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Attitude Determination and Control System of a 3U Cube Satellite

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INTRODUCTION

The 3UCubed project is a 3U CubeSat being developed by the University of New Hampshire, Sonoma State University, and Howard University as a part of NASA IMAP student collaboration. This project consists of a multidisciplinary team of undergraduate students from all three universities. The science mission goal of the 3UCubed is to understand how Earth's polar upper atmosphere ('the thermosphere' in the auroral and cusp regions) responds to particle precipitation and varying conditions associated with solar wind forcing and internal magnetospheric processes. The 3UCubed satellite includes two instruments with rocket heritage, an Ultraviolet Photomultiplier tube (UV-PMT) to measure neutral atomic oxygen emissions, and an Electron Retarding Potential Analyzer (ERPA) to measure energetic precipitating electrons. These two instruments require tight pointing along the magnetic field lines within the cusp region.

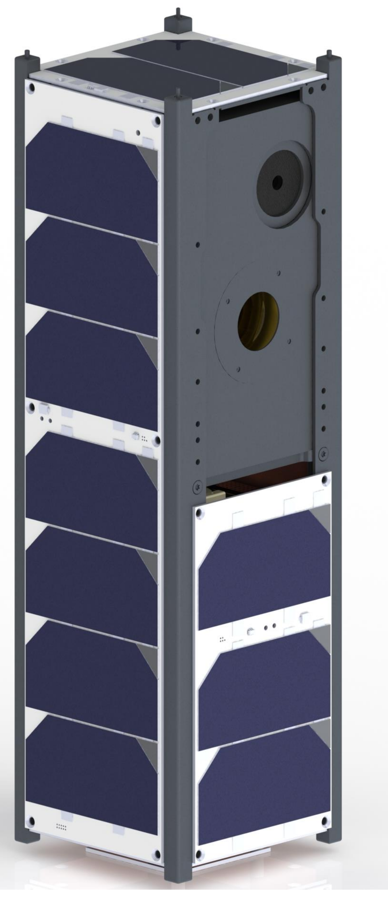

Figure 1: 3UCubed render

CONCEPT AND DESIGN

Mission Level Requirements

ADCS: 3UCubed shall be capable of determining attitude and position.

Bus Level Requirements

Attitude determination: ADCS shall allow for a knowledge of the pointing within ±5° with respect to magnetic field inside the cusp.

Attitude control: ADCS shall be able to point with accuracy ±10° with respect to magnetic field in cusp.

To meet these requirements, 3UCubed will use the Gen1 CubeADCS developed by CubeSpace. This ADCS is a 3-axis stabilized system and will be equipped with three magnetorquers (XYZ) and one Y-momentum wheel

DETUMBLING

To achieve the science goals for this mission, 3UCubed will be nadir (Earth) pointed such that the ERPA and UV-PMT are imaging along the magnetic field lines when the spacecraft is in the cusp (polar) regions. The spacecraft will initially be in a random tumble when released into the space environment, and thus uses the ADCS to stabilize.

The ADCS has two control stages, detumbling and Y-momentum. It will go through four control modes and three estimation modes (Figure 2) before reaching its final stabilized state.

		Control Mode				
		None	Detumbling & fast modes	Y-Thomson	Y-Momentum	XYZ wheel (all modes)
Estimation mode	None	OK	OK	X	X	X
	MEMS rate	OK	OK	OK	X	X
	Magnetometer rate	OK	OK	OK	X	X
	Magnetometer rate + pitch	OK	OK	OK	OK	X
	TRIAD	OK	OK	OK	OK	X
	Full-state EKF	OK	OK	OK	OK	OK
	MEMS Gyro EKF	OK	OK	OK	OK	OK

Table 2: Table depicting valid mode transitions, sourced from CubeSpace

Control Mode	Control Mode Description	Actuators Used	Estimation Mode	Estimated Information
BDot	Uses a BDot Detumbling magnetic controller to dump –X and –Z body rates, decreasing the satellite's angular rate.	Y- magnetorquer	MEMS Rate Sensor (MemsRate)	XYZ angular rates
Y Thompson Spin (YSpin)	Adds Y Thompson spin to BDot using the –X and –Z magnetic torquers	XYZ magnetorquers	Triad	Yaw, Pitch, and Roll angles, XYZ angular rates
Y-momentum Wheel Initial (YWheelInnit)	Y-momentum wheel ramps, and most of the body spin from Y Thompson is absorbed	XYZ magnetorquers, Y-momentum Wheel	MEMS Gyro Ekf	Yaw, Pitch, and Roll angles, XYZ angular rates, XYZ gyro Bias
Y-momentum Wheel (YWheel)	Steady-state mode. Occurs when the pitch angle is within 25 degrees of the reference angle	XYZ magnetorquers, Y-momentum Wheel	MEMS Gyro Ekf	Yaw, Pitch, and Roll angles, XYZ angular rates, XYZ gyro Bias

Table 1:ADCS control and estimation modes used for 3UCubed mission

Modes used by 3UCubed (Table 1) were chosen using the information in Table 2.

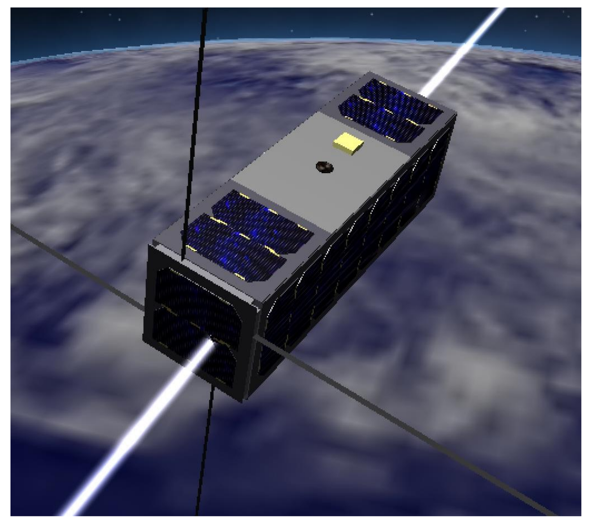

Figure 2: Image of 3UCubed satellite nadir pointed in EOS

OPTIMIZING ADCS PERFORMANCE

3UCubed aims to detumble and stabilize as efficiently and effectively as possible. To achieve this, each control mode has been analyzed and its stability determined. Table 3 was created based on the angular rate error (for XYZ body angles), which can be seen in the figure on the right

Control Mode	Estimation Mode	Mode Duration in EOS	Mode Duration (sec)	t_Stable	t_Final	t_Delta	Avg. X angular rate error (deg/s)	Avg. Y angular rate error (deg/s)	Avg. Z angular rate error (deg/s)
BDot	Triad	00:00- 02:00	7200	01:15	02:00	t_stable + 45 min (t_stable+ 2700 sec)	0.0064	-0.1552	-0.0604
YSpin	EkfFullState	02:00- 03:30	5400	02:25	03:30	t_stable+ 2700 sec	-0.0016	-0.0487	-0.0042
YWheelInnit	EkfGyro	03:30-04:45	4500	04:00	04:45	t_stable+ 2700 sec	0.0009	0.0030	0.0035
YWheel	EkfGyro	Begins @ 04:45		05:30		t_stable+ 2700 sec	-0.0027	-0.0060	-0.0035

Table 3: Table showing data used to determined stability of each mode

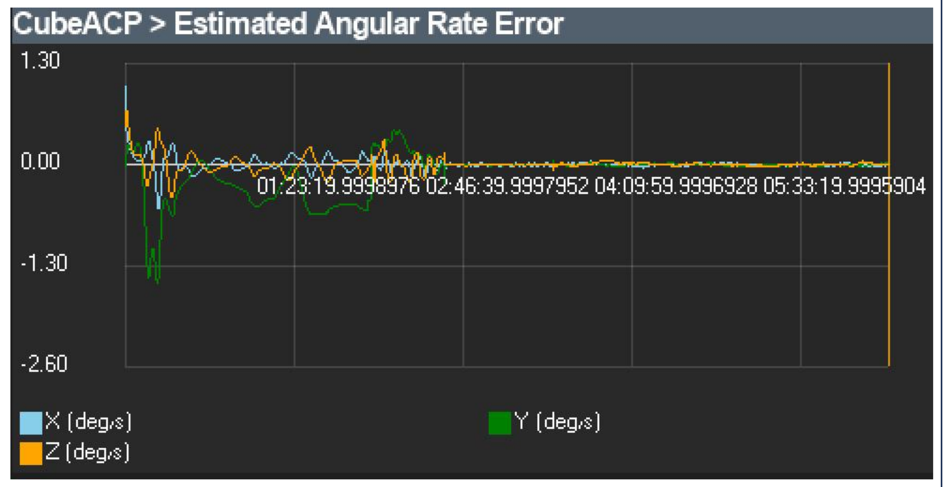

Figure 3:EOS generated analysis of estimated angular rate error (XYZ) over time, for all control modes

The point of stability (t_stable) was determined when the angular rate error became more constant or "settled" close to zero. An additional 45 minutes (≈ 0.5 orbit) was added to t_stable as a buffer. The average angular rate errors were determined from numerical error data collected from EOS.

FUTURE WORK

Power Analysis: In the future, power generation and consumption data extracted from EOS will be analyzed and compared to the same calculations done in Ansys Systems Tool Kit (STK) to ensure accuracy of the data. This will be used for the satellite's power budget in the future.

Continue Optimizing EOS Simulation: Work will continue in EOS to further optimize ADCS performance.

Update Scheduler Script: In EOS, a scheduler script can initiate transition from one mode to another based on time stamp. In the future, this script will be updated to reflect current control/estimation modes and their respective time stamps.

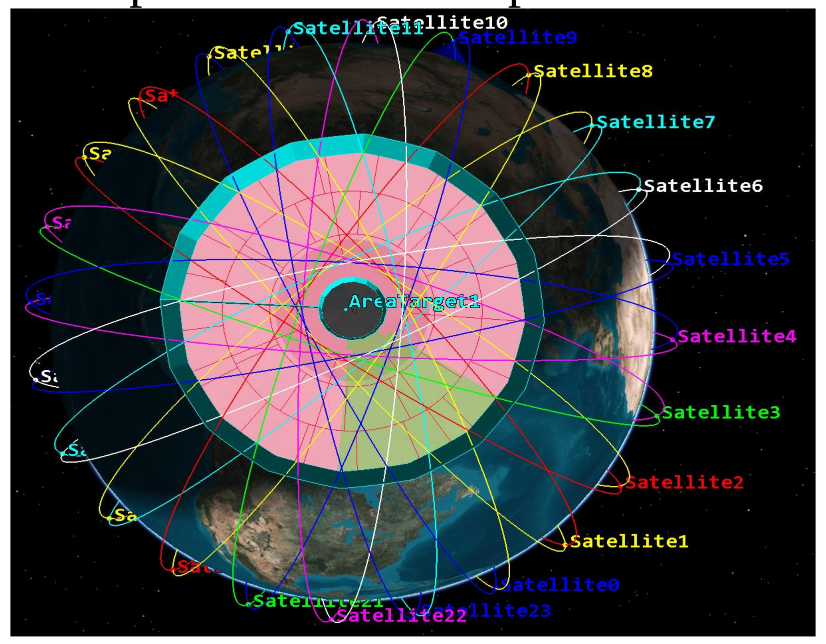

Figure 4: Image from Ansys STK of potential orbits for 3UCubed mission.

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