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

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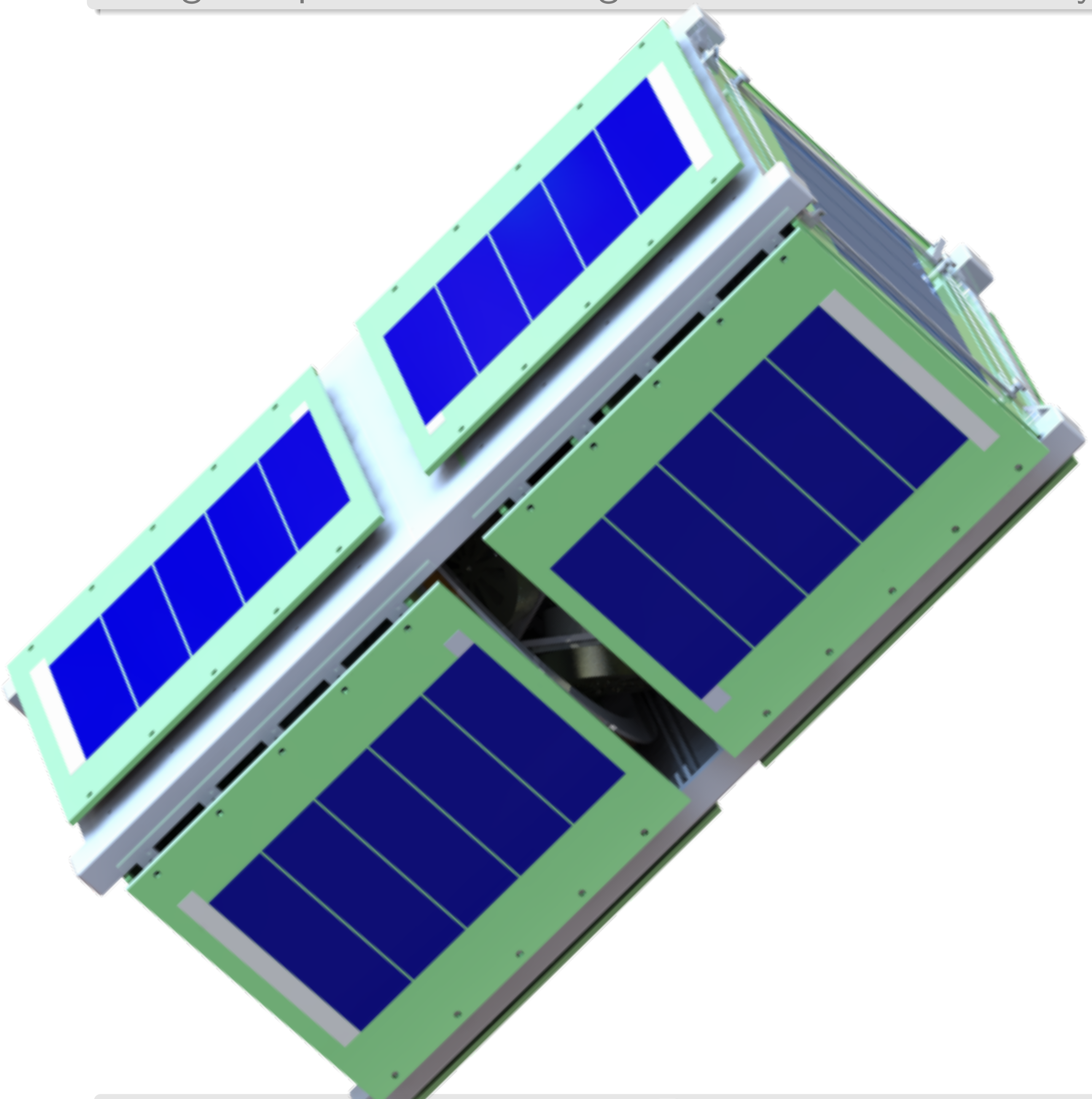
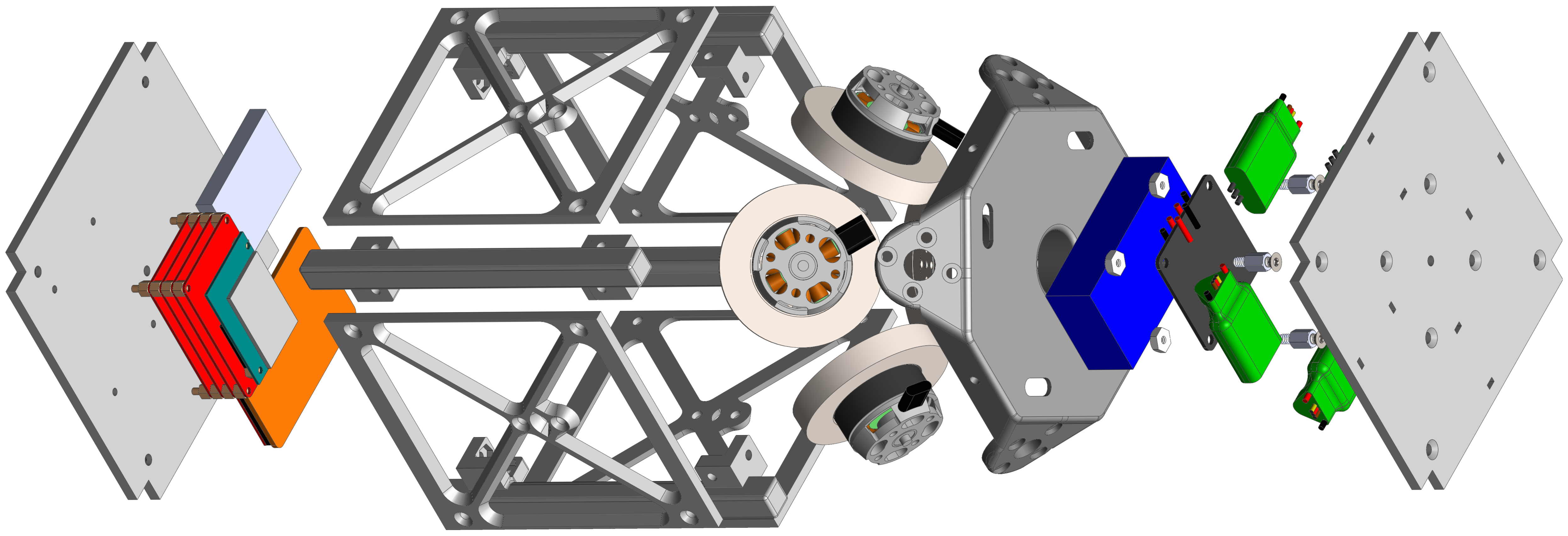
OreSat

- **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
- Downlink via 2.4 GHz 802.11b "DxWiFi" on helical with 1 W amplif er and approximately 15 dBi gain. Need to "point-and-stare" at ground stations with **5-10° of pointing**
- Can not satisfy slew and pointing accuracy requirements with magnetorquers so we're using a **reaction wheel** based system





Rapid Prototyping

- Designed for rapid iteration
- Uses FDM 3D prints for the main structure
- COTS components include: DC Brushless hobby motors, LiPo battery packs, Intel Edison microcontroller, and Sparkfun "blocks"
- Controller code written in Python, for readability and ease of sharing

Controls Development

- The controller for the reaction wheel system is a simple PID loop
- The microcontroller receives feedback from a 9-DoF IMU over analog-in, and sends signals via GPIO to the DC motors.
- 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):

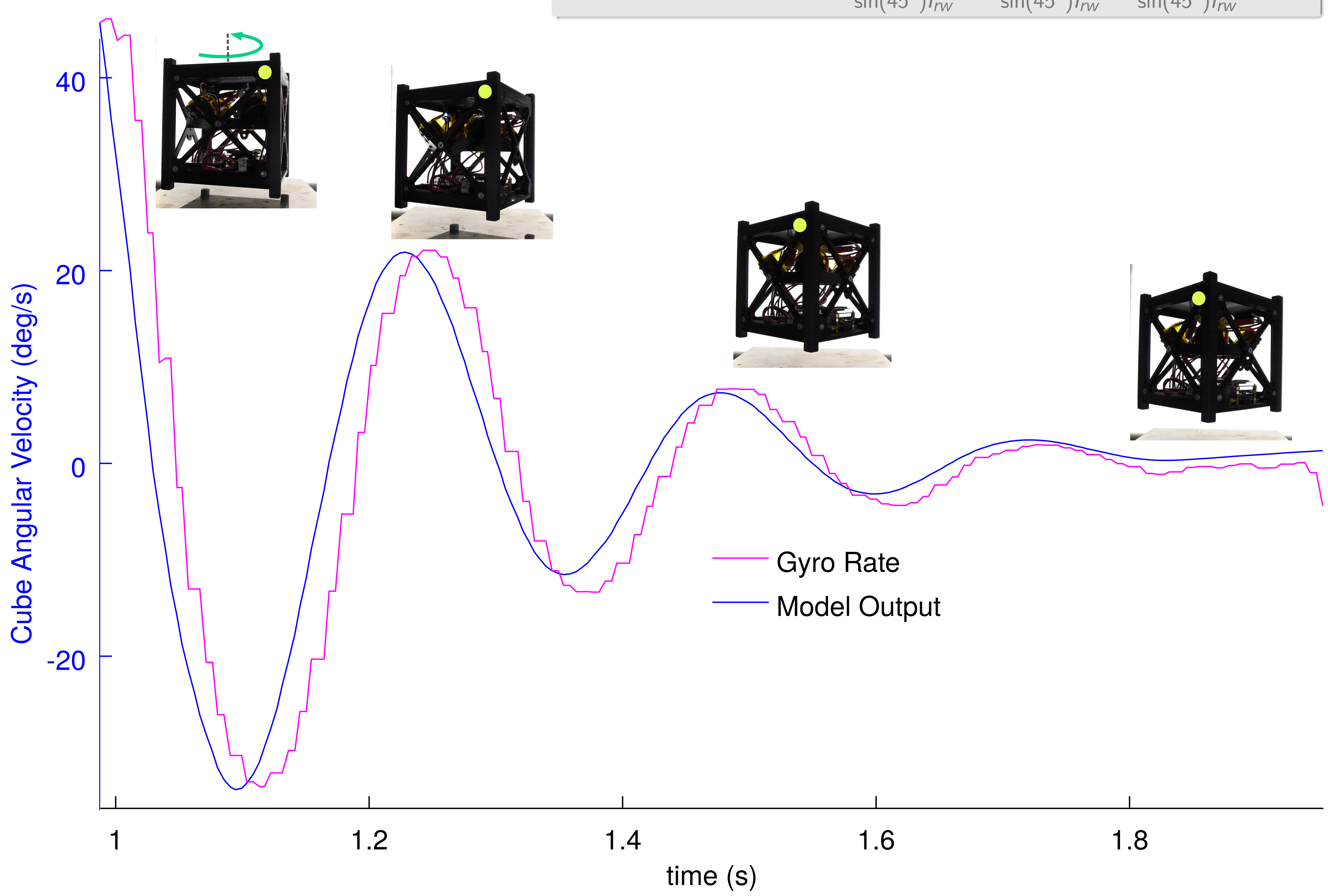
$$^{x}\ M_0^{+} = I_{x,cube}\ddot{\theta}_{x,cube} = T_{Ax}^0 + T_{Bx}^0 - T_{Cx}^0 - T_{Dx}^0 + T_x^0 - \dot{\theta}_{x,cube} - G_x\theta_{x,cube}.$$

- 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 have the 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 Drop-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



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
- For f ight: need to have a pointing accuracy of 10 degrees with a slew rate of 1 degree per second. Achieve sensor fusion via Kalman f ltering suntracker, magnetometer, gyroscope

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.