Ground-Based Attitude Determination and Control System Testing

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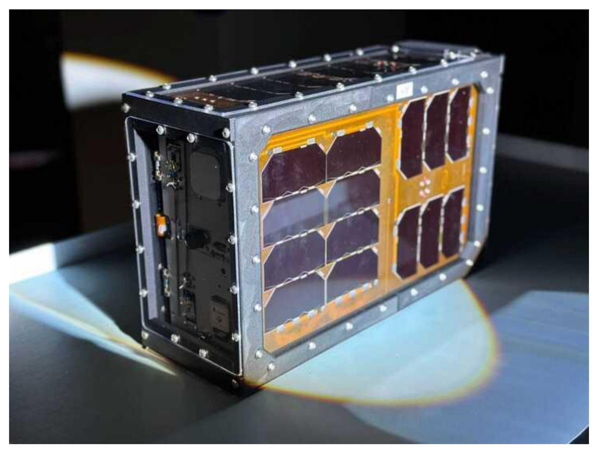
I. Abstract

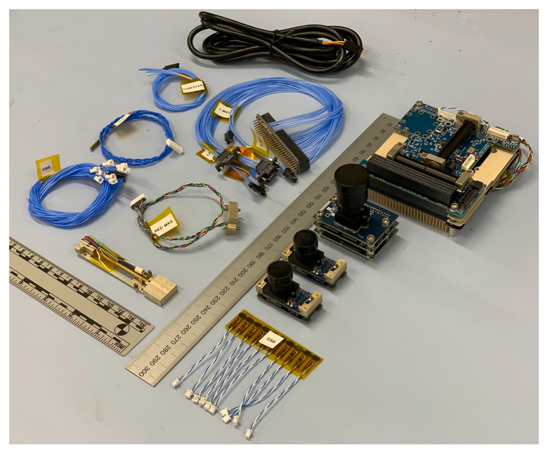
Automation of Attitude Determination and Control System (ADCS) commissioning steps and verification of actuator polarity on the ground for CubeSats can help decrease the commissioning timeline after deployment and allow nominal science observations to begin sooner, saving time for ground operators and maximizing science return.

This work focused on the verification and validation of the ADCS software and commissioning steps for the Hyperspectral Thermal Imager (HyTI) satellite, a 6U CubeSat whose ADCS was supplied by CubeSpace Satellite Systems.

The integrated HyTI CubeSat was tested on the Attitude Control System Testbed (ACSTB) located at the Hawai'i Space Flight Laboratory (HSFL), a laboratory at the University of Hawai'i at Mānoa. The tests utilized a Helmholtz cage, a single axis air bearing, and a motion-tracking system. The simulations were performed using the Earth Orbiting Satellite Simulation Software (EOS) provided by CubeSpace.



[Left] HyTI 6U CubeSat [Right] HyTI ADCS from CubeSpace (Gen1) minus the reaction wheels.



II. Automatic Commissioning Steps

The goal of testing HyTI using the ACSTB and with EOS was to validate the ADCS commissioning steps and our operational logic, with a priority on the automatic steps. The automatic steps are shown in the Table below along with their pass conditions, fail conditions, and what should happen if a failure occurs. By the end of these automatic steps, the bus should be in a controlled spin about the Y-Axis with angular rates of [0, -1, 0] deg/s, also known as Y-Thomson Spin.

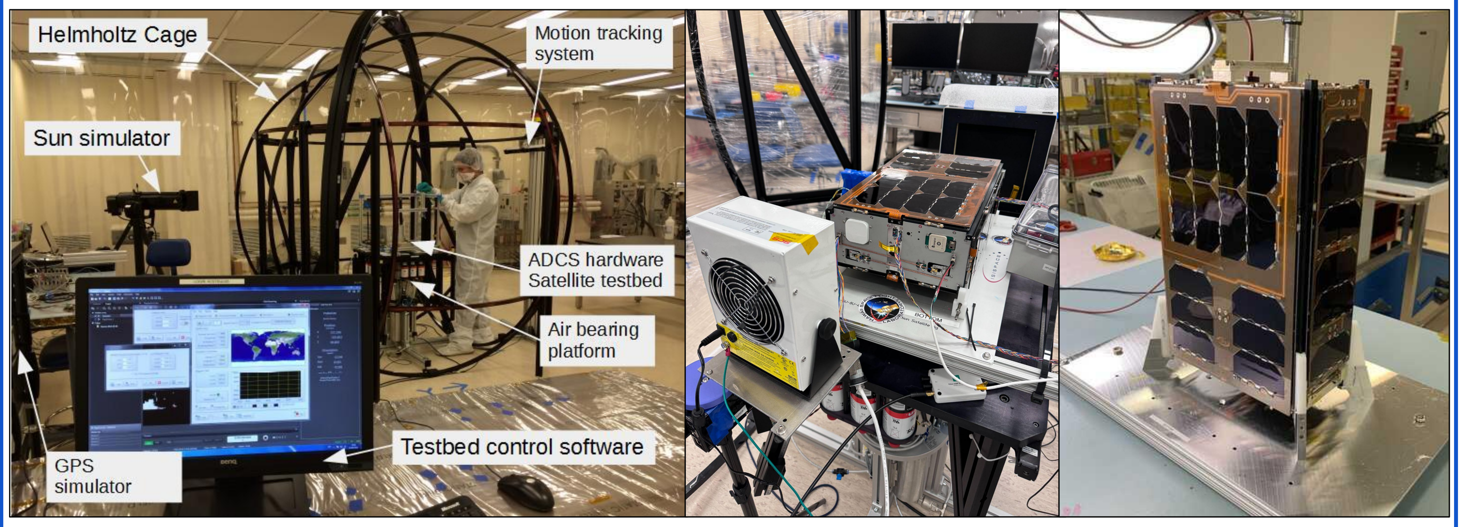
Commissioning Step	Purpose / Goals	Conditions [P] = Pass condition [F] = Fail condition	If Fails Step
1. Initial Angular Rates	Validate estimation mode 2, Magnetometer Rate Filter, by comparing the Gyro Rate Sensor Rates and the Magnetometer Estimated Angular Rates.	[P] The magnetometer angular estimated rates equal the Gyro rate sensor rates within 1 deg/s. [F] Rates do not exceed 35 deg/s. Timeout of 10 minutes.	Continue to Commissioning Step 2 using estimation mode 1, MEMS Rate Sensing.
2. Initial Detumbling	Begin the detumbling of the satellite and dampen the X and Z rates using the Y-magnetorquer.	[P] Rates are less than 5 deg/s for 60 consecutive data takes. [F] Rates exceed 30 deg/s [F] Max angular rate increases for 3 continuous minutes Timeout of 10 minutes	Turn off the control and skip step 3. Wait in safe mode (0d) for ground contact to analyse the problem.
3. Y-Thomson Spin	Put the satellite in a Y-Thomson Spin using the X-, Y-, and Z-magnetorquers.	[P] Angular rates are 0, -1, 0 deg/s ± 1.5 deg/s for 30 consecutive minutes [F] Angular rates are greater than 30 deg/s [F] The max angular rate increases for 3 continuous minutes Timeout of 1.5 hours	Turn off the control and go to safe operational mode (0d). Wait for ground contact.

III. Attitude Control System Testbed (ACSTB) Testing

The testing was started by rotating the spacecraft to an initial rate of ~30 deg/s. For Commissioning Step 1, the estimated magnetometer and rate sensor angular rate data were acquired and compared with each other. Since there was no attitude control during this step, this data was used as a baseline for characterizing the inherent rotation of the air bearing.

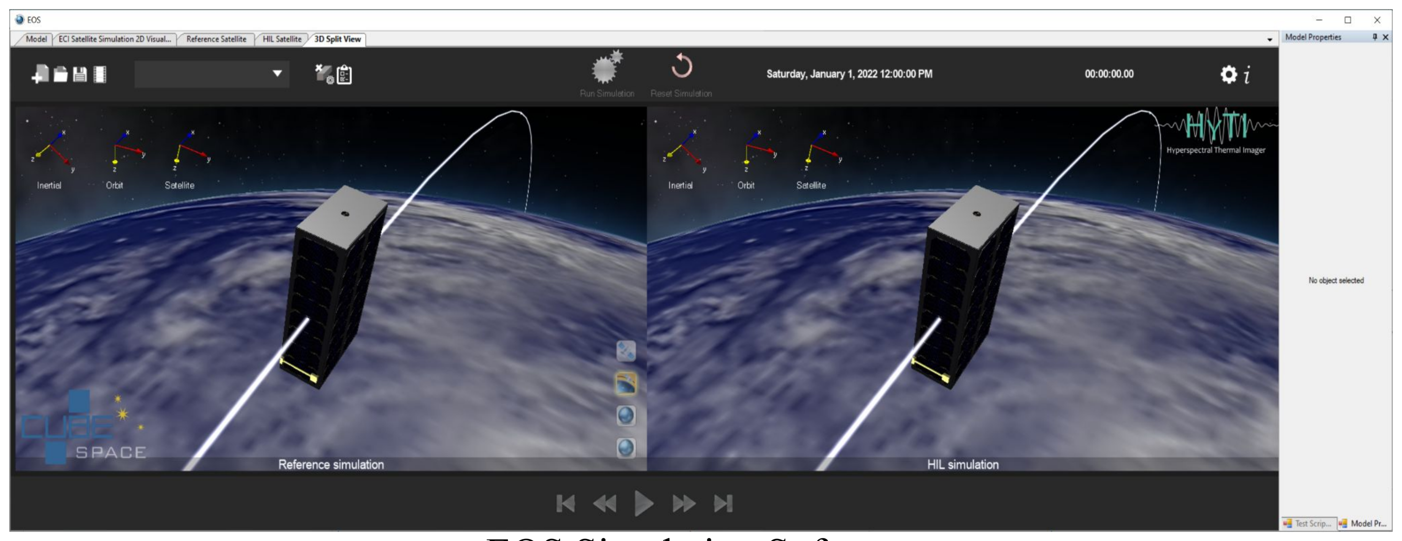
Since the the air bearing had no balancing system, there was an inherent torque causing a rotation. The magnetorquers could not overcome the inherent torque and reach the Detumble/Y-Thomson spin that was desired. Instead, the rotation was characterized during step 1 and compared to the detumble rate when using the magnetorquers. These tests were repeated several times for each step and each axis of the spacecraft.

Additionally testing was done to verify the polarity of each reaction wheel. This was done utilizing commissioning steps 7, 14, and 15 which validate the Y, X, and Z reaction wheel, respectively. These steps spun up the appropriate reaction wheel for 1 min and then set the wheel speed back to 0 rpm. Through this process, we could visibly see the spacecraft spin in the correct direction.



[Left] HSFL's ACSTB, [Middle] HyTI on the Air-Bearing in the Y-Axis Jig, [Right] HyTI on the bench in the Z-Axis Jig.

IV. Earth Orbiting Satellite Simulation (EOS) Testing



EOS Simulation Software

To properly test the operational logic for the commissioning steps to be automatic, EOS was used. Using EOS provided by CubeSpace allowed for the bus to be on the bench and more accessible. It also allowed for more streamline testing of anomalies and for the automatic pass/fail logic to be validated. There were 3 cases identified that needed to be tested for the automatic steps, as listed below:

- **Nominal:** Starting angular rates were varying and the hardware/ADCS was operating nominally.
- **Anomaly 1:** Rates started above 35 deg/s for commissioning step 1 and above 30 deg/s for steps 2 and 3. Rates above these thresholds need special estimation and control modes, which would not be done automatically.
- ***Anomaly 2:*** The angular rates increase when in control mode 1 and/or 2. This only applies to commissioning steps 2 and 3 since step 1 remains in control mode 0. Varying initial angular rates.

These cases were repeated several times for each step to ensure that not only did the logic get the spacecraft to the desired state but also that it recognized a failure and reacted appropriately. Along with thoroughly testing the logic of the automatic steps, the rest of the commissioning steps were ran using EOS to ensure that these steps used the correct estimation and control modes as well as gathered the necessary data.

VIII. Conclusion

From the data that was collected during flight, it was shown that the spacecraft was able to automatically go through the commissioning steps and Ops Modes to properly get itself into Y-Thomson Spin. As a result, contact was able to be made less than 3 hours after deployment from the ISS. In the future, this operational logic is planned to be tested and executed for the VIA-SEEs mission as it will use the same ADCS as HyTI. Additionally, Model-Based Design will be introduced as a way to automatically validate the ADCS requirements in the loop with the satellite attitude model.

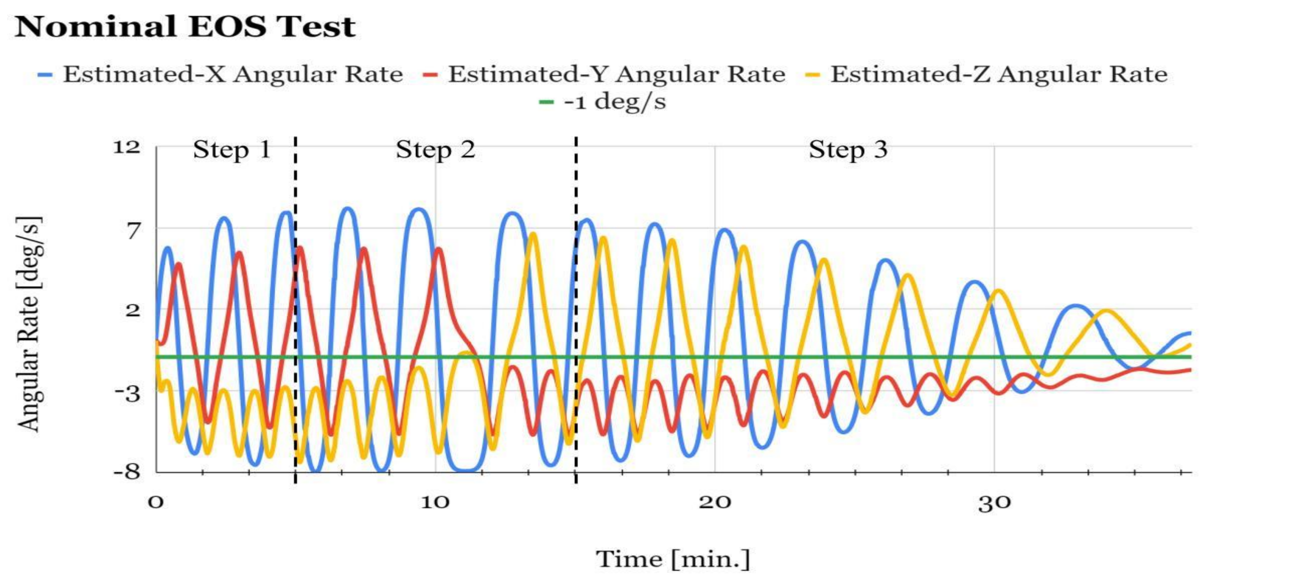
V. ACSTB Ground Results

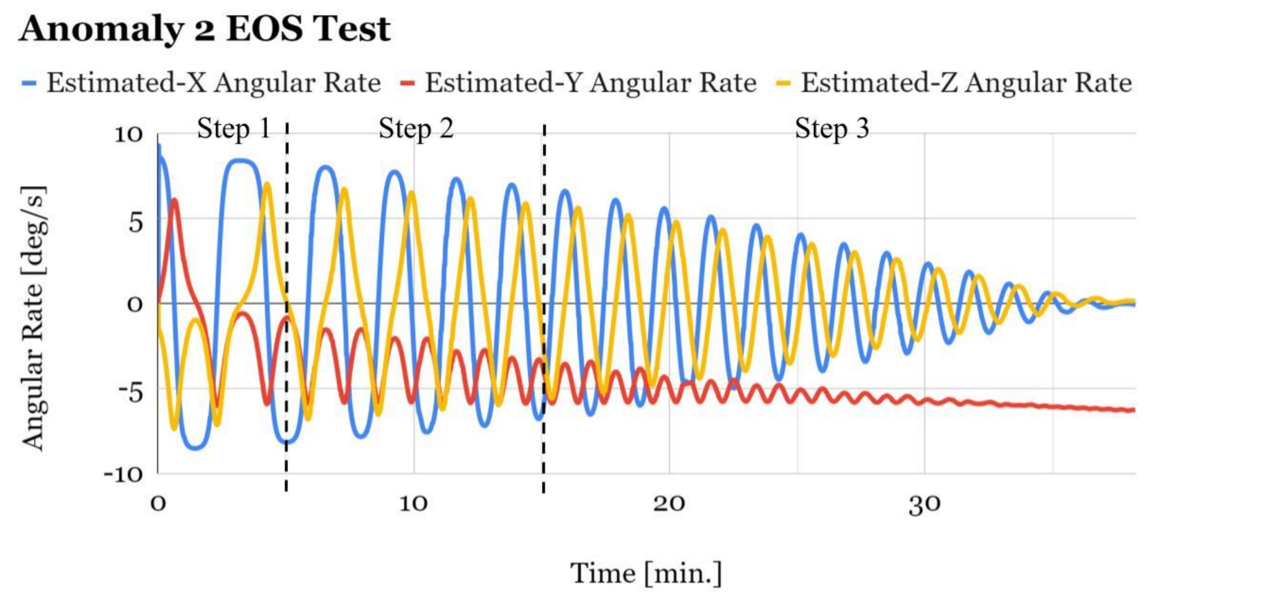
After performing the tests on the air bearing, for commissioning steps 2 and 3 the detumble rate was faster due to the active control, as compared to step 1 which had only passive control. This indicates that the Detumbling and Y-Thomson control modes worked properly to actively detumble the angular rates. The angular rate slopes can be seen in the table below.

		Step 1	Step 2	Step 3
Avg. Magnetometer Rate Slope	**X-Jig**	-0.0259	-0.0265	-0.0286
Avg. Gyro Rate Slope		-0.0259	-0.0265	-0.0283
Avg. Magnetometer Rate Slope	**Y-Jig**	0.0189	-	0.0214
Avg. Gyro Rate Slope		0.0194	-	0.0221
Avg. Magnetometer Rate Slope	**Z-Jig**	-0.0339	-0.0379	-0.0377
Avg. Gyro Rate Slope		-0.0345	-0.0424	-0.0394

VI. EOS Ground Results

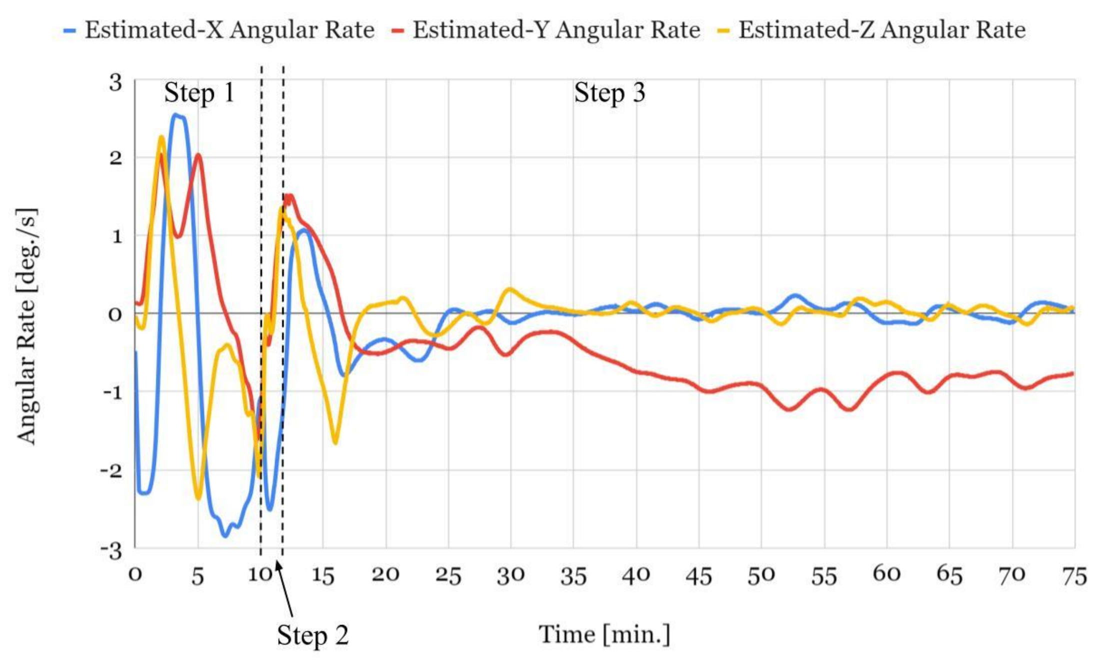
While conducting the tests with EOS, the automatic tests were fine tuned to pass and fail as desired. For instance, it was found that for step 1, with higher initial angular rates, the estimated and gyro rates did not converge in 5 minutes (the initial timeout) so the timeout was changed to 10 minutes. It was also discovered while testing anomaly 2 for step 3 that if the initial angular rates are high, the rates could be increasing even though they appear to be converging, see Anomaly 2 EOS Test graph below. To avoid this, the amount of time required to be in Y-Thomson before passing was increased to 30 minutes and the step timeout was increased to 1.5 hours.





VII. Flight Results

The HyTI CubeSat was successfully deployed from the ISS on April 18, 2024, at 11:36 UTC. The first contact with HyTI was through a set of UHF beacons received by the SatNOGS network less than three hours after deployment. From these beacons, it was determined that the angular rate of the spacecraft was [0.16, -1.25, -0.08] deg/s indicating that the automatic commissioning steps successfully reached Y-Thomson control mode. From the KSAT and MC3 networks, further beacons and data files were received verifying that the spacecraft had reached the desired state. Below is the data retrieved from the log files for the commissioning steps 1, 2, and 3 that occurred between deployment and the first received beacons.



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