An Open-Source Reaction Wheel System for Oregon's First Satellite

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OreSat

- **Mission: STEM outreach by sending live video space-to-ground to tracking stations built and operated by Oregon high schools**
- Ground stations will be built using 3D printers, COTS WiFi adapter cards, and existing augmented reality cellphone apps that track satellites
- S-band downlink at approximately 15 dBi gain. Needs to "point-and-stare" at ground stations with **5-10° of pointing at 1 deg/s of slew**
- Will use a **reaction wheel** based system to provide attitude control

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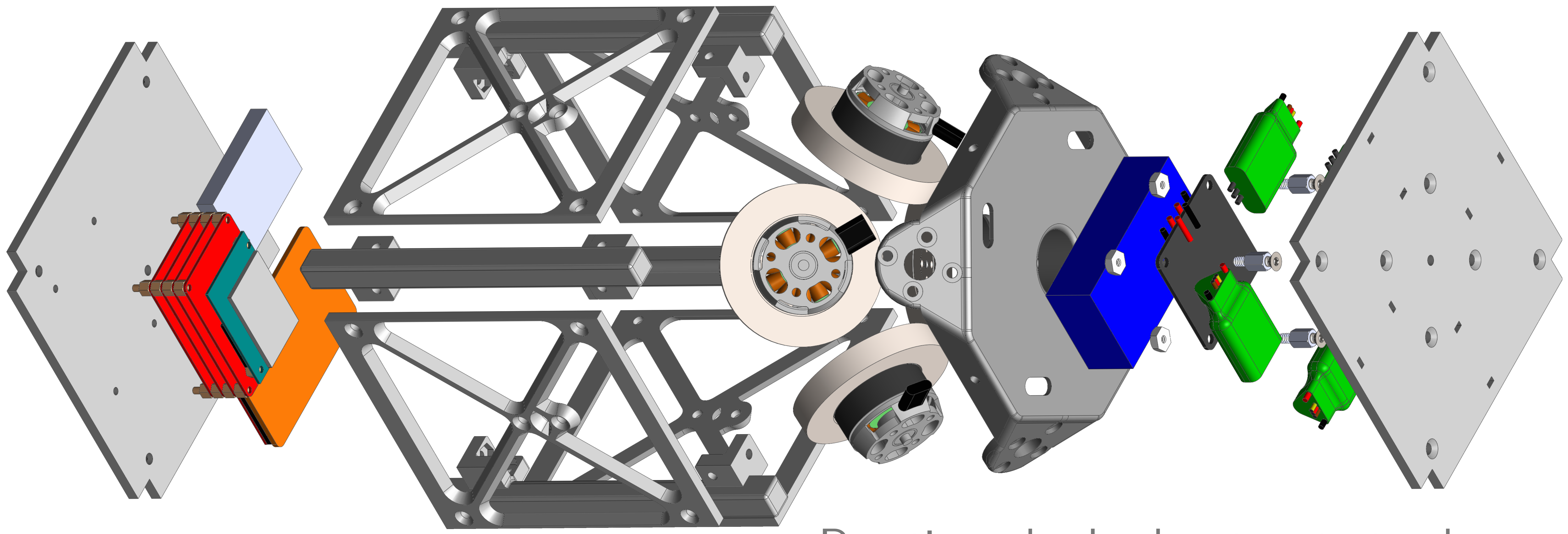


Reaction wheel subsystem test cube

Rapid Prototyping

- Designed for rapid iteration
- FDM 3D printed main structure
- Inexpensive COTS components: DC Brushless hobby motors, Intel Edison microcontroller, and Sparkfun "blocks"
- Controller code written in *Python*

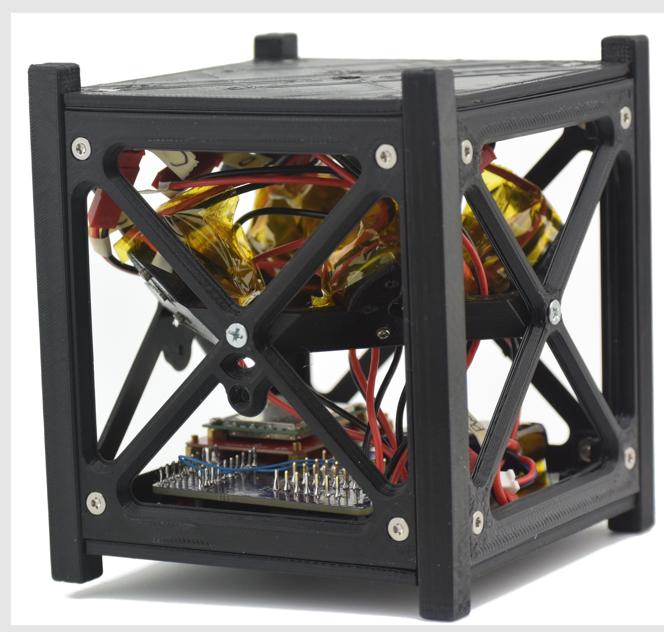


Figure: The reaction wheel subsystem test cube.

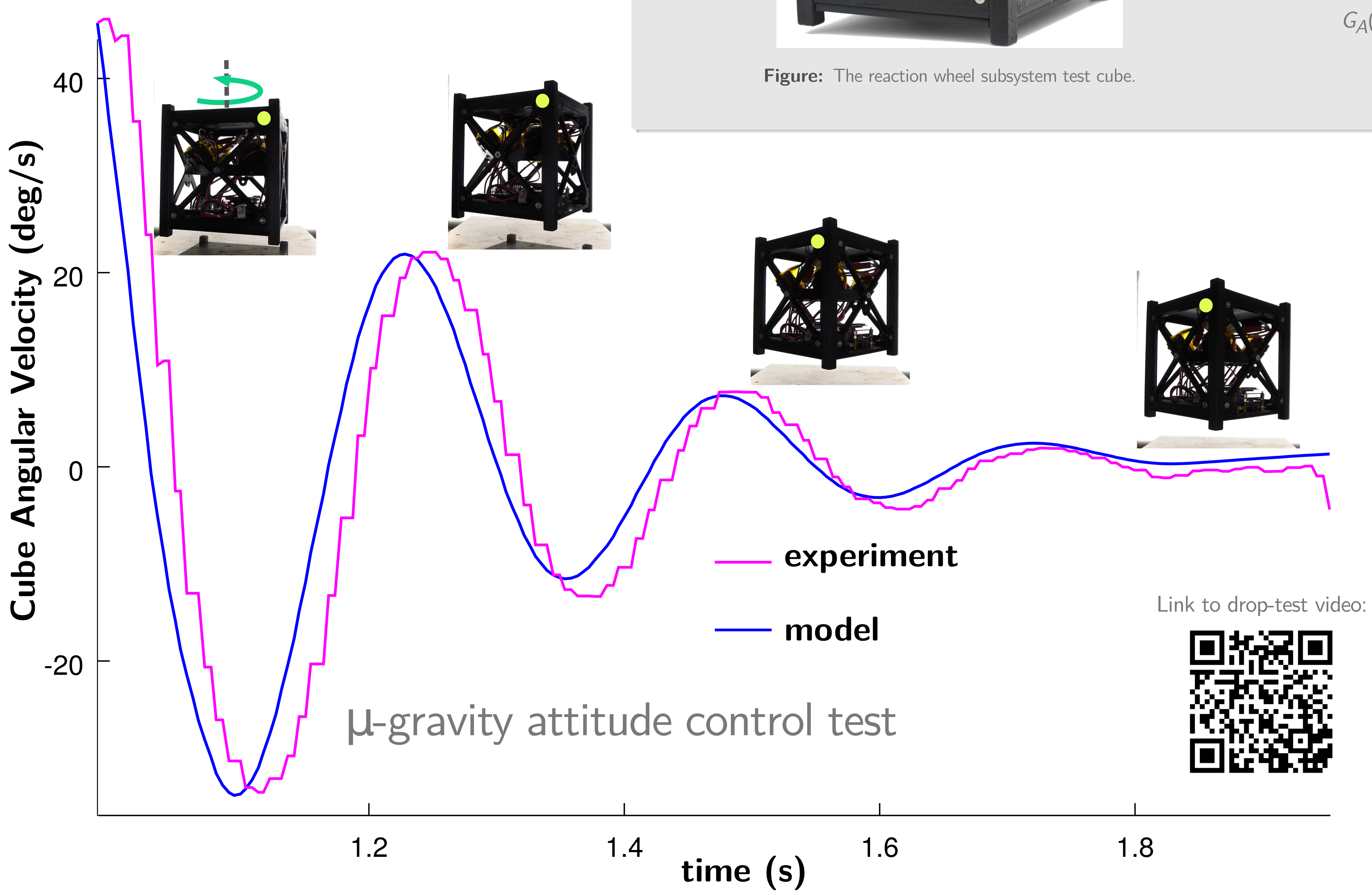
Control Development

- The controller for the reaction wheel system is a simple PID loop
- The top-level controller design procedure was as follows:
  1. Determine the transfer functions from dynamics analysis of free body diagrams of the system
  2. Create simulation in GNU Octave
  3. Design the controller using iterative testing (with comparisons to the model) and classical Bode techniques
- The forces acting on the cube are the torques created by the motors T_i^0, damping ef ects $b_1\dot{\theta}_{cube}$, and spring ef ects $G_1\theta_{cube}$. Summing the moments around the center of gravity gives the following equation (for the x-axis):

$$^{x}M_0^{+} = I_{x,cube}\ddot{\theta}_{x,cube} = T^0_{Ax} + T^0_{Bx} - T^0_{Cx} - T^0_{Dx} + T^0_{x} - \dot{\theta}_{x,cube} - G_x\theta_{x,cube}.$$

- By setting the system to Standard Equilibrium Position (at SEP the input perturbations are set to zero), considering only a single input, substituting the torque-inertia relation, and taking the Laplace transform we arrive at (*the incredibly simple*) transfer function of the cube:

$$G_A(s) = \frac{\theta_{x,cube}(s)}{\theta_A(s)} = \frac{s^2}{\frac{I_{x,cube}}{\sin(45^\circ)I_{rw}}s^2 + \frac{b_x}{\sin(45^\circ)I_{rw}}s + \frac{G_x}{\sin(45^\circ)I_{rw}}}.$$



μ-gravity attitude control test

μ-gravity Controls Testing

- Bode analysis of cube dynamics in "space-like" free-fall environment
- *Portland State University's* Dryden Drop Tower facility can access a $1\text{x}10^{-5}$ to 10^{-6}-g environment for 2.1 s
- Cube damps roll following a random (25% duty cycle PWM) perturbing impulse

Figure: *Portland State University's* Dryden Drop Tower (Credit: Andrew Wollman)

Open-Source

- Project deliverables freely and publicly available under a GNU GPL v2 license
- `https://github.com/oresat`

Further Work

- Need more drop-tests: complete Bode diagram to improve dynamical model, further controller design iterations
- State determination with sensor fusion via Kalman f ltering suntracker, magnetometer, and gyroscopes

References

- Mahoney, Erin. *CubeSat Launch Initiative: 50 CubeSats from 50 States in 5 Years.* NASA, April 9, 2015. http://www.nasa.gov/content/cubesat-launch-initiative-50-cubesats-from-50-states-in-5-years.
- The CubeSat Program, *Cal Poly SLO. CubeSat Design Specif cation Rev. 13.* San Luis Obispo: California Polytechnic State University; 2014.