

MISSION OPERATION FOR THE KUMU A`O CUBESAT

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ABSTRACT

UH is currently developing its 5th generation CubeSat, the Kumu A`o CubeSat, but will be the first to be placed in orbit. A successful mission depends highly on the design of the mission operations, as well as, the design of the satellite itself. The CubeSat will operate in a Low-Earth orbit at 400 km and be retrograde. To meet all mission objectives and requirements, the CubeSat will have two primary sets of Mission modes: the Post-Launch sequence and Normal orbital operations. The Post-Launch mission modes will be performed only once at the initial orbital insertion of the CubeSat. The second set of mission modes, Nominal Orbital Operations, relies heavily on the monitoring of the battery capacity to determine the proper state of the CubeSat.

INTRODUCTION

The Cube Satellite (CubeSat) Program was developed through collaboration between Stanford University and the California Polytechnic State University (Cal Poly). The simplistic CubeSat design allows an inexpensive way for students to manufacture a satellite and complete an entire mission within the duration of their undergraduate career. The University of Hawai'i has been an active participant of the CubeSat program since 2002. The Kumu A`o (Hawaiian for Source of Learning) CubeSat, UH's 5th generation CubeSat, will be an engineering demonstration to validate the design developed by the Kumu A`o team and to attain environmental data of Low-Earth Orbit atmosphere. The CubeSat will also house a gravity gradient boom, an experimental passive attitude control unit that will provide the satellite with Nadir orientation to optimize the generation of electrical power and communications with the ground station. The team is comprised of all undergraduate students in which over half is of Native Hawaiian, Pacific Islander or minority descent. The Kumu A`o CubeSat is set to be launched in the Spring of 2010, and will be Hawai'i's first CubeSat to be placed into orbit if successfully launched. The success of mission is dependent on the thorough and well thought satellite design and Mission Operations Plan (MOP). The MOP describes the operational aspects of the flight and ground-based elements. MOP emphasizes the way we operate the mission and use the flight vehicle, crew, and ground operations team. However, due to the nature in length of typical MOPs this report will only highlight certain attributes of the MOP notably the orbital description, ground station hardware and mission modes.

To support the CubeSat, the ground system must be able to command, control, monitor health, track orbital position, and determine the satellite's attitude from sensor data. The ground system controls the CubeSat by transmitting data to carry out necessary functions. It also acquires mission data from the CubeSat, which will then be analyzed by students to validate that the satellite is functioning as it is designed too. This data will also provide a reference for investigators and UH CubeSat developers to design instrumentation and more extravagant

CubeSats for future missions. In this report, the existing UH mobile ground station will be used for analysis and planning, however, a remote ground station that is semi-autonomous is expected to be up and running, upon the date the satellite is expected to be placed in orbit.

ORBITAL DESCRIPTION

The Kumu A`o CubeSat will operate in a 400 km retrograde orbit and have a ground track speed of 7 km/s which translates to an orbital period of 92.56 minutes or approximately 15.6 orbits per day. However, only three orbits out of the fifteen will be in the ground station field of view. And only one will be adequate enough to perform a complete data downlink to the ground station. Some orbital analysis done with the Satellite Tool Kit (STK) software estimated a six to eight minute communication window during an ideal pass. But, for developing the MOP, analysis was done with a four minute window to account for possible non-ideal downlink conditions.

GROUND STATION HARDWARE

The CubeSat's house-keeping telemetry is comprised of readings from 30 various sensors (voltage, current and thermal sensors) housed on the satellite that will be transmitted to the ground station. At the ground station the house-keeping telemetry will be compared with those readings taken during environmental and functionality testing of the satellite prior to launch. The results will then be document to assist in the analysis of future UH CubeSat projects. The CubeSat telecommunication unit was designed to be compatible with the existing UH mobile ground station and has the ability to shutoff shall it cause interference with other transmission. This shutoff function was to comply with Federal Communications Commission (FCC) regulations which states, "Space stations in the amateur-satellite service must have sufficient Earth command stations established before launch to guarantee that the space station transmitter can be turned off in case of interference." The mobile ground station, which can be seen in Figure 1, is comprised of the following components listed below:

1. Yaesu FT-847 Transceiver
2. Yaesu G-5500 Rotator
3. Yaesu G-5500 Controller
4. Yaesu GS-232A Computer Controller
5. Dual Output power supply (for the LNA and computer controller)
6. Yaesu FP1023 Power Supply (for transceiver)
7. 435 MHz Circular Polarized Yagi Antenna (UHF)
8. 145 MHz Circular Polarized Yagi Antenna (VHF)
9. SSB Low Noise Amplifier (LNA)
10. Two Fiber Glass Booms
11. TinyTrak4 TNC will be added.
12. Doppler software, to accommodate the Doppler shift.
13. Morse code decode.

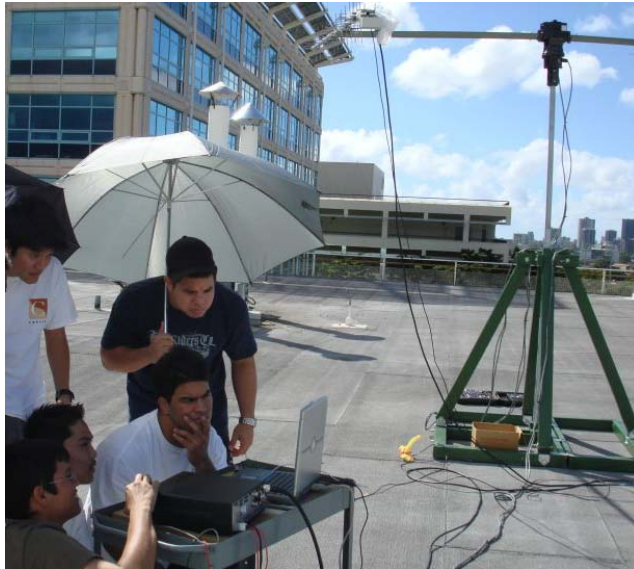


Figure 1: Image of ground station demonstration done on top of Hawaii Institute of Geophysics building

MISSION MODES

CubeSats will be deployed from a Poly-Picosatellite Orbital Deployer (P-POD) launch vehicle than can house a maximum of three “one-unit” (1U) CubeSats. The CubeSat will enter a **Launch** mode once placed in the P-POD and will remain in this state throughout its time it is contained within the P-POD. During this mode all electronics and batteries are deactivated to prevent any electrical or radio frequency interference with the launch vehicle and primary payloads.

Upon deployment from the P-POD the CubeSat will enter a **Post-Launch** mode which it will complete only once throughout its mission life. The **Post-Launch** mode is comprised of several phases. A *Standby-Timer* phase is initiated once the CubeSat is deployed from the P-POD and the deployment switch is released. The CubeSat’s C&DH and batteries are then activated and a 15 minute timer is triggered. Once the 15 minute timer is complete the CubeSat will enter the next phase known as *Deployment*. Under the *Deployment* phase, the CubeSat C&DH will enable the release of the antenna and commence retrieving house-keeping data from the various sensors and then stored in preparation for the initial downlink to the ground station. After the completion of the *Deployment* phase another 15 minute timer is set and the CubeSat enters its last **Post-Launch** phase known as *Checkout*. During *Checkout* the C&DH will do a complete diagnostic check functionality test of the entire CubeSat to ensure no components were damaged during launch and each subsystem is operating properly. As a result of the satellite’s simplistic design, a complete check-out should be completed within the 15 minute timer. Once *Checkout* is completed the CubeSat will begin its mission.

Under normal conditions, the CubeSat’s Nominal Orbital Modes will perform the basic day-to-day activities; a diagram of these modes can be seen in Figure 2. The primary state of these Orbital Modes will be the **Beaconing** mode. When in **Beaconing** mode, C&DH will perform a series of fundamental orbital tasks to ensure the CubeSat is running optimally. A list of these fundamental tasks can be seen below:

1. Ensure the antenna is deployed and check for command to deploy gravity gradient boom
2. Take sensor data at designated orbital intervals from the voltage, current and thermal sensors

3. Manage the storage of house-keeping data
4. Perform nominal communication through beaoning
5. Monitor telecommunications unit for inbound telecommand from ground system to switch over to telemetry mode and begin transferring data
6. Monitor the battery charger and transition to **Recharge** mode shall the battery capacity shall fall below 60%

The CubeSat will release short, periodic Morse code beacons which will serve as an identifier, a way to track the CubeSat, and a way to provide the ground system with some critical house-keeping data or space telemetry should telecommunication links with the ground station become unattainable. Space telemetry is a one-way transmission from a space station of measurements made from the measuring instruments in a spacecraft, including those relating to the functioning of the spacecraft. Upon the completion of the fundamental orbital tasks, the system will go into a sleep state, in an attempt to conserve power until it's time to complete another set of tasks.

The beacon will run on a three interval cycle with each beacon beginning 80 seconds after the start of the previous beacon. The 80 second interval enables three opportunities to hear a beacon from the CubeSat by the ground station during a four minute field of view window. The first two beacons will be approximately 3 seconds long which structurally include the UH club call sign and short packetized telemetry data burst. These beacons will serve as means for locating the CubeSat as it passes overhead and a brief means to attain some minimal data from the CubeSat. The third beacon will be approximately 11 seconds and structural form of call sign in the beginning and end of beacon, thermal, voltage and current data from the battery, thermal data from the C&DH and a packetized burst of data. At the end of each beacon the receiver will be turn on for 15 seconds to accept telecommands from the ground system and begin the downlink of telemetry data. A telecommand is defined by the FCC as a one-way transmission to initiate, modify, or terminate functions of a device at a distance.

The CubeSat will transition to **Telecomm** mode if the Telecomm subsystem receives a telecommand from the ground system to transmit data. The C&DH will carry-out all fundamental orbital tasks as in **Beaoning** mode, excluding the short periodic beacons. Once the system enters **Telecomm** mode it will remain in this state until one of the following: the ground station sends a telecommand to end telecom mode, communication link with the ground station is lost, or the satellite's battery capacity falls below 20% which places the system in a critical state.

Ideally house-keeping data taken by the CubeSat would be down linked to the ground station the within 24 hours. This will ensure that the ground system is updated on the status of the CubeSat. The up-to-date telemetry will allow the ground station to identify potential issues with the CubeSat before they become detrimental to the life of the mission. Every transmission from a ground station on amateur frequency must be in "plain language" or, in other words, in the clear. In the clear means that (1) technical descriptions of all emissions, codes, and formats are made publicly and widely available; and (2) technical descriptions must be sufficient to enable any technically competent licensed amateur radio operator to use the system. As a consequence, of course, all transmissions will be open to reception by anyone. (Encryption for critical spacecraft telecommand functions is accepted.)

The total amount of sensor data taken will not exceed 57.6 kb a day to prevent excess storage and allow the CubeSat to downlink an entire set of data within a four minute window. Assuming

a typical temperature reading is 16b (2B) and approximately 30 sensors on the CubeSat, one reading from every sensor on the entire satellite is about 480 bits. This translates to 120 readings a day or about 8 readings per orbit. The Telecomm subsystem can optimally downlink 960 bits/sec of packetized data; adding approximately fifteen seconds for acknowledgments and fifteen seconds for “handshaking protocol” with the ground station, an entire day of telemetry hypothetically could be transmitted in 90 seconds. Thus a four minute communication window should be sufficient amount of time to complete an entire transmission and compensate for any chance of interference occurring during downlink.

Recharge mode is initiated by C&DH if EPS power capacity falls below 60% during **Beaconing** mode. As before in **Beaconing** mode, C&DH will carry-out fundamental orbital tasks. The Telecomm subsystem will continue to beacon while in a **Recharge** state, however the interval of beacons are less frequent, occurring only once every 4 minutes. The receiver will continue to turn on at the start of every 80 second interval in attempt to intercept telecommands from the ground system. The system will remain in a **Recharge** state until the battery is recharged back to 90% capacity, which it will then transition to **Beaconing** mode. If the battery capacity shall continue to drop and fall below 20% while in the **Recharge** state the C&DH will switch the system to a critical state known as **Failsafe** mode.

Failsafe mode is the first line of action the C&DH will take, in order to recover the system from a critical state before resorting to rebooting and restarting the entire system. Under **Failsafe** mode the system looks to prevent further over draining of the EPS unit and recover the unit back optimum capacity. The C&DH will terminate all tasks that are non critical and eliminate all Telecomm actions until the system is able to recover out of the **Failsafe** state.

Reboot and Restart will be used as a last resort means to recover the entire system. C&DH will initiate a **Reboot and Restart** if a subsystem seems to be non-responsive, if electronics perform in an undesirable manner, or if EPS cannot recover from a critical battery state.

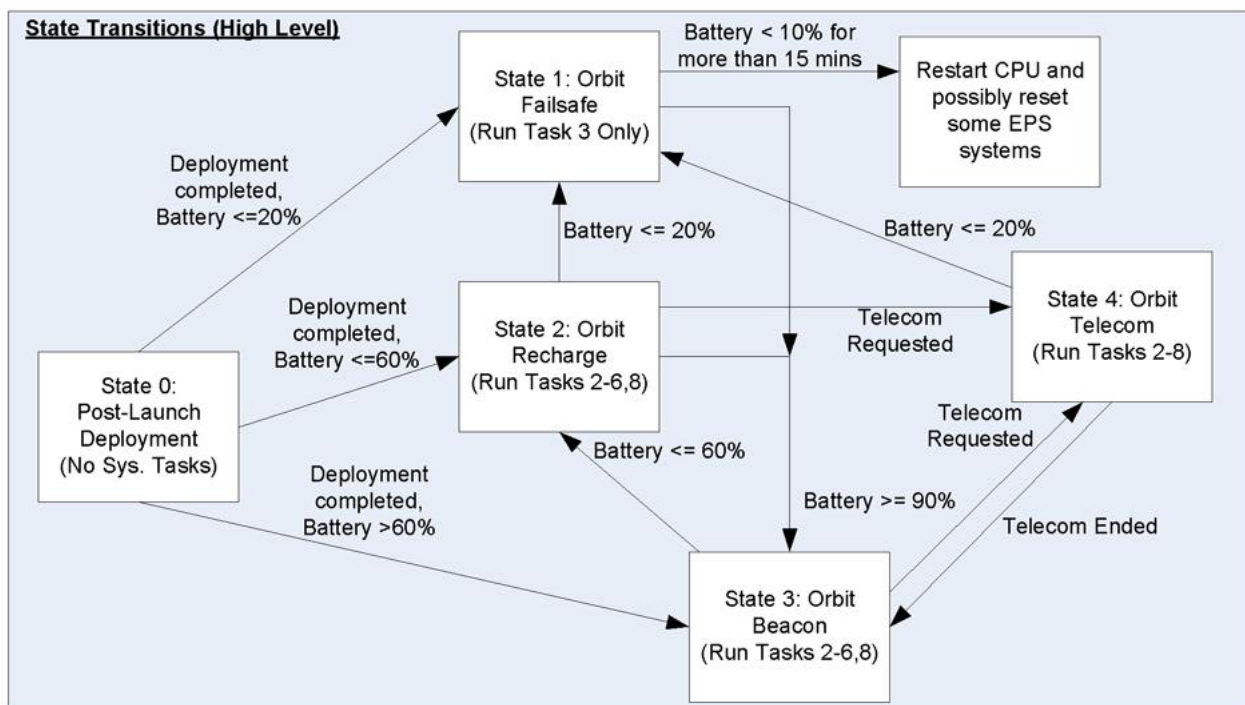


Figure 2: Diagram of the Mission Modes (Courtesy of Jeremy Chan)

CONCLUSION

The team looks to complete fabrication of the engineering model by the end of the summer semester and begin testing by fall semester. As the engineering model is being fabricated, new data through testing and programming will have direct implications to the final mission operations plan (MOP). Modifications of the MOP will continue long after the satellite is placed in orbit. However, a well thought MOP during the early fabrication stages will help mitigate risk, and therefore increase the reliability and longevity of the satellite overall.

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