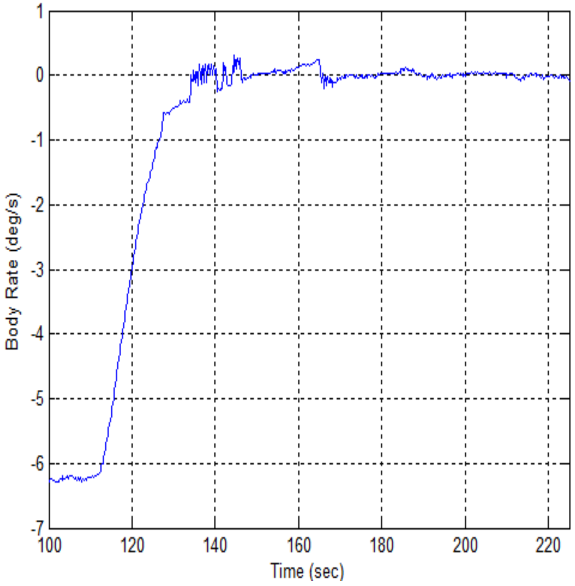
3-axis Reaction Wheels
(MAI-101)

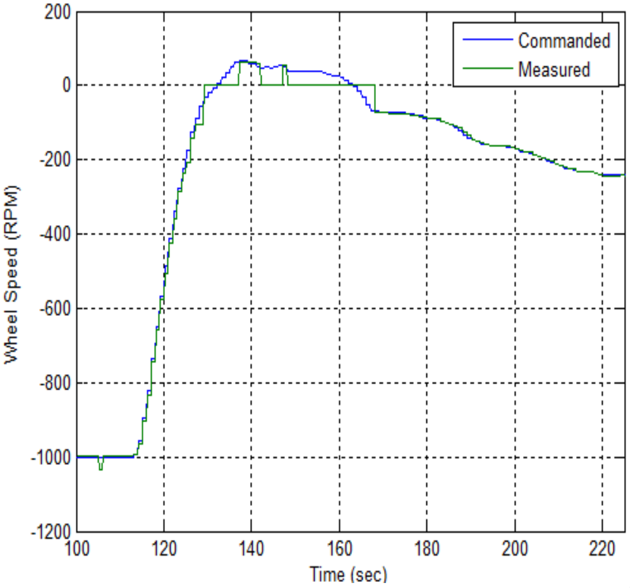
Testing Results

- Found torsional stiffness of tubing for air bearing provided too large of disturbance
- Modified cubesat to hang from ceiling to reduce torsional stiffness
- Began with IMU and reaction wheel only
- Used simple PD controller



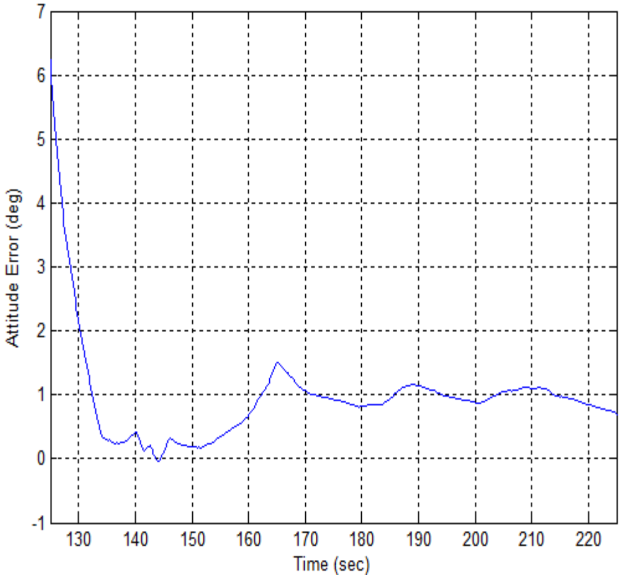


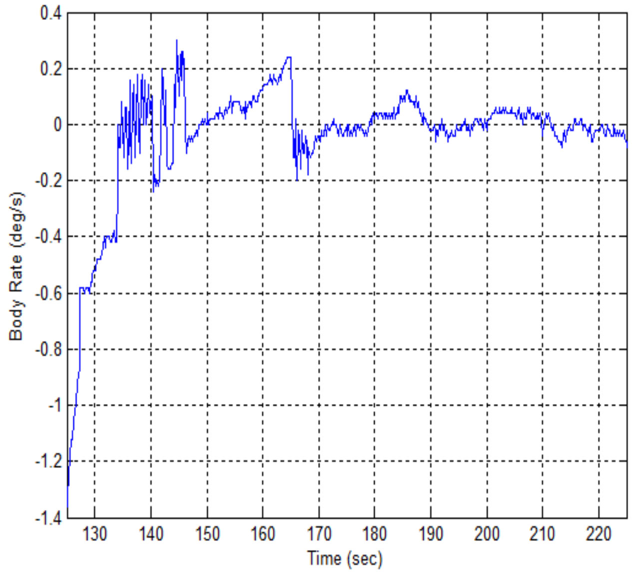


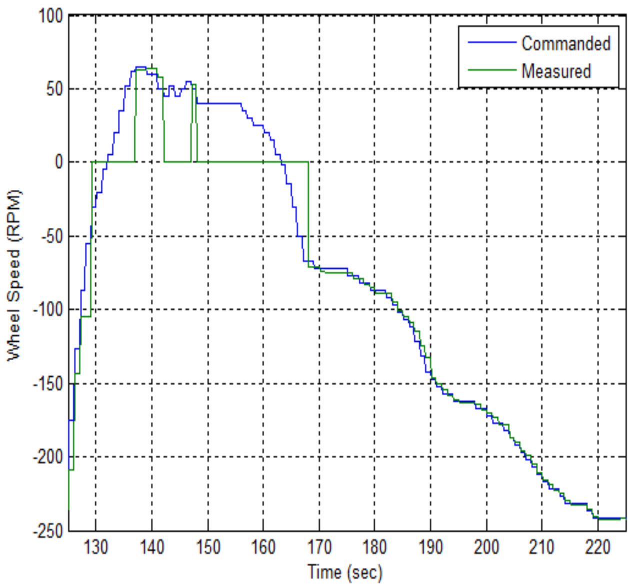


Testing Results

- ♦ **Attitude error around 1 degree and body rates driven to 0**
- ♦ **Spikes in attitude error and rates around RW deadband (+/- 50 RPM)**
- ♦ **Control system having to fight torsional disturbance of line**
- ♦ **Reaction wheels saturate ~5 minutes**







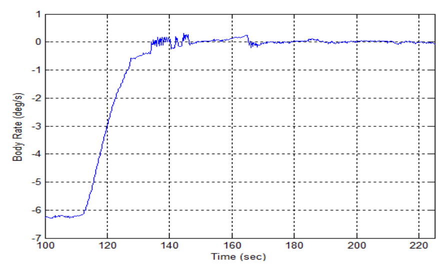
Lessons Learned

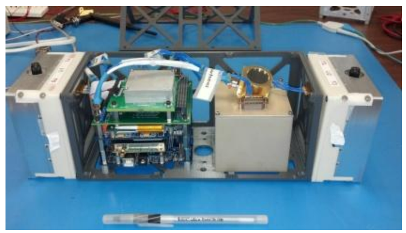
- Don’t underestimate the complexity of designing a spacecraft and the value of all the systems
- Understand risks and how to eliminate them possible
- System integration takes a lot more effort and is more challenging than expected
- Creating a relevant environment for testing can sometimes take as much or more effort than developing the technology which is being tested

Future Cubesat Work

FY12 CIF – CubeSat ACS

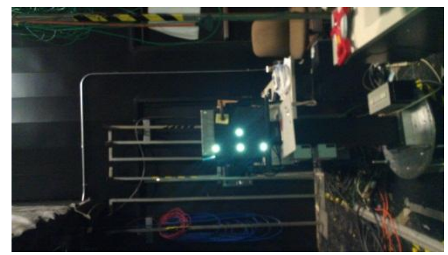
Demonstrated CubeSat attitude control system with MEMS rate gyros, sun sensor, reaction wheels, & micro propulsion system





FY12 CIF – Smartphone Video Guidance Sensor

Smartphone version of Advanced Video Guidance Sensor contains camera, flash, software and processor all in one small, COTS package for 6DOF state estimation of target vehicle

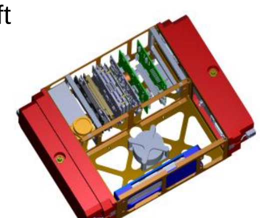


FY13 MSFC TIP – CubeSat Prox Ops

Autonomously rendezvous a CubeSat prototype with another CubeSat or FASTSAT mock-up in MSFC's Flight Robotics Lab ("The Flat Floor")

Technical Objectives

1. Integration and demo of miniature sensor and actuator suite for AR&C
2. Demo of cubesat proxops and formation flying with other small spacecraft



Conclusions

- MSFC pushing limits of cubesat technologies for future exploration opportunities
- Integrated a 3U cubesat breadboard with COTS hardware and propulsion
- Demonstrated single-axis pointing error of less than a degree