License to Operate a Private Remote Sensing Space System

Licensee:	**Sonoma State University**
Application Dated:	**May 28, 2018**
License Date:	**July 30, 2018**
System Name:	**EdgeCube**
Number of Satellites:	**1**
System Type:	**Electro-Optical**

Spatial and Spectral Resolutions:
889 m Ground Sample Distance (GSD) Panchromatic (PAN) (370 - 900 nm)

Ground Stations are listed in the Ground Station Appendix

1. Grant of License

a. The National Environmental Satellite, Data and Information Service of the National Oceanic and Atmospheric Administration (NOAA), an agency of the U.S. Department of Commerce, hereby grants to **Sonoma St University**, (herein "the Licensee"), a License ("the License"), to operate the Licensee's private remote sensing space system ("the System") described herein, consistent with the terms of this License. This License's terms and conditions reflect, among other significant provisions, the System parameters and operating conditions approved by the Secretary of Commerce, or his or her delegate ("the Secretary").

b. This License is granted under the authority of the National and Commercial Space Programs Act of 2010 ("the Act"), 51 USC § 60101 *et seq.*; the regulations promulgated thereunder, 15 CFR Part 960 ("the regulations"); and the U.S. Commercial Remote Sensing Space Policy of April 25, 2003. The authorization provided by this License is limited to the remote sensing operations of the System. It does not provide authorization for the conduct of any non-remote sensing operations that are proposed to be undertaken by the System.

c. The Licensee shall ensure that the information provided to NOAA and relied upon in issuing this License, and/or any subsequent licensing action, is current and accurate. Consistent with the time limits set forth in the regulations and this License, failure to notify NOAA in a timely manner of any changes to this information may result in penalties for noncompliance being levied for each inaccuracy and/or license suspension or revocation. (*See* 15 CFR §§ 960.11(a), 960.13 and 960.15).

d. In the event that factual circumstances surrounding the issuance of this License or any subsequent licensing action change, including but not limited to the factual representations upon which NOAA relied in the production of this document, NOAA reserves the right to reexamine and/or revoke this License or any subsequent licensing action at that time.

e. The terms and obligations of this License shall bind the Licensee's affiliates, subsidiaries, assigns, heirs, and successors (whether through merger, acquisition or otherwise).

f. This License shall not be transferred or assigned by any means, including without limitation, by operation of law or merger, by the Licensee, without the prior written consent of NOAA.

2. Term of License

a. This License for operation of the System shall be valid from the effective date through the operational lifetime of the System or until the Secretary determines that the Licensee is not in compliance with the requirements of the Act, the regulations promulgated thereunder, the terms and conditions of this License, or that the Licensee's activities or operation of the System are not consistent with the national security, foreign policy, or the international obligations of the United States. (*See* 15 CFR § 960.9(a)).

b. The Licensee shall notify the NOAA Assistant Administrator for Satellite and Information Services within seven (7) days of financial insolvency, dissolution, the demise of its System, or of its decision to discontinue system operation. Upon notification, the Assistant Administrator will terminate the License. (*See* 15 CFR § 960.9(b)).

3. Amendments to Licenses

a. Prior to undertaking any of the actions identified in 15 CFR § 960.7(a), the Licensee must promptly file all relevant information with NOAA.

b. The Licensee shall file applications for an amendment to an existing License at the same address at which the License application was filed, unless otherwise explicitly designated by NOAA. (*See* 15 CFR §§ 960.7(b) and 960.7(f)(1)).

4. Requirements for Additional Licenses and/or Other Governmental Approval

a. The issuance of a License does not relieve the Licensee of the obligation to obtain other licenses and specific written approval from other appropriate U.S. Government ("USG") agencies, pursuant to applicable statutes, regulations, or contracts. Such licenses or written approval may include licenses for the employment of foreign nationals at any facility involved in the implementation of this License, and for the use of any intellectual property.

b. Licensed operations are subject to applicable U.S. law including, but not limited to, any statutory restrictions or trade sanctions.

c. Once the satellite is launched into orbit, the Licensee shall register the payload with the U.S. Department of State Bureau of Oceans and International Environmental and Scientific Affairs, Office of Space and Advanced Technology which maintains the U.S. national registry of space objects pursuant to the Convention on Registration of Objects Launched into Outer Space.

5. Limitations on Data Collection and/or Dissemination During Periods of Crisis

a. If required by the Secretary of Commerce, after consultations with the Secretary of Defense or the Secretary of State, the Licensee shall limit data collection and/or distribution by the System as determined to be necessary to meet significant national security or significant foreign policy concerns or international obligations of the United States. NOAA will promptly notify the Licensee when such limitations may be required and their duration. (*See* 15 CFR § 960.11(b)(4)).

b. The Licensee shall, upon request, provide unenhanced restricted images collected by the System on a commercial basis exclusively to the USG, using USG-approved rekeyable encryption on the downlink.
The requirement for encryption is waived

c. The Licensee shall use a data downlink format that allows the USG access to and use of these data during such restricted periods as set forth in this License.

6. **Significant or Substantial Foreign Agreements**
The Licensee shall notify NOAA of any significant or substantial agreement ("agreement") the Licensee intends to enter with a foreign nation, entity, consortium, or person at least 60 days before concluding such an agreement. Notification shall consist of providing NOAA with an unsigned proposed agreement. The Licensee may not implement the agreement until NOAA advises the Licensee, it in writing, that the provisions of the proposed agreement are acceptable.
(*See* 15 CFR §§ 960.3, 960.8 and 960.11(b)(5)).

7. **Provision of Data to Sensed States**
Subject to the terms and conditions of this License, the Licensee shall make available to the government of any country, including the United States, unenhanced data collected by the System concerning the territory under the jurisdiction of such government (a "sensed state"), as soon as such data are commercially available and on reasonable commercial terms and conditions. Upon receiving an unenhanced data request from a government seeking to exercise its rights as a "sensed state," the Licensee shall consult with NOAA.
(*See* 15 CFR § 960.11(b)(10)).

8. **Provision of Data to the National Archive**
   a. Subject to the terms and conditions of this License, the Licensee shall make available unenhanced collected by the System requested by the Department of the Interior on reasonable cost and conditions as agreed by the Licensee and the Department of Interior. After the expiration of any exclusive right to sell, or after a reasonable period of time, as agreed with the Licensee, the Department of Interior shall make these data available to the public at the cost of fulfilling user requests, except for data which under this license may be approved for release only to the USG or USG-approved users.
   (*See* 15 CFR § 960.11(b)(8)).

   b. Before purging any licensed data collected by the System in the Licensee's possession, the Licensee shall offer such data to the National Satellite Land Remote Sensing Data Archive at the cost of reproduction and transmission.
   (*See* 15 CFR § 960.11(b)(9)).

   c. The Licensee shall provide to NOAA, upon request, a complete list of all archived, unenhanced licensed data which has been collected by its System which is not already maintained in a public catalog. Any information on this list which is deemed proprietary by the Licensee must be so noted by the Licensee when the list is provided.
   (*See* 15 CFR § 960.11(b)(7)).

9. Monitoring and Compliance Requirements

a. The Licensee shall comply with all NOAA monitoring and compliance requirements and requests. NOAA shall conduct all such enforcement activities as are necessary and authorized to ensure the Licensee's compliance with the conditions of this License, the Act, and the regulations promulgated thereunder. (*See* 15 CFR § 960.11(b)(3) and 960.14).

b. The Licensee shall complete and submit the Annual Audit by July 15th for the previous 12 months.

c. Following the launch of the first licensed satellite, and for as long as there is a licensed satellite in space, the Licensee shall complete and submit the Quarterly Audits for:

   i. January - March by April 15th
   ii. The Annual Audit submission by July 15th. The Annual Audit (see 9.b. above) fulfills the Quarterly Audit submission for April - June.
   iii. July - September by October 15th
   iv. October - December by January 15th.

d. The Licensee shall allow NOAA access, at all reasonable times, to all facilities which comprise the System for the purpose of conducting inspections.

e. No later than 120 days prior to launch, the Licensee shall submit to NOAA for approval, a Data Protection Plan (DPP) that ensures adequate protection for all uplinks, downlinks, and data relays. NOAA is the sole authority to determine the minimum DPP content.
i. The DPP must include the data downlink format that allows the USG access to and use of these data during restricted periods (See License Condition 5.c).
ii. The licensee's Data Protection Plan must be approved by NOAA before the licensee's remote sensing space system may be launched.
(*See* 15 CFR § 960.11(b)(13)(iii).
iii. The Licensee shall comply with the content of the NOAA-approved DPP.
The requirement for encryption is waived

f. The Licensee shall maintain, and provide to NOAA upon request, all records and data pertaining to, but not limited to, the following: Spacecraft telemetry; imaging sensor tasking and associated metadata to include date/time of collection, image number, imager used, image corner points in latitude/longitude, inertial position (x, y, z), scan duration, azimuth; imagery data purges and purge alerts provided to the National Satellite Land Remote Sensing Data Archive.

10. Conditions and Operational Parameters of the System

a. Unless otherwise prohibited by this license, the Licensee may distribute data, imagery and products from the System at no better than the allowed technical parameters specified on page 1 of this license.

b. The Licensee shall operate its System in a manner that preserves the national security and observes the foreign policy and international obligations of the United States. (*See* 15 CFR § 960.11(b)(1)).

c. The Licensee shall maintain operational control of the System from a location within the United States at all times, including the ability to override all commands issued by any operations centers or stations, as well as safeguards to ensre the integrity of the operations of the System. (*See* 15 CFR § 960.11(b)(2)).

d. The Licensee shall encrypt satellite tracking, telemetry and control and data transmission and storage, using USG-approved encryption.
The requirement for encryption is waived

e. The Licensee shall immediately notify NOAA of any operational deviation or proposed deviation of the System. This includes notification of any tests of downlinking data to prospective ground stations not authorized as being part of the System by the terms of this License. In the case of such testing, the Licensee shall notify NOAA, in writing, at least 14 days prior to its commencement. (*See* 15 CFR § 960.11(b)(11)).

f. The Licensee shall conduct any Non-Earth Imaging (NEI) operations in accordance with the NEI Appendix.

11. Disposal of Licensee's System

Consistent with the Act and the regulations, the Licensee shall perform all actions necessary to place the spacecraft in a safe configuration for deorbit. Prior to de-orbiting the spacecraft, all stored energy sources on board the satellite will be discharged. The Licensee will deorbit the spacecraft by means of an uncontrolled atmospheric re-entry. Satellite lifetime shall be no longer than 25 years after mission completion. No debris from the satellite is expected to reach the Earth's surface.
(*See* 15 CFR § 960.11(b)(12)).

IN WITNESS THEREOF, I hereby grant this License:

Stephen Volz

Stephen Volz, PhD
Assistant Administrator
NOAA Satellite and Information Services

July 30, 2018

System Information Appendix

Licensee:
Sonoma State University
1801 East Cotati Avenue
Rohnert Park, CA 94928

POC: Prof. Lynn Cominsky
Department of Physics and Astronomy
email: lynnc@universe.sonoma.edu
phone: 707 664 2655

Satellite	Launch Date	Altitude(km)	Inclination(°)
EdgeCube	NET Oct 2018	500-575	95-99

Frequencies: 437 Mhz

Encryption: None The requirement for encryption is waived

Non-Earth Imaging (NEI) Appendix

1. Non-Earth Imaging (NEI) principles:
   a. The Licensee may not conduct NEI unless it complies with NEI conditions in 2 and 3 below. NEI remote sensing operations consist of two categories: (1) imaging of non-man-made, naturally occurring phenomena and celestial bodies, including the moon, stars, etc., not including the Earth, referred to herein as "naturally-occurring phenomena," and (2) imaging of artificial resident space objects (ARSO) in Earth orbit, including man-made satellites, etc., which may occur either with or without the consent of the ARSO owner and operator.
   b. For purposes of NEI conditions 2 and 3, "resolved" refers to an image of an object in which the object fills more than 3 x 3 pixels of the imager's focal plane in two orthogonal axes simultaneously.

2. Imaging of naturally occurring phenomena:
   a. The Licensee may image at any resolution, and may disseminate images of, naturally occurring phenomena.
   b. Regardless of the Licensee's intent, incidental imaging of ARSO, coincident with imaging natural occurring phenomena and celestial bodies, must be conducted in accordance with License condition 3.

3. Imaging of ARSO:
   a. The Licensee may image ARSO in the electromagnetic spectrum from 370-900 nm. The Licensee may not image ARSO outside of this spectrum.
   b. The Licensee may image ARSO with or without consent, but the Licensee must comply with the below License conditions corresponding to whether or not consent exists.
   c. Consenting imaging operations of ARSO:
      i. If the Licensee obtains written consent from the owner and operator to image ARSO, the Licensee may resolve such imagery and may use it to any extent permitted by the consent.
      ii. Written consent from the owner and operator must also include confirmation that the owner and operator have obtained any necessary permission(s) for imaging from all applicable manufacturer(s), regulatory authority or authorities, and foreign entities with an interest in the ARSO.
      iii. At least 90 days prior to conducting consenting ARSO imaging, the Licensee shall provide notice to NOAA for that imaging. The notice shall include: an identification of the target ARSO to be imaged, a record of all consents obtained, the orbital location of the ARSO, proposed orbital maneuver plan, dates of the ARSO imaging, and the imager's distance from the imaged object.
      iv. If NOAA places conditions on the ARSO imaging, the Licensee shall comply with such conditions.

v. The Licensee shall delete all ARSO image content that is not part of the target resolved ARSO.

d. Non-consenting imaging operations of ARSO:

i. Absent written consent, the Licensee may image ARSO only to obtain unresolved imagery.

ii. Non-consenting imaging operations shall not be attempted at a resolution better than 0.5 meters.

iii. All non-consenting ARSO imagery shall be encrypted at all times using USG-approved encryption.

iv. The Licensee shall purge the following imagery upon its discovery: all non-consenting resolved ARSO, and all non-consenting ARSO images at a resolution better than 0.5 meters.

v. The Licensee may downgrade a resolved image to an unresolved image and retain it.

vi. The Licensee may disseminate non-consenting unresolved ARSO images subject to the below limitations:

1. Prior to dissemination, Licensees must correlate the tracking data of any unresolved ARSO imagery with the USG-approved space tracking catalog found at space-track.org Licensees shall maintain records of these correlations and submit to NOAA upon request.
2. Licensees may disseminate unresolved imagery of ARSO after removing meta-data such as time, position and attitude of the sensor.

vii. Should the Licensee desire to release imagery that it is unable to correlate pursuant to subparagraph 3.d.vi (above), the Licensee shall submit to NOAA the uncorrelated imagery proposed to be disseminated for correlation and determination of releasability. The Licensee must purge from servers and storage devices any imagery that NOAA determines is non-releasable.

Ground Station Appendix

Any facility or Ground Station, including those for tasking, receiving, and storing data are considered to be part of the System and subject to NOAA inspection. The Licensee shall allow NOAA access, at all reasonable times, to all facilities and Ground Stations which comprise the System for the purpose of conducting inspections.

NOAA must approve any Ground Station prior to the commencement of operations.

Mission Control Center: Rohnert Park, CA

Remote Ground Stations: None

Administrative Record Appendix

	Date	Description of Administrative Action Taken
1.	7/30/18	Issuance of License

NOAA File: SSU-2018-L1 July 30, 2018

Prof. Lynn Cominsky
Sonoma State University
1801 East Cotati Avenue
Rohnert Park, CA 94928

RE: Grant of License to Operate a Private, Space-Based, Remote Sensing System

Dear Mr. Holzinger:

I am pleased to enclose a license for the Sonoma State University (herein, the Licensee) to operate a remote sensing satellite system in low-Earth orbit designated as "EdgeCube." The license application was subject to a thorough interagency review.

The operational specifications approved in the license are based on current and expected national security, foreign policy and commercial conditions. Should these conditions change over the life of the mission, the Licensee may request to have the operational specifications of the license amended pursuant to the regulations. *See* 15 CFR Part 960.7.

Please keep in mind the Licensee must notify NOAA in a timely manner of any changes to information provided to NOAA and relied upon in issuing this license. The Licensee must also provide to NOAA additional information (launch vehicle, launch location, launch date, foreign owners, foreign lenders, space segment details, grounds station details, etc.) immediately upon determination via a standard license amendment application.

In accordance with 15 CFR § 960.8, the Licensee must notify NOAA of any significant or substantial foreign agreements that the Licensee intends to enter into no less than 60 days prior to entering into such agreements.

In accordance with 15 CFR § 960.5, the Licensee must provide a publicly-releasable summary of the licensed System within 30 days of the license issuance.

You are encouraged to engage early with the Joint Space Operating Center (JSpOC) to exchange information and establish formal communication channels prior to launch. This would allow the JSpOC to provide an assessment of how to support your mission and provide recommendations on how to best to achieve mission success. Email: jspoc.ssasharing@us.af.mil

This license is for the EdgeCube system and not for any other system, present or future. The issuance of this license does not indicate a commitment by any U.S. Government agency to purchase data or products from the system.

This NOAA license is not an export authorization, and does not satisfy any requirement for Licensee to obtain appropriate export authorizations from the Department of State.

Please refer any questions regarding this license approval to Tahara D. Dawkins, Director, NOAA Commercial Remote Sensing Regulatory Affairs at 301-713-3385.

Sincerely,

Stephen Volz

Stephen Volz
Assistant Administrator
NOAA Satellite and Information Services

Enclosure

Hans P. Blondeel Timmerman, PB2T
Satellite Advisor
Nieuwe weg 21, 4031 MN Ingen, Netherlands
Email: satcoord@iaru.org

Date: 9 July 2018

To Dr. Garrett Jernigan KJ6ZRH

Dear Garrett,

With pleasure I confirm the IARU frequency coordination for your satellite **EdgeCube**.
Coordinated frequency for downlink and uplink: 437.465 MHz, Emission Designator 12K0F1D, EIRP 1 Watt

Planned launch date: 1 October 2018.
Licensing administration: USA.
Planned Height and Orbit: apogee 545 km, perigee 545 km, 97.6 degree sun synchronous inclination, 1.59 hours orbital period.
Earth Command station: KJ6ZRH

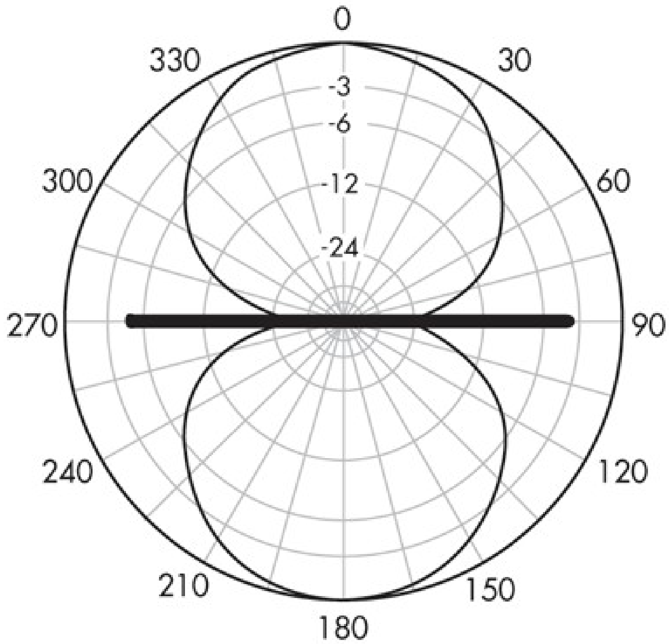
IARU has coordinated frequencies in bands allocated to the amateur satellite service. All frequencies in the amateur satellite service are shared frequencies.
Please inform me about the final launch date and the API/A number as soon as that information becomes available.

Best wishes for a successful project.

HPBlondeel TL

Hans Blondeel Timmerman
IARU Satellite Advisor

Flight Antenna – Simple Dipole Design



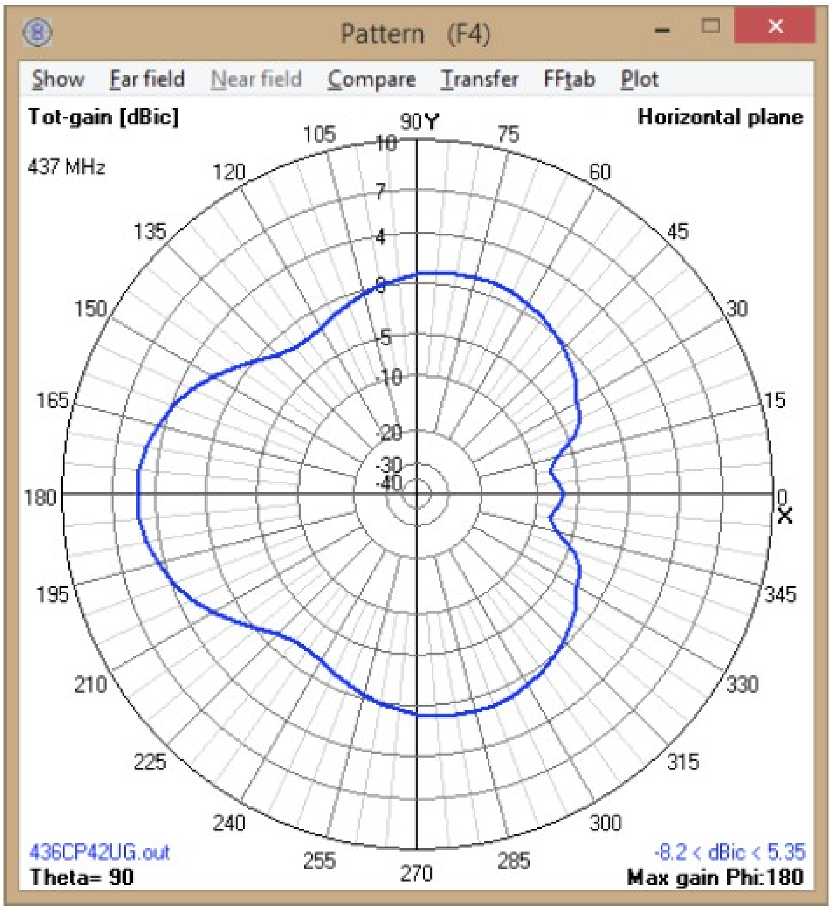
Transmit Power	0. dBW	1 W
Coupling Loss	-0.4 dB	
Antenna Gain	0. dB	Dipole Average
EIRP	-0.4 dBW	0.912011 W
Path Loss	-154.8 dB	437 megahertz 3000 kilometers
Antenna Gain	14.2 dB	
Polarization Loss	-3.0103 dB	RHCP
Coupling Loss	-2.3 dB	
Received Power	-146.31 dBW	2.33876×10^{-15} W
Receiver temperature		150. K
Bit Rate		19 200. b/s
Eb/N0	17.6951	
Threshold	9.4 dB	GMSK Theoretical 10^-4 BER
Demod loss	-3. dB	Practical
Link Margin	5.29511 dB	

Flight Equipment

Transmitter RFM22B

Note: This flight and ground system shown here have worked with a previous CubeSat see URL: //lbym.sonoma.edu/T-LogoQube (aka Eagle1 by AirForce). We can operate our RFM22B transceiver at a lower rate ~500 baud if we need extra bandwidth margin.

Ground System



Transmit Power	18.7506 dBW	75 W
Coupling Loss	-3. dB	
Antenna Gain	14.2 dB	RHCP
EIRP	29.9506 dBW	988.693 W
Path Loss	-154.8 dB	437 megahertz 3000 kilometers
Antenna Gain	0. dB	Average
Polarization Loss	-3.0103 dB	Dipole
Coupling Loss	-0.11 dB	
Received Power	-127.97 dBW	1.59605×10^{-13} W
Receiver temperature		1200. K
Bit Rate		9600. b/s
Eb/N0	30.0151	
Threshold	9.4 dB	GMSK Theoretical 10^-4 BER
Demod loss	-3. dB	Practical
Link Margin	17.6151 dB	

Equipment

RFM22B Transceiver
Baojie BJ-450 UHF 420-430Mhz Radio Amplifier
MSP136VDG-160 Preamp 136-138 (preferred frequency range)
M2 436CP42UG
MSP136VDG-160 Preamp 136-138 (preferred fre

EdgeCube Satellite

Dr. J. Garrett Jernigan, Technical Lead
Call Sign KJ6ZRH
email: jgj@h-bar.com
phone +1 707 332 7926
FRN 22054688

Jernigan can send ground commands to turn off all RF either temporarily or permanently

Dr. Lynn Cominsky, NASA Principal Investigator
email: lynnc@universe.sonoma.edu
phone +1 707 695 7140

The Applicant, Sonoma State University, is a unit of the California State University system. It is a comprehensive state university.

The project is funded by NASA award #NNH15ZDA010C from the Undergraduate Student Instrument Project (USIP) and is also supported by the California Space Grant Consortium (CaSGC).

EMC Analysis of EdgeCube

Summary of EdgeCube

EdgeCube is a 3U cubesat being launched into orbit at 545-km altitude, and 97.4-degree Sun synchronous orbit. EdgeCube is operated from a single ground station location at Sonoma State University in California. The frequency used for space to earth communication and earth to space communication is 437.465 MHz (typical desired frequency). This report reviews the situation as regards other authorized operators in this frequency range and operating range. No significant interference is reasonably expected to occur with the local amateur radio club due to the low power (0.5 watt) of the omni-directional RF radiation.

Compliance with Local Amateur Radio Operators

Because the operating frequency is in the amateur frequency range, we coordinated with the local amateur radio club. For a previous cubesat the operator of the S/C has discussed the situation with the local amateur radio club in Santa Rosa the largest nearby city. Previously we operated a CubeSat in this band called T-LogoQube. All communication with the CubeSat occurred at elevations with high gain antennas at angles greater than 30 degrees. Longer duration downlink communications have a maximum RF power of 0.5 watt. We can examine any situation for a downlink and see the RF path is clear and halt any overlapping transmissions if necessary. Past experience with cubesats has shown that significant interference is unlikely at RF powers less than 0.5 watt. All EdgeCube transmission will be under 0.5 watts of RF power.

Interference would only occur for a physically nearby satellite using the same frequency. FCC frequency coordinated assignment should avoid this possibility. Even if this type of interference were to occur we can cease transmission for a modest period until differential drag physically separates the two spacecraft.

Rare short duration uplinks, typically less than ~1 sec, at higher power are implemented with high gain pointed Yagi antennas on the ground for which the RF power is directed away from any ground RF sources to avoid any nearby receivers. The likelihood of any interference is cause the loss of data reception by the CubeSat with no comparable interference of with the HAM communications.

Compatibility within Operating Range

ITU radio regulations provide power flux density (PFD) limits, above which coordination with terrestrial and aeronautical mobile systems is required.

* Terrestrial Services: -125 dBW/m2/4KHz

* Aeronautical Mobile (R): -125 dBW/m2/4KHz

* Aeronautical Mobile (OR): -140 dBW/m2/4KHz

These specified power levels typically would adversely effect the RF environment are much higher than the omni-directional emission expected from a <0.5 watt transmitter used by the EdgeCube cubesat. Clearly this fact would not be the case for higher levels of power which transmit data at higher baud rates.

EdgeCube Satellite Technical Description

Mission Overview: EdgeCube will make a global measurement of the red edge that monitors a sharp change in leaf reflectance in the range 600 to 800 nm from changes in vegetation chlorophyll absorption and mesophyll scattering due to seasonal leaf phenology or stress. EdgeCube has been specifically designed to monitor the red edge characteristics of ~200 km areas of the earth using 9 narrow spectral bands in the wavelength range 600-800 nm. Two additional sensors will be flown: one will measure the optical and Infrared broadband signal in order to measure the incoming solar radiance. The incoming solar radiance is needed in order to calculate the top-of-atmosphere reflectance (at-sensor radiance/incoming solar radiance), thus normalizing the data through the seasons and by latitude. Although EdgeCube's ground spatial resolution is substantially less than conventional multispectral satellites, its design will monitor changes in the red-edge on a global scale within the telemetry limitations of a cubesat.

The satellite will be launched as a secondary payload on a Falcon 9 scheduled for launch during October 2018. EdgeCube will be inserted into a Sun synchronous circular orbit at 545 km. Transmission will begin ~3 hours after launch. Atmospheric friction will slow the satellite and reduce the altitude of the orbit, until de-orbiting occurs 3-5 years after launch. See the Orbital Debris Assessment Report for details.

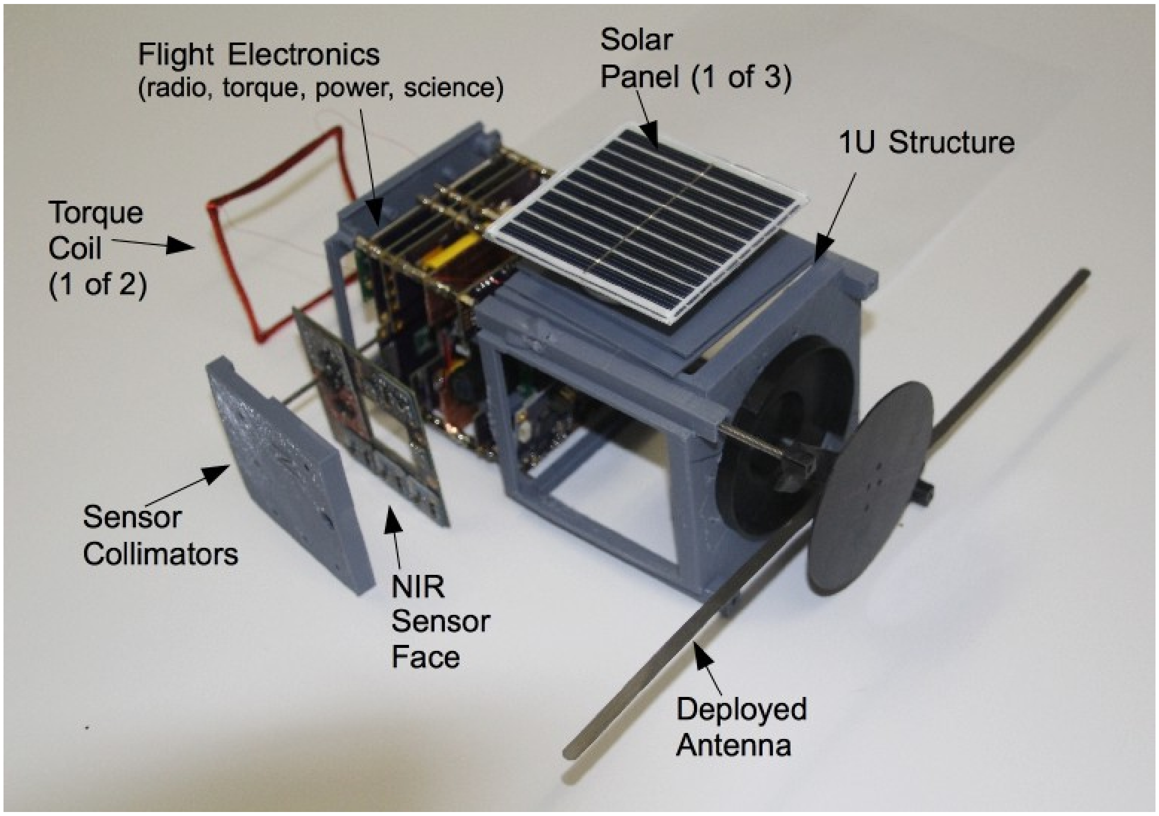


Figure: This figures shows an image of the EdgeCube flight electronics. The 1U board stack is arranged in the 1U flight configuration and is mounted with actual hardware. The 1U outer structure is shown translated to towards the antenna to reveal the details of the internal structure. The stack of flight includes the science electronics for operating the NIR sensors, the S/C power monitor, the torque board for controlling the spin rate and pointing of the S/C. The stack also includes a ~300 g copper block (total S/C mass ~1.4 kg) to define the principle momentum axis. The NIR collimator and the sensor face that carries hold the sciences sensors are displaced separated from the 1U box for clarity. Similarly one solar panel and one torque coil are shown separated from the compact electronics box for visual clarity. The pop up dipole antenna is shown in the deployed configuration.

The satellite contains the following systems: **Attitude Determination and Control (ADC), Command and Data Handling (CDH), Communications (COM), and Electrical Power System (EPS).**

Attitude Determination and Control (ADC) Subsystem: The ADC is a purely electromagnetic system to keep EdgeCube's spin axis pointing within ~30 degrees of the north pole. The system consists of 2 torque coils, triaxis magnetometer, triaxis rate gyros, and a sun sensor. The spin rate is controller

Command and Data Handling (CDH) and Communications (COM) Subsystem is integrated into a single COM concept.
EdgeCube's CDH system is a distributed network which integrates the data gathering process across many nodes on a network. There is a special network node that monitors the power system. A special node called the uStar gathers all the telemetry data from all the nodes on the network. This function is integrate into the tiny simple OS. This tiny OS also sends all telemetry packets to the ground using an RFM22B packet transceiver.

Electrical Power Subsystem (EPS): The Electrical Power Subsystem will is based on three fixed identical solar module arrays. A fourth face houses the sciences sensors. The system uses 3 five watt solar panels and one 1 amp-hour NiCd battery pack. The system has a power point tracker.

Thermal Control Subsystem (TCS): The TCS moderates temperature changes passively using a large 300 g copper heat sink. The heat sink resides near the CG of the S/C also serves as a momentum reservoir.

Structure Subsystem: The structure is fabricated with Aluminum that is 3D printed.

Propulsion Subsystem: No propulsion subsystem is included.

Payload Subsystem: The payload consists of a set of single element NIR sensors with narrow band filters.

The Goal of the EdgeCube Missions

The overall goal of the EdgeCube mission map the surface of the Earth (~200 km resolution) in chlorophyll using ~10 narrow band NIR filters.
The radio communications links are necessary to support control of the experiment, and to transmit the telemetry data to the University.

Department of Physics and Astronomy
School of Science and Technology
1801 East Cotati Avenue
Rohnert Park, California 94928

June 19, 2018

Secretary
Office of the Secretary
Federal Communications Commission 445 Twelfth Street, S.W.
Washington, D.C. 20554

Subject: ITU Cost Recovery Fees for the EdgeCube Satellite

Reference: FCC experimental application file number 0651-EX-CN-2018

Dear FCC Secretary,

The Physics and Astronomy Department at Sonoma State University, proposed operator of the subject network (herein after "applicant"), is aware that as a result of actions taken at the International Telecommunication Union's 1998 Plenipotentiary Conference, and modified by the ITU Council in 2001, 2002 and 2004, processing fees will now be charged by the ITU for satellite network filings. As a consequence, Commission applicants are responsible for documented fees charged by the ITU. The applicant hereby states that it is aware of this requirement and accepts responsibility to pay any Cost Recovery fees associated with these applications. Invoices for such fees should be sent to the point of contact specified below:

Prof. Lynn R. Cominsky
Department of Physics & Astronomy
Sonoma State University
1801 East Cotati Avenue
Rohnert Park, CA 94928

Thank you.

Lynn R Cominsky

Lynn Cominsky
Professor and Chair
Principal Investigator for NASA's EdgeCube mission

ODAR: EdgeCube – Sonoma State University – 1U CubeSat
Date: May 12, 2018

Full USIP Title: **EdgeCube: A 1U Global Monitor for Earth's Ecosystems**

* Platform type: 1U CubeSat
* PI Name: Prof. Lynn Cominsky
* PI Email: lynnc@universe.sonoma.edu
* PI Institution: Sonoma State University
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Mission Overview: EdgeCube will make a global measurement of the red edge that monitors a sharp change in leaf reflectance in the range 600 to 800 nm from changes in vegetation chlorophyll absorption and mesophyll scattering due to seasonal leaf phenology or stress. EdgeCube has been specifically designed to monitor the red edge characteristics of ~200 km areas of the earth using 9 narrow spectral bands in the wavelength range 600-800 nm. Two additional sensors will be flown: one will measure the optical and Infrared broadband signal in order to measure the incoming solar radiance. The incoming solar radiance is needed in order to calculate the top-of-atmosphere reflectance (at-sensor radiance/incoming solar radiance), thus normalizing the data through the seasons and by latitude. Although EdgeCube's ground spatial resolution is substantially less than conventional multispectral satellites, its design will monitor changes in the red-edge on a global scale within the telemetry limitations of a cubesat.

Mission requirements and goals:

(R1) Demonstrate mapping of a large fraction of the globe (+-50 degrees latitude) in Near IR to measure Red Edge and NDVI at a resolution of 100-300 km.
(R2) Minimum Requirement for Success: Global map of Red Edge from an initial two week period and thereby prove that the concept of EdgeCube works
(R3) Stretch Goal: operate EdgeCube for >2 years to monitor seasonal changes and year to year changes.
(R4) Map the Normal Optical Colors (RGB) of the Earth's surface to identify ocean/continent boundaries
(R5) Required Spectral Coverage (NIR - 9 narrow bands near red edge of chlorophyll - 1.3 micron for Cirrus cloud detection; and Optical – Red, Green and Blue for pointing)

(R6) After the fact pointing accuracy (<3 degrees using 3-axis magnetometer, gyroscope and Sub sensor). Stretch Goal: develop Star Tracker with ~0.1 degree accuracy to verify attitude determination for a sample of pointing.
(R7) Telemetry: ~500 bits per second for two 6-minute passes per day. Stretch Goal: ~5000 bits per second for two 6-minute passes per day.
(R8) Power: 0.25 watts orbit averaged including S/C night time. Brief Overview: Describe the satellite and mission objectives.

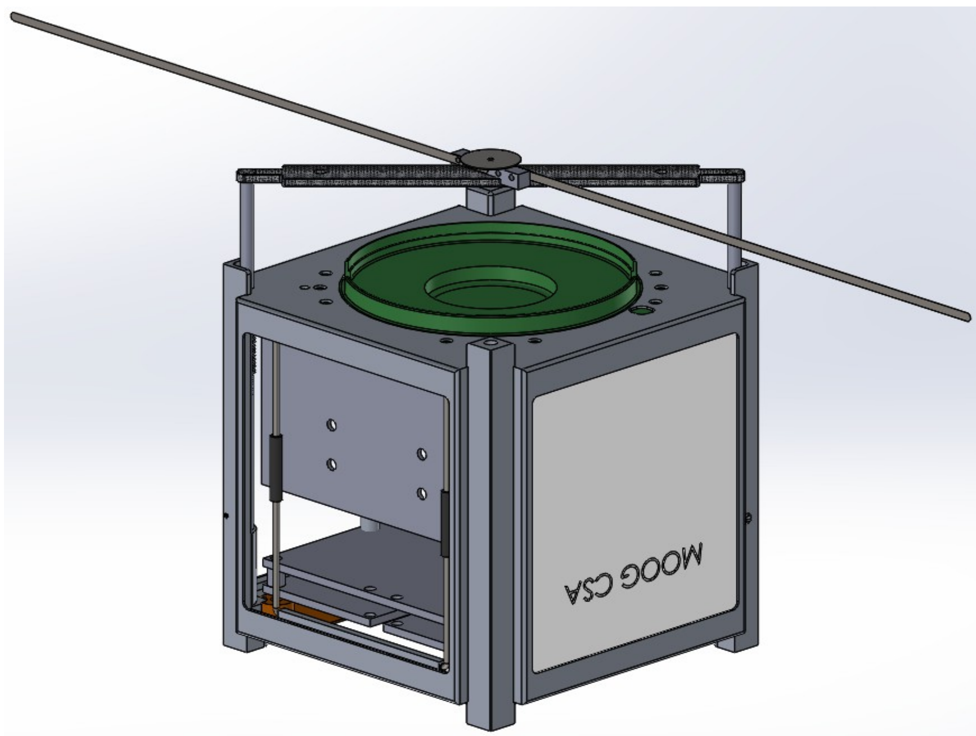


Figure 1: Outside view of the 1U CubeSat with the pop up antenna in the deployed configuration. The 1U body is 3D printed in Al in three major pieces. The main 1U body has four open window frames that house the three solar panels (82 mm x 85 mm). The four face house the sensors that built on a frame made of Dalrin that is exactly the same size as one of the solar panels. The top of the S/C is also printed In Al and has a mechanism to house the stowed antenna (enclosure shown on green). The bar below the antenna is also machined from Dalrin. This bar pops up and releases the curled up antenna which deploys and forms a dipole antenna (17 cm from tip to tip as needed for a RF frequency of ~437 MHz). The antenna is made of spring steel.

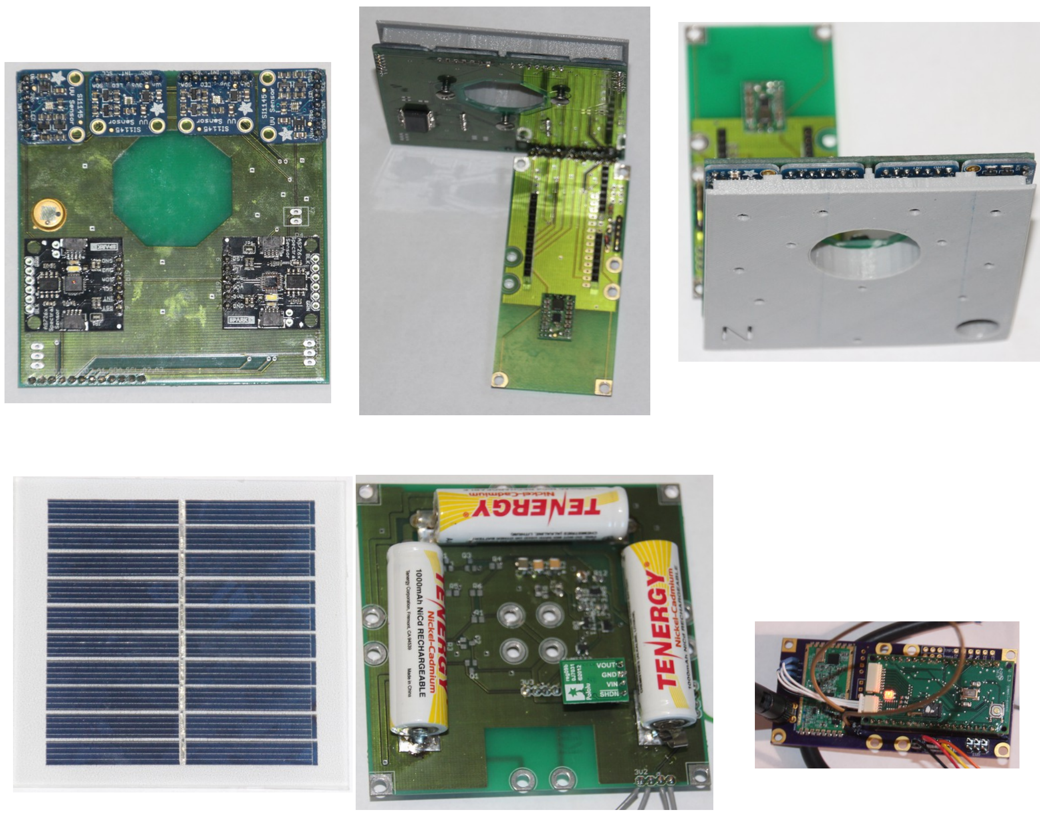


Figure 2: Shows the electronics boards that fill the interior of the 1U box. These image are all shown to approximately the same scale. All boards are either 4 cm x 8 cm or 8 cm x 8 cm. The board on the lower right is the RF system is that carries the RFM22B and RFM23BP transceivers. The upper left image shows the science sensors which occupy one face of the 1U and is the same size as the solar panel (1 of 3) that occupy the other three faces. The upper middle and right shows two views of the science sensor electronics connected to the sensor face made of Dalrin with viewing ports for the science sensors. The sensors on the upper left are not seen because these are behind the collimators. The larger hole in the middle of the sensor face is a viewing port for a camera that images both the Earth and stars to verify attitude of the S/C. The middle lower panel shows the power system and the flight NiCd batteries which also has the electronics for the safe mode of the S/C. If the battery voltage drops to a marginal low level the safe mode turns the system off for 2 hours so that the batteries have a full daylight cycle to recharge.

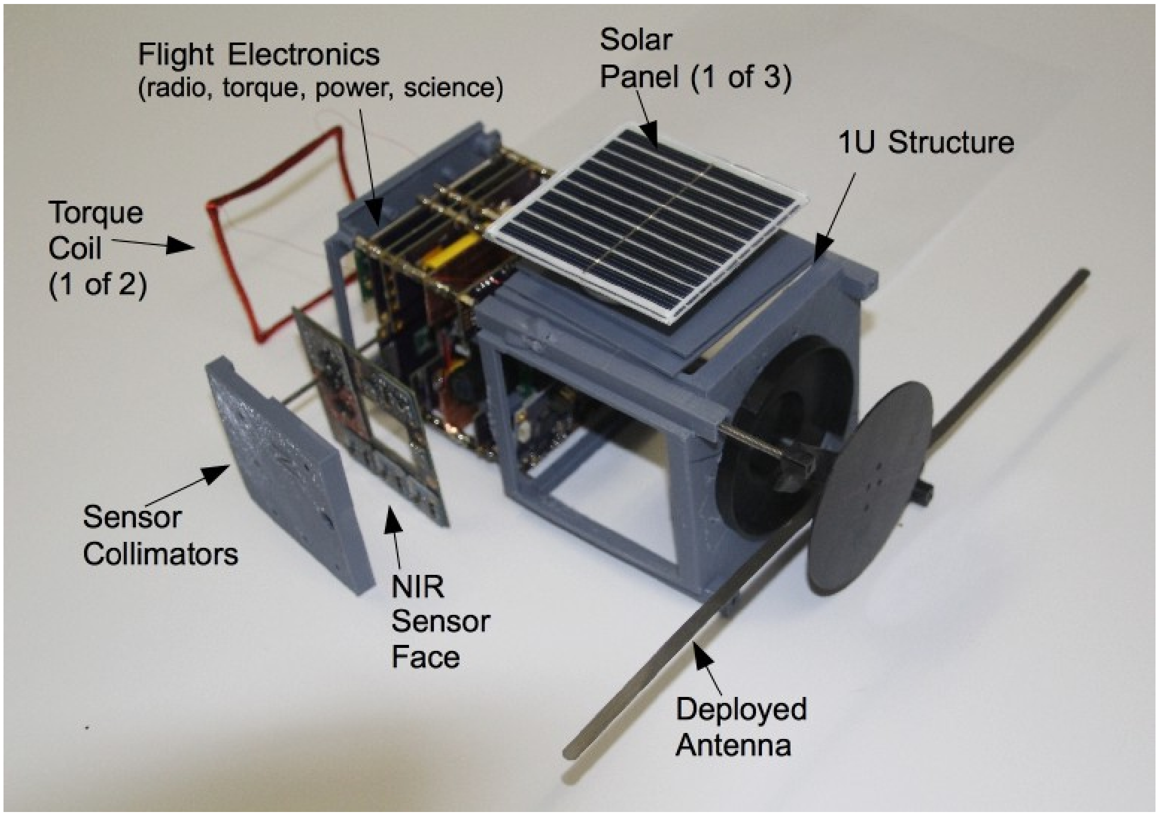


Figure 3: Shows a partially exploded view of the the stack of electronic boards that fill the interior of the 1U box. The bolts in the four corners are grounded to the 1U metal frame and also server to ground all the electronic boards in the stack. These means that the electronic grounding system does not require any cables except for the ground leads to the solar panels. The four grounding rods form the 8 cm x 8 cm x 8 cm structure that terminates at the top and bottom plates that are 3D printed in aluminum. The three NiCd batteries are the most massive components and are placed near the center of the mass of the system. This helps define the principal rotation axis as vertical in the image so that the sensors face scans over the Earth for every rotation of the 1U body. The fields of view of the sensors are set so that all parts of the Sun lite Earth are scanned once a day during the ~15 orbits.

CONOPS: EdgeCube is mounted in the launch dispenser with the antenna stowed on the outside of the top of the S/C in a thin aluminum canister. There are two retention pins that slide along two of the four launch rails on opposite sides that releases the pop up mechanism for the antenna as the 1U enclosure is half way out of the dispenser. The pins are captured to the 1U body after the CubeSat leaves the dispenser and are not released from the 1U body. No part of EdgeCube ever detaches from the system during normal operation prior to break up during re-entry.

Two series inhibit micro-switches on the top face of the S/C are activated by the popup mechanism which connects battery power to the electronics system. We have designed the power system so that during initial turn on the S/C goes into safe mode for ~2 hours to fully charge the NiCd batteries. The selection of NiCd batteries ensures that if we are left in the rocket for an extended period (many months) we will charge the batteries during one full day light cycle (~1.6 hours).

The system then exits safe mode and powers up the S/C processor that operates the RF system. The system can tell that this is the initial startup and then waits an additional 30 minutes before any RF transmission. This approach ensures that if the safe mode fails in a way that causes an early termination of safe mode then the processor will wait an additional 30 minutes to meet the requirement of at least 30 minutes before any RF transmission. The expected normal operation will wait 2.5 hours before any RF transmission.

Once the 30 minutes wait is over the S/C begins beacon transmissions every ~31 seconds. These beacon packets have sufficient information to determine the health of the power system. Once the ground system confirms the safe state of the flight electronics then science operations can proceed. The torque system will regulate the spin rate and point the spin axis within ~30 degrees of the NS direction. As the S/C rotates once every ~5-10 seconds the science sensor will scan a portion of the Earth under the S/C orbit path and record the NIR sensor reading in the form of packets that can be commanded for download when the S/C passes over the ground station on the roof of the student center at SSU. These data can then we used to compute a map of the globe of chlorophyll on a ~200 km scale every few days.

After the orbits lowers sufficiently due to atmospheric drag (years after launch) the S/C will break up and re-enter the Earth's atmosphere.

Materials:

The total mass of the S/C is 1.39 kg. The center of mass of the system is located within ~2 mm of the geometric center of the 1U electronics box. The total mass and center of mass can be easily adjusted because there is a central mass belt made of copper that helps retain and cool the solar panels and increases the moment of inertia about the spin axis to improve spin stability. The shape and mass of this thin copper belt near the central outer edge of the cubesat contacting the back of the solar panels can be easily adjusted because the mass allocation for the belt is ~500 g which is about 1/3 of the total mass. If any other element of the system is heaver than expected we can reduce the weight of the copper belt to keep the entire system under the weight limit.

The moment of inertia is estimated as:

$I_z = 2408$ kg cm^2 Note: Z is the spin axis.
$I_x = 2062$ kg cm^2
$I_y = 2055$ kg cm^2 Note: X and Y are the principle axises normal to the spin axis.
These axes are nearly degenerate as expected.

All off-principle axis terms of the moment of inertia are <6 kg cm^2

Summary of materials:

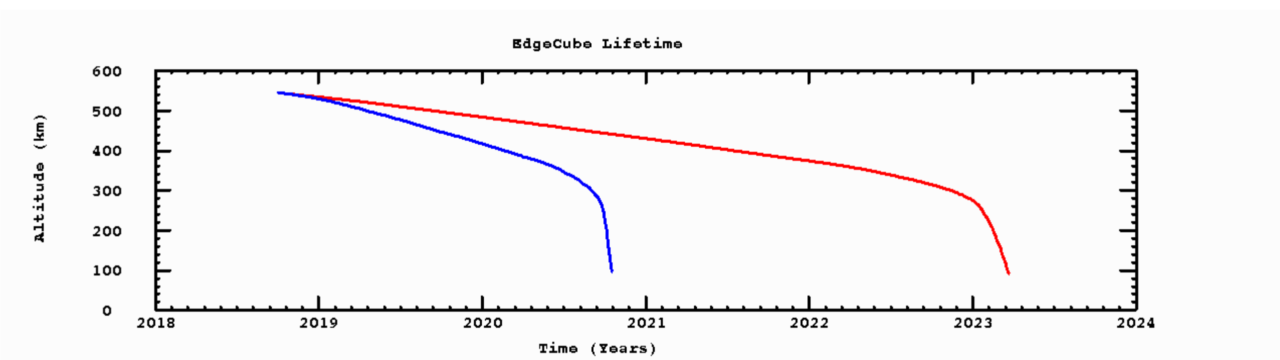
* Copper central mass belt	<500 g
* 1U body in the Al frame and the top and bottom Al structure	270 g
* Entire electronic board stack without the NiCd batteries	380 g
* Three NiCd batteries (each 50 g)	150 g
* Three Solar panels (each 56 g)	168 g
* Sensor Collimators (Dalrin)	50 g
* Dipole Antenna (spring steel)	10 g
* Dipole Antenna support structure (Dalrin)	20 g
* Magnet wire for two torque coils (each 10 g)	20 g
* Small amount of flight qualified wire	20 g
* ,Small amounts of low outgassing flight epoxy	10 g
Total Mass:	<1.39 kg

Hazards: There are no pressure vessels, hazardous or exotic materials. There are no hazardous systems on the satellite.

Batteries: We use three NiCd batteries similar to the ones flown on a previous successful mission (see URL http://lbym.sonoma.edu/T-LogoQube). Similar batteries were also flown on NASA HETE2 mission. These type of batteries are often used in heavy duty power tools because of safety and robustness. NiCd batteries can be safely discharged to zero and then recharged many times. We will test the specific flight batteries in vacuum with the spacecraft turned on to determine if the heat generated by use will cause any problems. This test is entirely independent of the required bakeout vacuum test. We do not expect any problems based on the prior use of NiCd batteries on orbit. NiCd batteries are lower energy density than any Lithium batteries and are known to be safer. Our 1U CubeSat is power limited by the solar panels and not by the NiCd batteries. We do not require Lithium batteries for normal operation.

EdgeCube Lifetime

The curve below shows a numerical simulation of the lifetime of the EdgeCube orbit. The initial height of the circular orbit is 545 km. These predictions are precise since the model is calibrated by the actual data for several 1U CubeSat for the full lifetimes as measured by the TLE database provided by the air force. The major uncertainty in the estimates of orbital lifetime is due to the uncertainty in the variation in the drag as a function of solar activity. The blue curve below assume a 3X above normal solar activity. The red curve assume a 3X reduced solar activity. Such extreme variations in solar activity are common and can not be reliably predicted for the future. The results are consistent with a range of orbital lifetimes of ~2 to ~5 years as shown in the figure below. The time axis of the figure is plotted assuming a nominal launch on Oct 1, 2018 (2018.75 years). The lifetime of a 1U CubeSat such as EdgeCube is sufficiently short so as not to require any special de-orbit measures. The largest items that would result from the re-entry breakup are three ~160 g pieces of copper that act as a mass belt around the middle of the S/C to help with spin stabilization of the S/C during normal operation. These largest components are not expected to survive reentry and impact the Earth's surface.



EdgeCube

ELaNa CubeSat ODAR Template, Rev. 2.0, 9/25/17

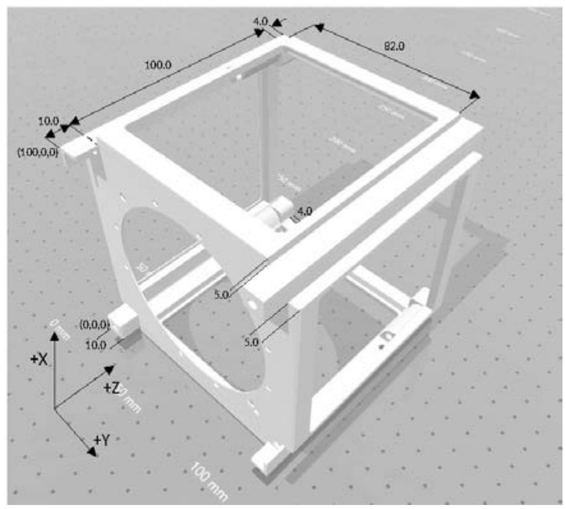
Row Number	Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Unit Mass (g)	Total Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)
1	EdgeCube 1U Structure	External – Major	1	Aluminum (3D)	Box	270	270	100	100	100
2	Solar Panels	External - Major	3	Glass – Si	Rectangular	62.5	187.5	85	80	5
3	Battery	Internal – Major	3	NiCd	AA	20.3	60.6	48.5	14.5	14.4
4	NIR Collimators	External - Major	1	Dalrin + electronics	Rectangular	30	30	77.5	75	9.5
5	Primary Mounting Rods	Internal – Minor	4	Steel 4-40 Threads	Rod	3.6	14.4	2.7	100	2.7
6	Secondary Mounting Rods	Internal – Major	10	Steel 4-40 Threads	Rod	3	30	2.7	85.2	2.7
7	4-40 Nuts	Internal - Major	200	Steel 4-40 Threads	Nut	0.5	100	4.7	5.3	5
8	Power Board	Internal – Major	1	Electronics	Rectangular	16.6	16.6	85	40	7.5
9	S/C Monitor	Internal – Major	1	Electronics	Rectangular	24.4	24.4	85	40	13
10	Sensor Controller	Internal – Major	1	Electronics	Rectangular	24.8	24.8	85	40	13
11	Sensor Face	External – Major	1	Electronics	Rectangular	27.9	27.9	77.5	75	7.5
12	Torque Board	Internal – Major	1	Electronics	Rectangular	38.9	38.9	85	85	15
13	Battery Board	Internal – Major (no batteries)	1	Electronics	Rectangular	33.4	33.4	85	85	16.5
14	Copper Plate	Internal – Major	1	Copper alloy	Rectangular	200	200	85	85	4.5
15	S/C Controlled (uStar)	Internal – Major	1	Electronics	Rectangular	23.5	23.5	80	40	14
16	Torque Coils	External – Major	2	Electronics	Rectangular	22.4	44.8	75	75	4
17	Aspect Camera	External – Major	1	Optics/Electronics	Rectangular	10.7	10.7	32	32	28
18	Camera Holder	External – Minor	1	Dalrin	Rectangular	3	3	45	34	15
19	Antenna	External – Major	1	Spring Steel/Dalrin	Rectangular	21.3	21.3	10	340	6
20	Aluminum Bottom Plate	External – Minor	1	Aluminum	Plate	32.7	32.7	110	110	1
21	Flight Wire	Internal – Minor	12	Insulated Wire 20 c	wire	0.6	7.2	1	20	1

Total Mass
1201.7 kg

Guide/Descriptions of Each Column

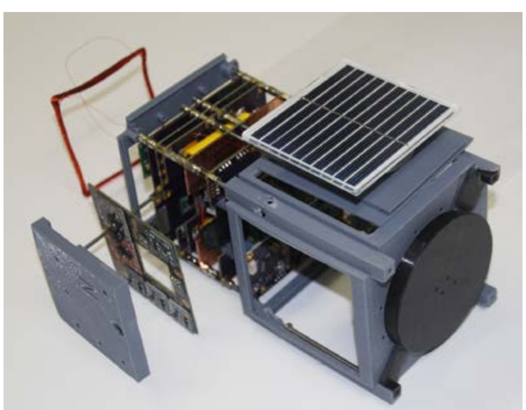
Row Number: List Components in decreasing importance (Follow Column C)
Name: List your CubeSat first as the parent, and each component and subsystem associated with your CubeSat
External /Internal: Rank CubeSat components from External to Internal and Major to Minor
Qty: List the quantity of component
Material: List the parent material for the component, specify alloy type if possible
Body Type: List the general shape of the component
Unit Mass List the mass a single component in grams
Total Mass List the mass for the total quantify of this component in the satellite (Qty * Unit Mass) = Total mass
Dimensions: List the Width/Length/Height in millimeters
Total System l the sum of all the total mass should equal the cubesat's full listed mass in all documents.

Outer Dimensions of 1U structure (meets all mechanical requirements for launcher)

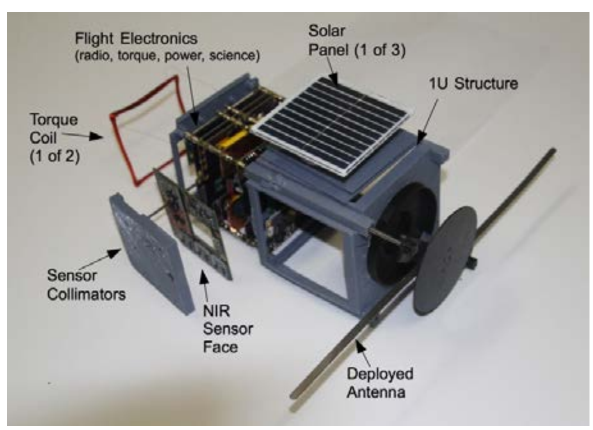


Images of the final flight system (deployed and stowed antenna)

EdgeCube: Antenna Stowed in Black Dalrin canister on right (79 mm diameter)



EdgeCube: Antenna Deployed (17 cm antenna tip to tip; popped up 3.5 cm from stowed location: cover disk 79 mm diameter)



CubeSat Developer: Sonoma State University

CubeSat Name: EdgeCube

Date Provided: May 12, 2018

Purpose: The purpose of this document is to provide a listing of materials that have been selected for use in the CubeSats. http://outgassing.nasa.gov/

Table 1 – Metals

Item #	Material ID	Specification	Description	% TML	% CVCM	Location	Data Reference
1	Stainless Steel	Retains straight form after releasd (determined by testing)	Two Antenna blades	N/D	N/D	Top face of 1U structure; pops up 4 cm	N/D
2	Aluminum	3D printed by Moog	1U structure	N/D	N/D	Main 1U body and top and bottom faces	N/D
4	Steel	For mechanical structure	Threaded rods spacers, nuts 4-40 size	N/D	N/D	1U electronics support structure	N/D
5	Copper	Solderable	Lugs soldered to copper wire with low outgassing coatings	N/D	N/D	Solar panel connections	N/D

Table 2 – Non-Metal

Item #	Material ID	Specification	Description	% TML	% CVCM	Location	Data Reference
1	Dalrin	machinable	Antenna support	N/D	N/D	Top of 1U as part of antenna	N.D
2	Dalrin	machinable	Sensor Collimators	N/D	N/D	One side face of 1U box	N/D
3	Glass	UV resistant	Covers for Solar panels	N/D	N/D	Three side faces of 1U box	N/D

4	PC boards	Conformally coated	With electronic components	N/D	N/D	Most of the interior of he 1U box	N/D
5	SMA coax cable		Antenna connector	N/D	N/D	From RF electronic board to the center fed dipole antenna	N/D

Table 3 – Surface Coatings

Item #	Material ID	Specification	Description	% TML	% CVCM	Location	Data Reference
1	Adonization	Black	Coating for launch rails	0.67	0.05	Rail surfaces that contact the dispenser rails	N/D
2	PC board coatings	Protective insulating layer	Solder mask for PC boards	N/D	N/D	All flight boards that fill the interior space of the 1U box	N/D

Table 4 – Elastomerics

Item #	Material ID	Specification	Description	% TML	% CVCM	Location	Data Reference
None	None	N/A	N/A	N/A	N/A	N/A	N/A

Table 5 – Adhesives

Item #	Materia l ID	Specification	Description	% TM L	% CVC M	Location	Data Reference
1	Kapton Tape	Acrylic Adhesive	Tape	0.62	0.12	Solar Panel Harness	GSFC3590
2	epoxy	3M Scotch-Weld 2216 Epoxy Adhesive	Low outgassing epoxy	N/D	N/D	Stake down for solar panel leads; 4-40 nuts for frame	Flight tested by CalPoly CubeSat team

Table 6 – Miscellaneous

Item #	Material ID	Specification	Description	% TM L	% CVC M	Location	Data Reference
1	Solder	nominal	N/D	N/D	N/D	Electronic boards	N/D

Notes:

N/A Non Applicable

N/D No Data Available

The Spacecraft uses the following receive and transmit frequencies.

Note: Discrete values are expected rather than ranges.

Description	**Transmitter 1**
Communication System Nominal String	RFM22BP
Carrier Frequency, MHz	437.465 MHz
3 dB Bandwidth, MHz	~0.005 MHz
Necessary Bandwidth per NTIA redbook, MHz	0.0083 MHz
20 dB Bandwidth, MHz	~0.012 MHz
60 dB Bandwidth, MHz	~0.028 MHz
Receiver sensitivity, dBW	-145 dBW
Antenna gain, dBi	2.2dBi
Modulation type and characteristics (total data rate)	GMSK 9600 baud
Receiver Input Damage Threshold*, (line loss included), dBm	Unknown, presumed high with antenna stowed.
Receiver span (MHz)	40 MHz
Intermediate frequency, MHz	937 kHz
Local Oscillator frequency, MHz	436.528 MHz
Transmit Antenna output (EIRP), dBW	1.8 dBW
Receive Antenna Flux Density, dBW/m2	Simplex mode: RX off when TX on.
(receiver ON)	
Antenna Description, Polarization	Dipole, linear
Operating on PAD	No
Operating during launch	No
Ground Equipment output power, dBm	20 dBm

*If Spaceflight is not provided Receiver Input Damage Threshold, Spaceflight will assume -40dBm.