CubeSat Design for LEO-Based Atmospheric Science Mission

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Abstract – The 2019 Students for the Exploration and Development of Space (SEDS) Chapter of Rice University has developed a design proposal of a CubeSat platform to accomplish science objectives related to modeling of the Earth's atmosphere. This proposal describes the **OwlSat CubeSat** (referred to as OwlSat), a 1U satellite bus that supports a mission architecture based on a three-instrument package. The architecture includes EUV radiation probes to measure the solar activity of the sun, an accelerometer to monitor the velocity of the satellite, and a GPS receiver to determine the location and altitude of the satellite.

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1. MISSION OBJECTIVES

The mission objective of the OwlSat is to measure EUV (Extreme Ultraviolet radiation) from the Sun. That data will be used to quantify the expected correlation between the EUV heating of the Earth's atmosphere and OwlSat's orbital decay rate. This will provide a more accurate prediction model for future orbiting bodies.

Energetic emission from the Sun, particularly in the X-ray and Extreme Ultraviolet wavelengths (XUV) can have tangible effects upon the atmosphere of the Earth [1]. Increased EUV radiation caused by solar activity serves to heat the Earth's atmosphere, leading to atmospheric expansion, which increases the amount of atmospheric drag satellites encounter and subsequently increases their orbital decay.

EUV radiation originates in the corona and chromosphere of the Sun's atmosphere. The solar EUV spectrum, between 1 and 120 nm, is dominated by spectral lines from hydrogen (H), helium (He), oxygen (O), sodium (Na), magnesium (Mg), silicon (Si), and iron (Fe). The EUV photons reach Earth and are absorbed in the upper atmosphere, above 80 km. The thermosphere of the Earth is heated predominantly by solar EUV radiation. The EUV photons also ionize the atmosphere, creating electrons that ultimately form the ionosphere. Solar EUV irradiance varies wildly from minutes to hours (solar flares), days to months (solar rotation), and years to decades (solar cycle). The highly varying EUV radiation causes the thermosphere and ionosphere to vary greatly over similar magnitude and time scales [19] and can affect satellite communications.

During the geomagnetic storm of March 1989, the North American Aerospace Defense Command (NORAD) lost track of thousands of satellites, which increased the likelihood of satellite collisions with other satellites or orbiting space debris during that time [2] (Fig 1). In 2009, such a collision occurred between an Iridium communications satellite and a Russian Cosmos 2251 satellite, creating 10,000 pieces of debris that varied in size from a few millimeters to a few centimeters in diameter.

The consequences of such satellite collisions can range from performance degradation to failure and satellite fragmentation [8]. In low Earth orbit (LEO), debris as small as a few millimeters in diameter can puncture unprotected fuel lines and damage sensitive components, while debris smaller than 1 mm in diameter can erode thermal surfaces and damage optics. Although smaller objects can partly be mitigated through the use of meteor bumpers, such as on the ISS, the only way to mitigate larger objects impact is to maneuver the spacecraft to avoid collision. Such maneuvers are expensive, impact the operation of sensitive experiments on board, and ideally should only be done if the chance of collision is high.

These problems appear to compound themselves as the number of satellites in orbit around Earth are set to increase significantly in the near future [8]. For context, from 2012 to 2018, the numbers of orbiting satellites increased by a factor of 6, and with the aggravating nature of collisions and the debris they spread, a run-away space debris effect is possible if satellite collisions are not actively prevented (Fig. 2).

To avoid these scenarios, orbit propagation models are used to determine the location of space objects, including small satellites and CubeSats, in the relatively near-term (typically over a period of a few days or less) for purposes of collision avoidance or reentry predictions, and also to make long-term predictions (typically over a period of years) about the debris environment [9]. These models are mostly physics-based models. However, these physics-based models cannot predict orbits precisely for a long time duration or during events such as a solar flare, where orbits can change drastically within a day or so [13]. These deficiencies are due to varying levels of forces that act on satellites in different ways. As shown in Figure 13, the primary forces acting on a space object in LEO are the gravitational attraction of the Earth, Moon, and Sun, atmospheric drag, and solar radiation pressure. Moreover, there are many other less-influential criteria that still affect orbital behavior, such as the thermal radiation force asserted by the satellite itself and the satellite's gravitational torque. These criteria are crucial for precise orbit calculation.

Ultimately, the largest uncertainty in determining orbits for satellites operating in LEO is atmospheric drag [1] (Fig. 3). Drag is the most difficult force to model mainly because of the complexity of neutral atmosphere variations driven by the Sun. Below is the equation commonly used to calculate atmospheric drag.

Equation (1) $$F_D = \frac{1}{2} Cd \varrho A V^2$$

$Cd = Drag\ Coefficient$

$\varrho = Atmospheric\ Density$

$A = Cross - Sectional\ Area\ of\ Object$

$V = Fluid\ Velocity\ (Velocity\ of\ Satellite)$

The heating of atmosphere due to varying levels of EUV radiation can additionally change the drag coefficient in equation 1. The drag coefficient is subject to the shape of the object passing through a stream of fluid. As the orientation of the object changes, the shape of the object passing through the stream changes as well. Under constant atmospheric conditions, the drag coefficient of an object can be derived from wind tunnel tests. However, drag coefficients are also subject to atmospheric densities and the molecular behavior of the fluid through which the object is passing[18]. Figure 16 shows an example of the differences in drag coefficients found with respect to shape and orbital altitude.

Atmospheric neutral density models routinely used in orbit determination applications are mainly empirical. These models are based on historical observations to which parametric equations have been fitted, representing the known variations of the upper atmosphere with local time, latitude, season, solar and geomagnetic activity[14].

For higher accuracy in predicting the orbit, F10.7cm solar radiation emission data is generally used to indicate the change in density that affects the drag force which leads to orbital decay. The solar radio flux at 10.7 cm (2800 MHz) is an excellent indicator of solar activity. Often called the F10.7 index, it is one of the longest running records of solar activity. The F10.7 has been measured consistently in Canada since 1947, first at Ottawa, Ontario; and then at the Penticton Radio Observatory in British Columbia, Canada [4].

Unlike other solar indices, the F10.7 radio flux can easily be measured reliably on a day-to-day basis from the ground in all types of weather. The EUV emissions that impact the ionosphere and modify the upper atmosphere track well with the F10.7 index. Many UV emissions that affect the stratosphere and ozone also correlate with the F10.7 index. And because this measurement can be made reliably and accurately from the ground in all weather conditions, it is a very robust data set to use with few gaps or calibration issues[17].

There are many models currently used to correlate the F10.7 index to atmospheric density[14]. However, using F10.7 accuracy is still not enough for the long-time predictions of orbits. F10.7 can be derived on a daily basis and most of the F10.7 indices are based on interpolated estimation models that are not accurate enough for the estimation of longtime orbital change[18].

In order to accurately predict the long-term nature of orbits, an iterable prediction model must be created that takes into account and actually learns from the vast number of determinant factors that affect orbital behavior. This model needs accurate EUV data in addition to the real-time positional effects the EUV radiation exerts on an orbiting body.

Thus, the 2019 Rice University Chapter of the Students for the Exploration and Discovery of Space Organization (SEDS Rice) will seek to develop a linear regression algorithm to draw patterns and predict behaviors based on the previously accumulated data. As we gather more data, we will be comparing our prediction model with the new data to further enhance its accuracy. This supposed algorithm may be used as a base for the prediction of orbits of other orbiting bodies and will hopefully contribute to the ability of other satellites to predict the amount of drag that they will feel due to EUV solar radiation.

SEDS Rice will undertake this mission by developing and constructing a CubeSat platform capable of recording EUV radiation data found in the upper atmosphere and comparing that data to the subsequent positional values of the orbiting OwlSat CubeSat.

Additionally, the availability of solar EUV radiation data from government agencies such as the National Aeronautics and Space Administration (NASA) will allow our team to validate the radiation levels measured on OwlSat and in the unlikely event that our EUV sensors become inoperable, will allow our team to still make correlations between that EUV data and the positional data provided by OwlSat.

2. ENGINEERING CAPABILITY

A. SYSTEMS ENGINEERING

The proposed OwlSat platform consists of all subsystems needed to support and power small science instruments as well as collect, store and communicate observational and positional data to a ground station [3]. Additionally, an active attitude control subsystem was designed to facilitate the scientific objectives of the mission.

Mission Plan

The current plan for the OwlSat launch is to release OwlSat from a NanoRacks CubeSat Deployer from the International Space Station. These are the orbit parameters that were used in developing the mission plan.

Day 0:	Deployment from NanoRacks launcher; deployment of solar panels and antennas
Day 1:	Active attitude stabilization into data-taking formation and communicational connection with ground-based station
Month 1-12:	Scientific data collection
Month 12-18:	Mission margin, additional data collection
Month 18:	De-orbit and end-of-life

Mission Modes

Table 1 defines the modes of operation of the CubeSat system.

Table 1. Mission Modes

Mission Mode	Task
1	Deployment, External Systems Positioned
2	Attitude Stabilization
3	Scientific Data Collection
4	Ground Communication
5	Conservation of Power, Recharge
6	Standby, Sleep

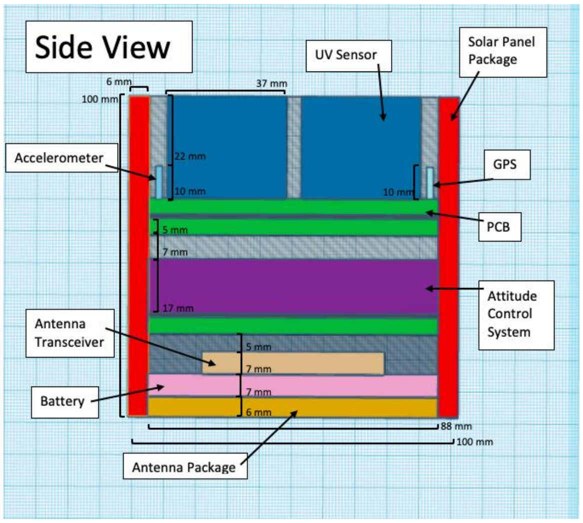
Modes 1 and 2 apply only to the initial deployment and stabilization portions of the mission. Mode 3, science data collection, is the primary mode of operation, with the OwlSat switching to Mode 4, ground communication, as communication and data downlinking opportunities occur. Mode 5, conserve power and recharge, is only used in the unexpected event where normal operations cannot be supported by the power system. Mode 6, standby/sleep, is the default mode when no other modes apply and will be the mode in place when the OwlSat is in the Earth's shadow, shielded from the sun.

Internal and External Components

The external components of OwlSat include the cube structure, four deployable solar panel sets (with sun sensors), and four deployable antennas.

The internal components of OwlSat include four EUV sensors, an accelerometer, a GPS chip, a microcontroller for the EUV sensor data, a transceiver module to transmit data to the ground station, an external memory to store data on-board, a microcontroller for the accelerometer data, the attitude control system, and a battery array.

Figure 4. Internal Structure of OwlSat



When designing the internal configuration of the satellite, it is important to take into account the

Center of Mass (CM). Per NanoRacks launch guidelines, the CM, relative to the geometric center of the satellite, must be within 20 mm on all Axes. During satellite construction, SEDS will be using the center of mass equations to properly orient all materials within the satellite. The equation will take into account the CM of each material and overlay them in OwlSat to properly orient each material within the satellite. Calculations for the CM will be completed during the final design process and confirmed with the physical components to ensure that the team meets the NanoRacks Requirement.

All OwlSat components are off-the-shelf components. This decreases costs and increases reliability. The primary testing of these components will be through thermal vacuum and vibration testing at the component, subsystem, and spacecraft level. A FlatSat (2-Dimensional prototype) of OwlSat will also be created to perform component, subsystem, and integrated system tests.

Mass Budget

Table 2. Mass Budget

Component	**Mass**
UV Sensors (x4)	0.100 kg
Battery Array	0.115 kg
Attitude Control Sys.	0.176 kg
Antennas (x4)	0.100 kg
Microcontrollers + Ext. Memory (x3)	0.075 kg
GPS Chip	0.005 kg
Accelerometer	0.002 kg
Solar Panels (x4)	0.200 kg
External Structure	0.100 kg
TOTAL	**0.873 kg**

Table 2 is the mass budget allocated for the OwlSat mission. Of the 1-kg maximum launch mass goal, .873 kilograms are allocated to the subsystems, allowing for a .127 kilogram contingency.

SUBSYSTEM COMPONENT DETAILS

Structures

The primary structure of the spacecraft will transmit loads throughout the spacecraft to the interface of the deployment system. Secondary structures, such as solar panels and antennae, will be attached to this structure. It is essential the primary structure performs as expected, since a failure of the primary structure can have dramatic consequences that are difficult to overcome after the spacecraft has launched.

When beginning design, material selection is a necessary and highly important step for the structure. Properties taken into consideration are most importantly, but not limited to, strength, operational temperatures, and weight. OwlSat must withstand the loads experienced during launch and withstand the thermal stresses that may exceed 200 °F when operating. The ideal material will exhibit properties surpassing the requirements, giving a safety factor to our structure, and be as light as possible to maintain our mass budget. Taking these into consideration, our material of choice is Aluminum 6061.

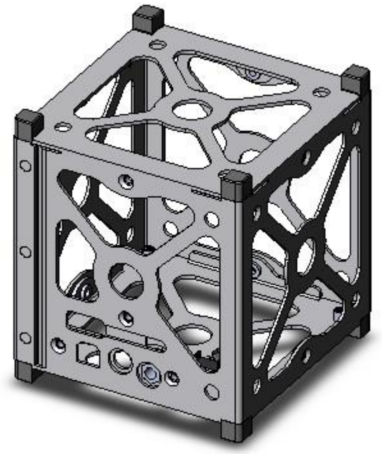
With the material decided, the focus moves into the design requirements of the primary structure. First, the design should satisfy the requirements placed by the Nanoracks CubeSat launch interface. These are to provide adequate interfaces to each subsystem to ensure safe passage through all phases of the mission. In addition, an ability to accommodate the scientific payload without large modification of the design is a strong driver. Alongside these requirements, the frame should be designed in such a way to maximize volume efficiency. The structure will carry loads in the external shell to increase internal volume. This design will allow us to add extra EUV Sensors within OwlSat, giving us redundancy and increasing our success rate. The EnduroSat 1U CubeSat Structure (TRL 9) fits these requirements and is the ideal choice. The structure is built using Aluminum 6061, giving strength while providing one of the lightest external structures. Also, the structure has been tested under various circumstances (including vibration tests, thermal cycling, and successful space flights), and uses a design maximizing internal volume.

Some of the requirements listed by Nanoracks, and followed by the EnduroSat structure, are explained here. The primary structure must have external rails that are the only mechanical interface between OwlSat and the NanoRacks CubeSat Deployer (NRCSD). The rails make up four parallel edges of the CubeSat and their dimensions are defined by the NanoRacks launch interface. The rails will have a length of 113.5mm (+/- 0.1mm) along the Z axis. The +Z rail ends will have a minimum area of 6mm x 6mm and be bare as well to ensure OwlSat will provide no issues within the NRCSD. Other rail characteristics include edge radii of 0.5mm (+/- 0.1mm), minimum extensions from the +/- Z planes of 2mm, and smoothness and proper alignment of the rails with one another (+/- 0.1mm). All of these requirements, alongside other specifications, are abided by the EnduroSat external shell.

The frame is machined with multiple mounting locations on the exterior that will allow for the addition of solar panels and antennae. The antennae will be mounted on the - Z face, while the solar panels will be mounted on the +/- X faces. The + Y face will contain the access port Nanoracks requires that will allow the interior of OwlSat to be reached when the outer shell is in place.

Internally, the components will be fastened to the structure as a single package using brackets and fasteners, keeping in mind structural load is on the external shell. Not only does this create maximum volume efficiency, but it also keeps the internal components away from stress concerns. The six faces covering the sides of OwlSat are attached to the structure base with screws, enabling easy removal should access to the internal components of OwlSat be desired.

Figure 5. EnduroSat CubeSat Structure



Power

The Power subsystem is made up of the integration of deployable DSA/1U titanium solar panel arrays and a BA0x high energy density battery array from the Ecuadorian Space Agency.

Each solar panel array will consist of two solar panels that use an expanding material mechanism to extend. There will be four arrays total, all of which will deploy in a parallel plane. Two arrays will coincide with the top OwlSat panel and the other two will coincide with the bottom panel (Fig. 7). Each solar panel array will include sun sensors, which will be linked to the attitude control system to orient the solar panels and UV sensors towards the Sun.

One solar panel array will supply 5.2 V on the top side, and 3.2 V on the bottom side. Power delivered will be 4.2 W minimum per array in full sunlight. Assuming that the top of each solar panel is facing the sun, this means that the entire solar panel configuration will provide 20.8 V, and deliver at least 11.2 W total.

The solar panel arrays release and deploy through artificial muscle technology, which allows for a more gentle and safe deployment than the usual thermal knife systems seen on CubeSat systems. A deploy signal is sent through a DSA control module, which releases and extends the solar arrays to a pre-programmed final position, which in our case will be parallel to the top and bottom plates of our structure. The release sequence takes 10 seconds, and the deployment takes 10 seconds, ensuring a smooth transition with no backlash.

The battery array will be used to store and deliver power to our electrical components. This array was specifically chosen because its design is specifically made to couple with the DSA solar arrays that will be mounted in our system. The battery array will ensure that we have a continuous source of power at all times, which will become particularly useful when our satellite and the sun are on opposite sides of Earth.

There are multiple redundant cells within the battery array to ensure that power will always be available. It will supply a nominal voltage of 3.7 V, and can supply up to 4.2 V at full charge. It can supply 6000 mAh of current, and about 22.2 W per hour.

Table 3. Power Budget

Component	**Necessary Power**
UV Sensors	0.4 W
Attitude Control Sys.	1.2 W
Antenna Sys.	4.7 W (transceiving)
Computer	0.1 W
GPS	0.09 W
Accelerometer	0.02 W
TOTAL (max)	**6.51 W**

Table 3 is the required power budget allocated for the OwlSat mission. The values derived are the power values correlated to each component's peak power consumption, which would not be realistically in place while the mission is underway. With this contingency in place, the mission requires a max power allotment of 6.51 watts. Of the 6.51 watt max power requirement, a contingency of 10%, or .651 watts, is reserved. With this contingency in place, the solar panel arrays will be capable of generating 11.2 watts of power, surpassing the in-place contingency by 64%.

Communications

An amateur-band communications system is planned for OwlSat for three reasons. First, there are fewer regulatory constraints in attaining the frequency bands. Second, commercial off the shelf parts can be used for the flight system. Third, other schools can be coordinated such that there is more ground station access.

We will be using a SATELLINE-M3-TR4 UHF data transceiver module for radio communication with the ground station. This specific transceiver has a low power consumption, which makes it suitable for our needs. The module comes with a configuration software, making it rather easy to deploy in our mission. The module has also been deployed in previous CubeSat missions, proving that it is capable of performing in the environment of outer-space [4].

The antenna of choice is the Deployable Turnstile Antenna System from ISIS Space Systems, specifically its dipole antenna variant. A dipole antenna was chosen because it has a larger beam width than a monopole antenna, allowing for longer communication windows (more science data) and easier attitude control requirements. The system made by ISIS Space Systems is also easily compatible with our data transceiver module, has low mass and power requirements, and operates in various amateur radio bandwidths.

One of the goals of this team is to operate a ground station of our own. While the majority of our efforts have gone towards the design of our actual satellite, there has been research and brainstorming done on how communications would be received on Earth. One potential system that we have considered using is the ISIS Full Ground Station Kit for VHF/UHF/S-band. This ground station is designed to communicate with satellite in LEO, specifically for the reception on the ground of a satellite downlink and for commands uplink.

Another option that has been researched is building a simpler and less expensive ground station, based on recommendations published by the American Institute of Aeronautics and Astronautics, of which several students on the team are members. The overall design of this ground station would design a receiver of some sort (likely a Software Defined Radio), a low noise amplifier, one or more antenna, software compatible with the receiver, satellite tracking software, data decoding software, and a personal computer.

Overall, although there is not a finished design of the ground station, there are established plans to move forward with the design and construction of a functional ground station. If this proves to be too ambitious, the ISIS Ground Station Kit mentioned earlier will be a good back-up plan. We are also open to collaborating with other universities or other institutions with amateur radio groups and plan on reaching out to nearby groups in the future.

Due to the relatively low amounts of memory space needed for EUV sensor data and to the efficiency of the chosen antenna system, OwlSat will require considerably less ground station access to transceive data than traditional CubeSat missions.

Command & Data Handling

The Command & Data Handling (C&DH) subsystem consists of the onboard flight computer with memory for science storage, as well as data interfaces for science, telemetry, and communications (Fig. 8).

The microcontroller of choice is the ATSAMD21J18, which provides the necessary interfaces for our auxiliary sensors and modules, such as SPI, I2C, and USB. In addition to its internal 256KB flash memory and 32KB SRAM, we will be using a magneto-resistant MR25H10 4 MB external memory to store applications and log experiment results. Both microcontroller and external memory have been previously used in a variety of CubeSat missions, and MR25H10 is proven to be resistant to extreme environmental conditions, including severe radiation [15]. Additionally, we estimate that each data-collection period will only require around 20KB of memory, well within our memory storages.

Previous space missions illustrated that space radiation can arbitrarily flip the bits written on regular random access memories. In OwlSat, this problem will be addressed in the following way [4]: First, we will be using magneto-resistant memory, which has tested in similar environments and proven to successfully secure the stored data. Secondly, we will use redundancy in our applications as a second layer to further minimize the risk of losing our experimental applications.

The microcontroller will be running an open-source operating system, FreeRTOS. This is a suitable operating system for a space mission as it adheres to strict structure and ensures events are responded to in a timely and deterministic manner. All applications will be written as independent tasks and will be executed according to the priority assigned to them. FreeRTOS comes with an open-source IDE - Atmel Studio - which we will be utilizing. All applications will be programmed in low-level programming languages C and Assembly to ensure efficiency.

There are various different functions within the software that perform different tasks given different needs. The science function is called when the GPS indicates that the satellite is within the appropriate data taking region. This function collects and records science data for a length of time determined by the mission's region of interest. The science function also periodically monitors the health sensors and can call the fault response function if necessary.

The communications function is called when the transceiver indicates that it has received a beacon signal from a ground station. The function sends science data to the ground until all of the stored data have been sent or the function determines that the beacon signal has been lost, indicating that the satellite has passed out of communication range. As with the science function, the communications function monitors satellite health and can call the fault response function if needed.

The fault response function is activated if any other function detects abnormal health readings. The fault function examines the abnormal reading and calls an appropriate health function, for example, a "too hot" function or a "too cold" function.

Attitude Control

The attitude control system of OwlSat will be the ISIS Magnetorquer board, produced by ISIS Space Systems. It provides attitude control via a 3-axis magnetic torquer system capable of providing actuation of up to $0.2\mathrm{Am}^2$. It draws 1.2 watts of power during peak operation and weighs .176 kg, both of which fit within our desired contingencies. A 3-axis magnetometer detects the interaction between Earth's magnetic field and the field created by the magnetorquer coil. The board also includes a detumbling algorithm, which can be tested and modified to suit our satellite's needs. This attitude control system was chosen because it was specifically designed for CubeSat applications and provides a reasonable amount of actuation specific to this mission's needs.

The magnetorquer board can act as a standalone detumbling system, but it can also be integrated into more advanced attitude determination and control systems (ADCS). This allows the team flexibility for the future, since we have discussed potentially using reaction wheels in addition to this magnetorquer board to provide greater torque for attitude control. While the current plan and design will only include the magnetorquer board, we acknowledge the possibility of needing additional components to provide higher torque onto the system if the magnetorquer board proves to be too weak during testing.

This passive attitude control system is critical to this mission's success because the main data-collecting instrument, the EUV sensors, and the main power source must be directed towards the sun in order to function. This magnetorquer board fulfills these requirements by inducing torques on the three-axis relevant to the satellite's orientation in free space. In order to most efficiently utilize the torque generated by this system and to adhere to NanoRacks specifications regarding the center of mass of OwlSat, the attitude system will be placed at the center of mass of the structure.

This attitude control system is a passive system that uses data from sun sensors located on the solar panel arrays to orient the EUV-Probe facing side of OwlSat towards the sun. When OwlSat enters the portion of its orbit where its view of the sun is obstructed by the Earth, it enters mission mode 6, standby/sleep, until it reaches a sun-facing orbit.

B. PAYLOAD ENGINEERING

As stated above, the mission objective of OwlSat is to take EUV radiation measurements of the sun and compare those data points with the positional and velocity data of OwlSat. The mission architecture meets this objective using a scientific payload package. This section will describe the payload package and the attitude-correctional system that enables OwlSat to take direct measurements of solar radiation.

Linear Regression Orbital Propagation Model

Our mission concept under development makes use of four science instruments to measure solar

EUV radiation directly. These instruments consist of four different EUV sensors produced by Gigahertz-Optik that are capable of EUV measurements over a broad range of the EUV spectrum (1 nm to 200 nm). In total, the four EUV sensors draw 0.1 Watts of power and weigh 0.1 kilograms combined, falling within our desired mass and power allocations. To optimize our data collection, the EUV sensors will be pointed directly at the Sun at all times (except when in eclipse). This requires that their apertures be located outside of the satellite structure and controlled by the aforementioned attitude control system (Fig. 4).

This mission employs two additional science instruments: an accelerometer sensor and a GPS transceiver. The accelerometer sensor will take repeated measurements of OwlSat's orbital velocity and the GPS transceiver will monitor its location.

Each of the four EUV scientific instruments are connected to a single science board using coaxial cable. The science board then transmits the data to the onboard computer, where it is stored until it can be downlinked to Earth. The two positional science instruments are connected to a second communications board, which is likewise connected to the onboard computer and downlinked to Earth.

Preliminary analysis of the communications subsystem indicates that OwlSat is capable of downlinking a maximum of about 1 megabyte per day of science data. This is based on one ground station, at 9600 baud. A data taking region consisting of +/-10° of latitude, corresponding to about 11 minutes of data-taking time per orbit, was chosen to fit within the downlink capability.

C. HARDWARE AND SOFTWARE

Extensive hardware and software prototyping of spacecraft subsystems has and will continue to be conducted. The sections below highlight some of these prototyping activities and the various tests performed on them.

Structure

A three-dimensional model of the final OwlSat Structure was 3-D printed to serve as a visual aid when considering the internal geometry of OwlSat. Additionally, this model will be used to easily inform potential SEDS Rice members or donors of the CubeSat we intend to develop (Fig. 6).

Future Prototypes and Tests

The vast majority of the components of OwlSat will be bought off-the-shelf. This is because professionally made products are of a higher quality and precision than similar products produced by our own team. Therefore, the process of prototyping components that we intend to purchase is not necessary.

Regardless of their origins, all final components, subsystems, a FlatSat replica of the final CubeSat, and the final OwlSat CubeSat itself will undergo rigorous testing procedures required by Nanoracks. Instruments capable of carrying out these tests are available to the OwlSat team at Rice University's Ryon Engineering Laboratory. This lab is suited for thorough mechanical and structural testing and also has access to some aeronautic testing equipment.

Another great resource that we are fortunate to have is access and support from the Oshman Engineering Design Kitchen (OEDK), an undergraduate engineering facility that provides students with access to design tools, prototyping equipment, computational facilities, meeting rooms, and ample space for prototype design and development. The OEDK has served our team as the primary space for our meeting and design sessions, in which we have been able to bring this project to life. We plan on continuing our relationship with the OEDK for the remainder of our project.

Failure Scenarios

The team created a Failure Modes Effects and Analysis (FMEA) to assess the potential failure points of the proposed design, highlight the causes and effects of these failure points, predict the probability of occurrence and severity, and establish a mitigation plan for each point (Fig. 12). This analysis helped inform the team on which systems are the most critical, and also served as a tool to ensure that there is an established plan to minimize the risk of failure of this mission.

The FMEA shows that our most critical components are the solar panel arrays' deployment system, the antenna deployment system, and the overall power storage and delivery system. While we plan on doing extensive testing on all components and systems, identifying these systems as the most critical ensures that special attention is given to them throughout the engineering process.

While there is a significant number of potential failure modes that will result in the overall failure of the entire mission, the likelihood of any of them happening is extremely low. We have designed redundancy into various subsystems by having more than one of the same component, such that the failure of one of these components will not lead to the failure of the mission. Some examples of this include having multiple solar panel arrays, antennas, UV sensors, sun sensors, and accelerometers. The entire system was designed by prioritizing the insurance that our minimum mission will be met, as will be discussed in the next section. Testing will also be a very large part of our engineering process, as explained in our previous section.

Minimum Mission

As stated previously, the overall mission is to characterize the relationship between solar EUV radiation and atmospheric drag in LEO conditions. This requires our system to measure EUV irradiance, together with satellite position and acceleration. In order to ensure mission success, redundancies have been built into the system. This section will show what OwlSat components can fail without jeopardizing mission success.

OwlSat will have four EUV sensors, each of which will measure EUV radiation of greatly overlapping wavelengths. This means that we can lose up to three sensors and still collect a significant amount of EUV radiation data. Additionally, in the extremely unlikely event that we lose all four EUV sensors, our team plans on using EUV radiation data collected by public satellites such as those operated by NASA, and use this data as an estimation of the EUV radiation affecting the OwlSat orbit.

OwlSat will also have multiple sun sensors, which will be referenced by the attitude system to orient OwlSat towards the sun. If one of these sensors fail, the system will still be able to detect the sun. If all of the sun sensors fail, an integrated passive attitude system will work to use the Earth's magnetic field to orient OwlSat orthogonal to the Earth's magnetic field. While this means that OwlSat will no longer be pointed directly at the sun, the passive attitude system will allow it to still pointing outwards, and therefore EUV data can still be collected. These data will be augmented by EUV data from NASA solar space missions.

OwlSat's GPS system will allow our ground station to locate the satellite's position, and it can also be used to approximate the acceleration of the satellite. If this system fails, tracking of the satellite will be done by simulation, and the acceleration data needed will still be collected through the accelerometer.

OwlSat's accelerometer is the primary source of acceleration data, used to characterize the atmospheric drag effect on the satellite. If the accelerometer fails, the GPS system will allow us to approximate the satellite's acceleration by using position data points.

Overall, our mission can still be accomplished if we lose all four EUV sensors, all of our sun sensors, and one of our GPS system or accelerometer (but not both).

On the other hand, our critical components include the solar panels, antennas, and microcontrollers. If any of these components fail, our mission will result in failure.

5. NON-TECHNICAL CAPABILITY

Budget

After seeking guidance from our faculty and considering the cost of the desired CubeSat components, a budget of $40,000 was agreed upon. While relatively large, we feel it is reasonable considering the context of this project and the scientific information it promises to yield.

Fundraising

There are many different methods our team can utilize when securing funds for our CubeSat. Perhaps the simplest and most effective of those methods is to apply to various research and project grants provided by Rice University. For example, the Rice Center for Engineering Leadership has routinely provided other engineering design student groups grants of up to $10,000 and various research projects currently underway receive funding in excess of $50,000 directly from Rice. Since this project is classified as a research experiment under the guidance of our faculty mentors, research funding of the level prescribed by our budget should be attainable.

SEDS Rice has already received a pledge from the Rice Space Institute of $3,000 to support the OwlSat Project. The team has also reached out to the Rice Engineering Alumni (REA) Board that supports Rice students by donating over $500,000 to the University each year. The application for funding from the REA is currently under review. SEDS Rice has also applied for additional funding through the School of Engineering and the School of Natural Science. Both of these applications are currently under review.

Additionally, SEDS Rice will reach out to companies in industry and solicit their support. SEDS Rice, Rice Engineering and the Rice Space Institute have numerous connections to industry leaders and the OwlSat team will approach them for support: it is not unreasonable that the necessary funds will be obtained. For example, the current President of SEDS Rice, Ryan Udell, has previously attracted companies such as ExxonMobil to support Rice's Rocketry Club.

Finally, SEDS Rice holds various events throughout the year capable of raising significant funds. For example, SEDS Rice recently hosted the "Owls in Space" Symposium. This event hosted current NASA Administrator Jim Bridenstine, astronauts Peggy Whitson, Don Pettit, and Rex Walheim together with aerospace industry leaders from companies such as Lockheed Martin and Boeing, all of whom gave talks promoting students to explore and develop space. This single event generated SEDS Rice $2,000 to be used for further event promotion, member recruitment, and for SEDS Rice projects, such as this CubeSat.

Project Management

The SEDS Rice OwlSat Project is headed by Paul Glenski, an undergraduate electrical engineering major. The leadership structure further includes the sub-team leads who independently have authority over their particular teams. This allows the different sub-teams to customize their meeting and work structures to meet their specific needs, enabling a more efficient project management structure.

While the project is managed in a way that allows for sub-team specialization, each sub-team is kept on track by weekly team lead meetings where progress reports of each sub-team's progress are given. Also, the Integration Sub-Team's purpose is to facilitate universal communication across the whole OwlSat Team and to integrate the sub-systems of each sub-team into one, all-encompassing project, the OwlSat satellite itself. This grants the OwlSat Team a special type of group cohesion that is malleable and efficient, yet structured and productive.

Under the aforementioned project lead, there are four sub-team leads: Alp Yakici of the Avionics and Communications Sub-Team, Paraksh Vankawala of the Structures Sub-Team, Alejandro Toscano Rodriguez of the Integration and Power Sub-Teams, and Liana Hamm of the Payload Engineering Sub-Team.

Gantt Chart

Figure 13 shows a Gantt Chart, created to document all aspects of the CubeSat to be completed after the submission of this proposal, scheduled to start on August 26, 2019 or the start of Rice University's fall semester [5]. The chart has five main groupings of tasks to be completed: (1) CubeSat Construction, (2) Government Documentation and Paperwork, (3) CubeSat Testing, (4) CubeSat Reviews Before Launch, and (5) CubeSat Deployment and Active Tracking. The Gantt Chart is based on NASA's Vee Model and Project Lifecycle Model shown in Figures 9 and 11 [6].

The Gantt Chart takes into account time for testing on both the FlatSat, for ground use only, and the actual CubeSat itself to be flown in space. With the current chart, OwlSat is scheduled for launch in the Summer of 2021. SEDS Rice will complete the main construction of the FlatSat and of OwlSat in the 2019 Fall Semester and the beginning of the 2020 Spring Semester. The base 1U structure will need the largest amount of construction time because the team will be building this structure in-house. The critical path items of the timeline are highlighted in red in Figure 13 and the critical path item timeline is based on NASA's Spiral Process Model (Fig. 10). Rigorous testing of all systems will follow the construction of OwlSat with the majority of the testing happening in the 2020 Spring Semester and throughout the 2020 Fall Semester. SEDS Rice plans to complete all testing by the end of the 2020 Fall Semester.

Starting in the 2019 Fall Semester, SEDS Rice will begin to make a full outline of the licensing path for all NASA and NanoRacks regulatory documents for OwlSat. This process will continue throughout the 2020 Spring Semester with the majority of the documentation to be completed during the testing phase of the project in the 2020 Fall Semester. The team will begin the final OwlSat reviews and documentation in the 2021 Spring Semester leading up to the planned launch date during the Summer of 2021. All documents and the final CubeSat will be delivered to NanoRacks by the end of the 2021 Spring Semester.

Following the successful launch of OwlSat to the International Space Station (ISS), the SEDS Rice team plans to wait to deploy the satellite until the beginning of the 2021 Fall Semester. This will allow the team to have time to regroup after the summer and prepare the ground station and equipment for active tracking.

The proposed lifetime of OwlSat is one year. This time will allow the UV sensors to be operational over a complete orbit of the Earth around the Sun allowing us to assess the effect of the variability of the EUV between perihelion and aphelion. The Project Life Cycle will come to an end at the beginning of the 2022 Fall Semester (Fig. 13)

Communications and Marketing

All communications performed within SEDS Rice are done through the Slack Team Messaging Software. In this software, there are various channels for different groups and teams in addition to a general, universal channel that allows messages and pictures to be sent from computers, cellphones, etc.

Within the SEDS Rice Slack community, the OwlSat Project has its own separate channel where OwlSat-specific communications are sent.

Additionally, there are channels for each of the four aforementioned sub-teams and one channel only accessible by those in leadership positions. This was done to make sure that communications specific to a certain group are kept locally, which decreases the amount of non-applicable messages group members receive and prevents members from other groups from being interrupted by details not immediately important to them. However, if a group member is interested in the communications of another group, they can still very easily join that other group's channel.

The OwlSat Team of SEDS Rice has learned a lot about marketing their CubeSat mission by helping to produce the promotional materials needed to publicize public events hosted by SEDS. For example, the majority of the sub-team leads and the overall project lead helped to publicize the aforementioned "Owls in Space" Symposium, which attracted hundreds of attendees.

Some of the methods employed by SEDS Rice to publicize this event included creating promotional flyers, social media posts, newspaper articles, and the inclusion of the event's description into many of the departmental emails sent out to every member of Rice University's academic departments. These methods have, and will continue to be, utilized when recruiting new members and mentors into our CubeSat Project and SEDS Rice in general.

The "Owls in Space" Symposium was a major success in marketing to the Houston Community. In total, the Symposium had two articles written about it in the Houston Chronicle, one public release by Rice University, and one article written by the Rice Thresher. Furthermore, NASA Administrator Jim Bridenstine, President of Rice University David Leebron, Rice University, and NASA all tweeted or retweeted the event on Twitter or posted on Facebook or Instagram.

SEDS Rice plans to utilize its social media and marketing successes from the recent Owls in Space Symposium to further market its CubeSat to the Houston Community and the rest of the United States. With great connections at NASA's Johnson Space Center and close proximity to NanoRacks in Houston, the team is confident that it will be able to market its CubeSat and make the project very visible throughout the community. SEDS Rice aspires to show how Rice University is still the outstanding space sciences school that it was when President Kennedy gave the "We Choose to Go to the Moon Speech" in Rice Stadium and when Rice University created the world's first Space Sciences Department. With this vision in mind, SEDS Rice will be extremely visible in the Rice community and the Houston space community for many years.

6. TEAM DIVERSITY

The SEDS Chapter at Rice University contains both graduates and undergraduate students and is open for all students to join at Rice University. On the OwlSat Project team, there is a mix of undergraduates and graduate students as well. There are seven undergraduate students and three graduate students on the team. These graduate students are pursuing a combined Master's degree in Space Studies and Business Administration, a Ph.D. in Materials Science and Engineering, and a Master's Degree in Space Studies.

Of the undergraduate students who comprise the majority of the team, most are pursuing STEM degrees, particularly mechanical engineering. However, there are several team members who are studying the social sciences, with one sub-team lead pursuing a degree in economics and several team members and leaders pursuing degrees that include a business or arts component. Additionally, the Avionics Sub-Team lead is pursuing a degree in computer science and the overall OwlSat Team Leader is studying electrical engineering.

When interviewing for Sub-Team Leads, the OwlSat recruiting team recognized the value a diverse set of sub-team leads would bring to the team. With those considerations in mind, all four of the chosen sub-team leads represent commonly underrepresented minorities in STEM. Our group displays various backgrounds: an immigrant from Mexico, a first generation student, an international student from Turkey, and a woman in STEM.

This diverse leadership team allows for many different perspectives when attempting to solve design problems. This consequently provides us with many different design solutions and a greater probability of success.

7. TEAM MENTORS

The OwlSat Team of SEDS Rice is fortunate to have several outstanding Rice University Staff and members from industry as its mentors.

Dr. Stephen Bradshaw is a Physics and Astronomy Professor at Rice University who serves as the Associate Chair for that undergraduate program. His primary research is focused on developing a better understanding of heating mechanisms that occur in the solar corona and in the coronae of other Sun-like stars. Due to his expertise, Dr. Bradshaw will be contributing to the UV sensor payload development, deployment, and research. He will help the team map the data received from the UV sensors and explain its impact on aerospace environments and future satellite missions in the same orbit.

Dr. David Alexander is also a Physics and Astronomy Professor at Rice University who serves as the director of the Rice Space Institute and is SEDS Rice's sponsor. He performs research on solar physics, exoplanetary physics, and remote sensing capabilities. He also serves on the board of the American Astronautical Society. Dr.Alexander will contribute to all aspects of the project. Dr.Alexander will provide additional expertise in EUV sensor development and deployment. He can contribute to marketing, outreach, and engineering capability. Moreover, the Rice Space Institute will financially contribute to the project and fully backs all initiatives undertake by SEDS Rice.

Susanna Fragoso is a Senior Mechanical Engineer for Schlumberger and received a master's degree in aerospace engineering from Manchester University in 2008. She has extensive, real-world engineering design and project management experience and has helped our team focus on the most critical aspects of our CubeSat design. Due to Ms. Fragoso's expertise in real-world engineering design and management, she will be contributing to the systems integration, development, and testing of OwlSat.

Nick Espinosa is a Deputy Life Support Component Manager of the Exploration Extravehicular Mobility Unit (xEMU) with Jacobs Engineering. He received his bachelor's degree in aerospace engineering from the University of Texas Austin in 2002. Prior to joining industry, he served in the United States Army, where his group management skills were refined and he learned the importance of producing deliverables on an ordered time frame. Since Mr. Espinosa has a large amount of experience working with NASA as a contractor, he can contribute to delivering government regulatory documents and NanoRacks integration documents.

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APPENDIX

Figure 1: Number of satellites lost in connection with the March 13-14, 1989 solar flare [10]

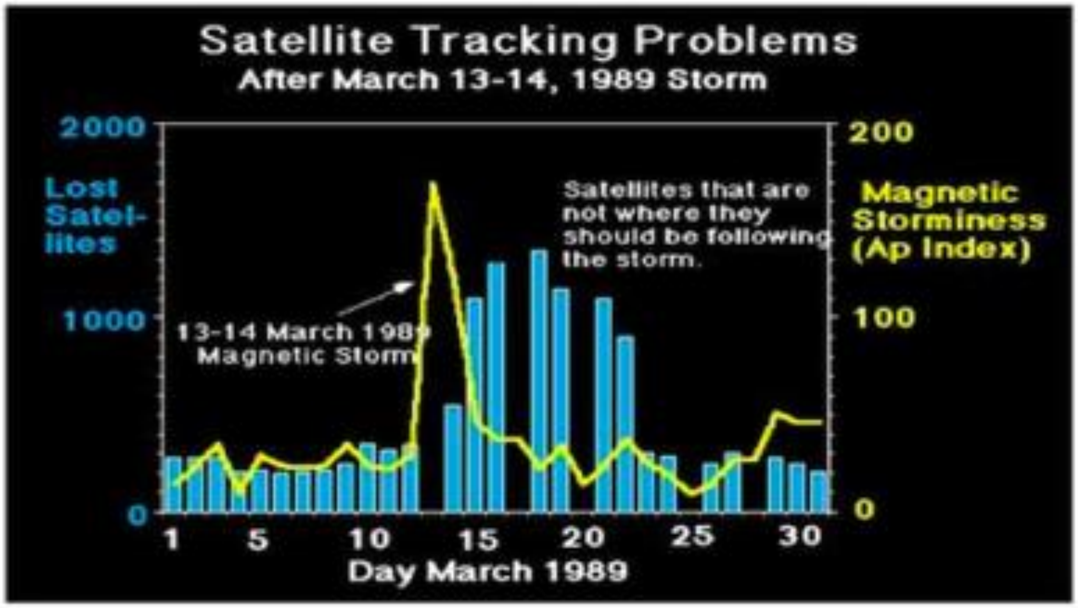


Figure 2: Thousands of manmade objects—95 % of them “space junk”— occupy low Earth orbit. Each black dot in this image shows either a functioning satellite, an inactive satellite, or a piece of debris. [8]

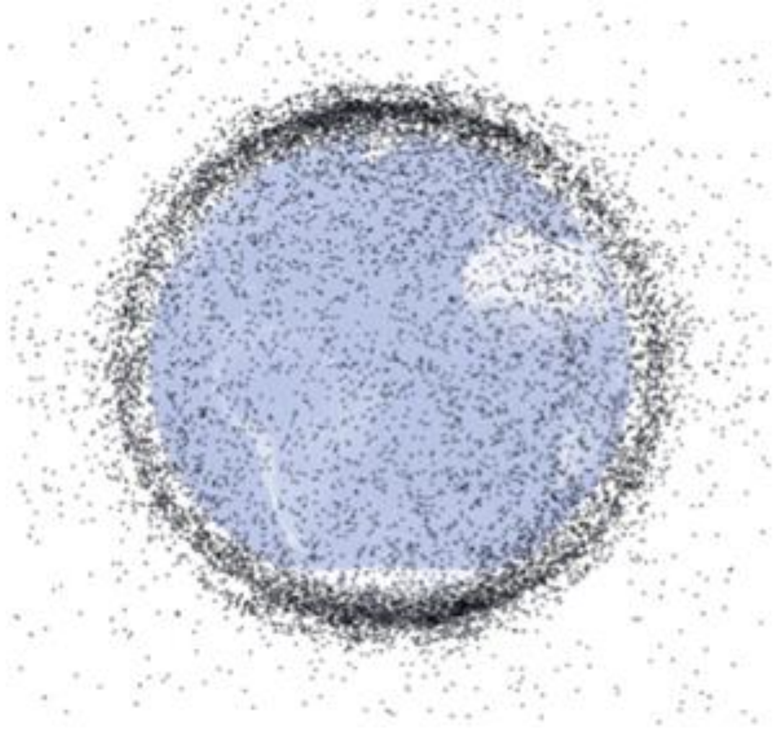


Figure 3: The effect of atmospheric drag on an orbiting satellite [1]

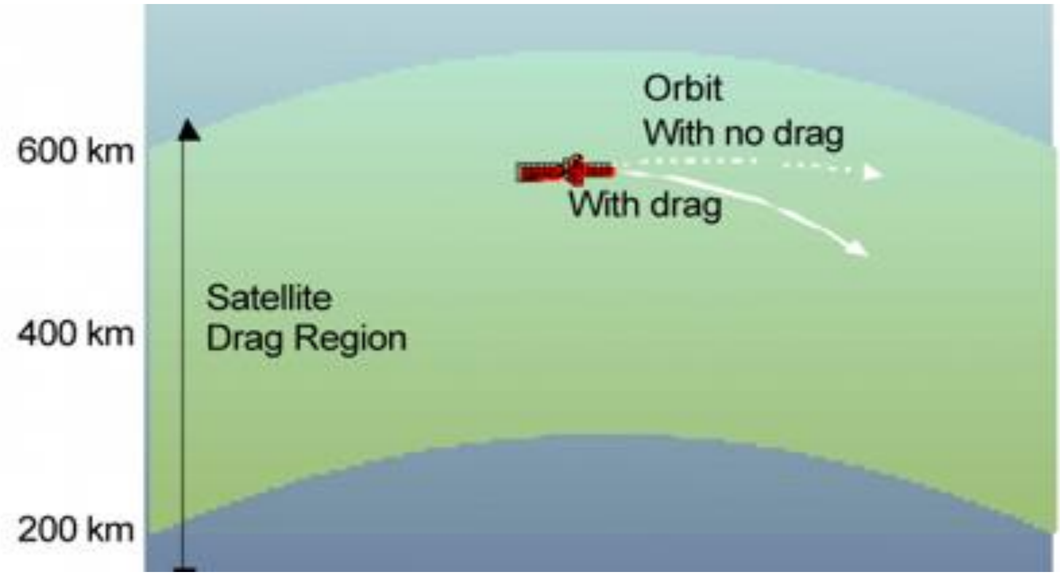


Figure 4: A side-facing view of the internal configuration of the proposed CubeSat

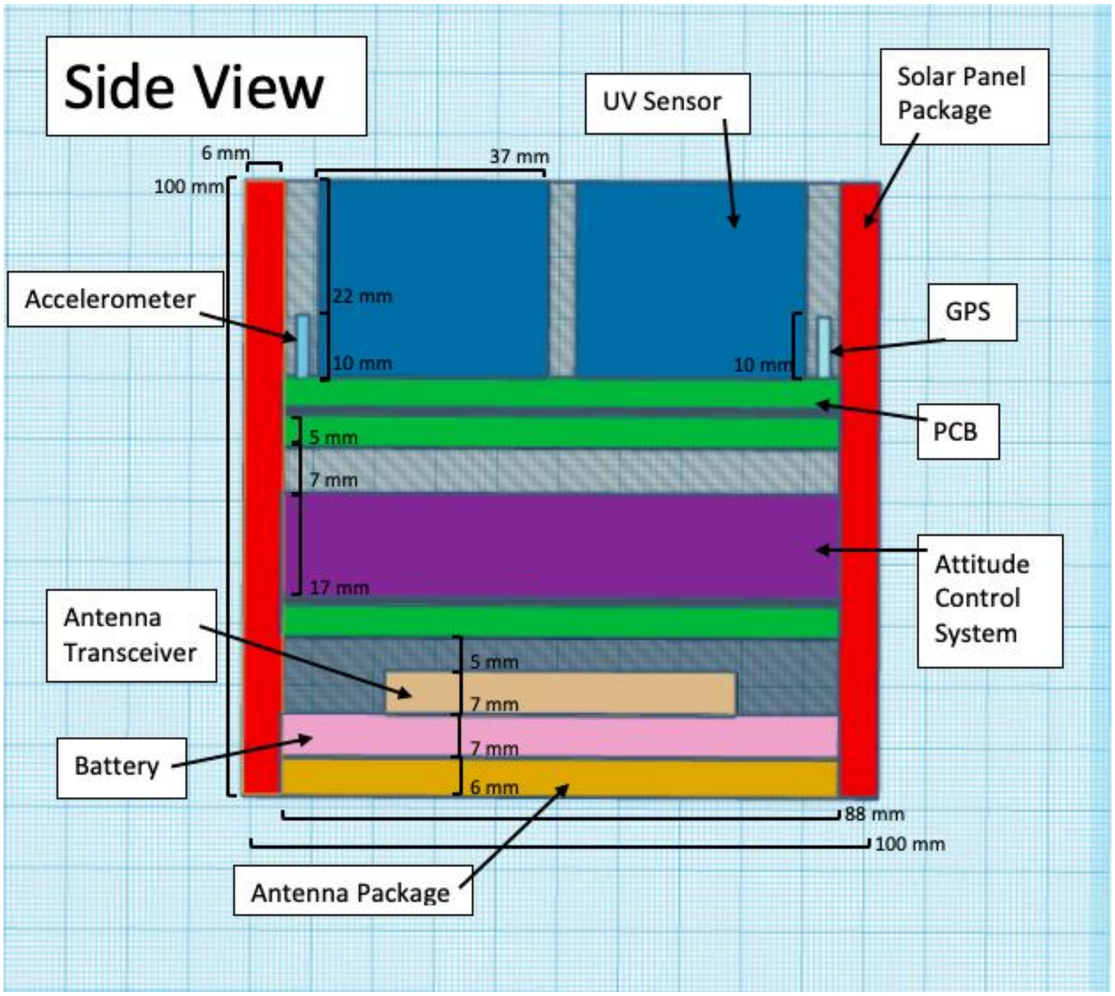


Figure 5: EnduroSat CubeSat Structure

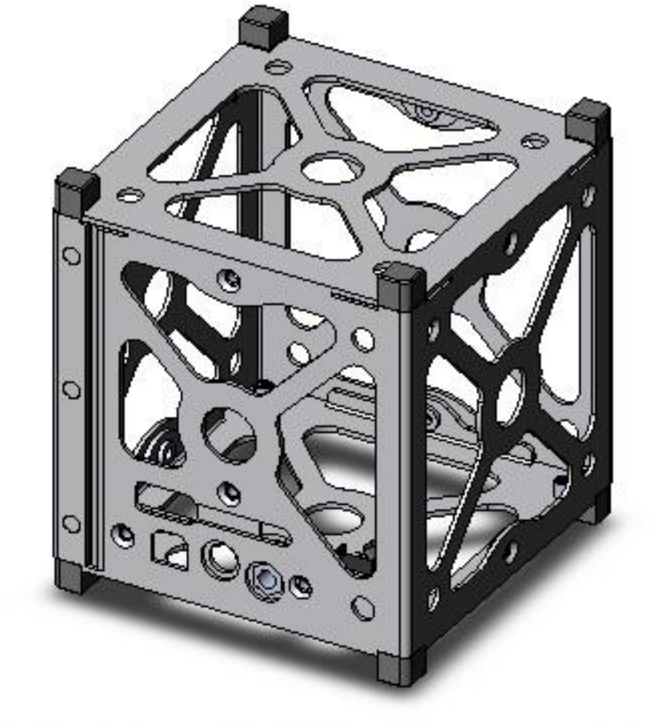


Figure 6: The 3-D printed prototype of the structure made by SEDS Rice

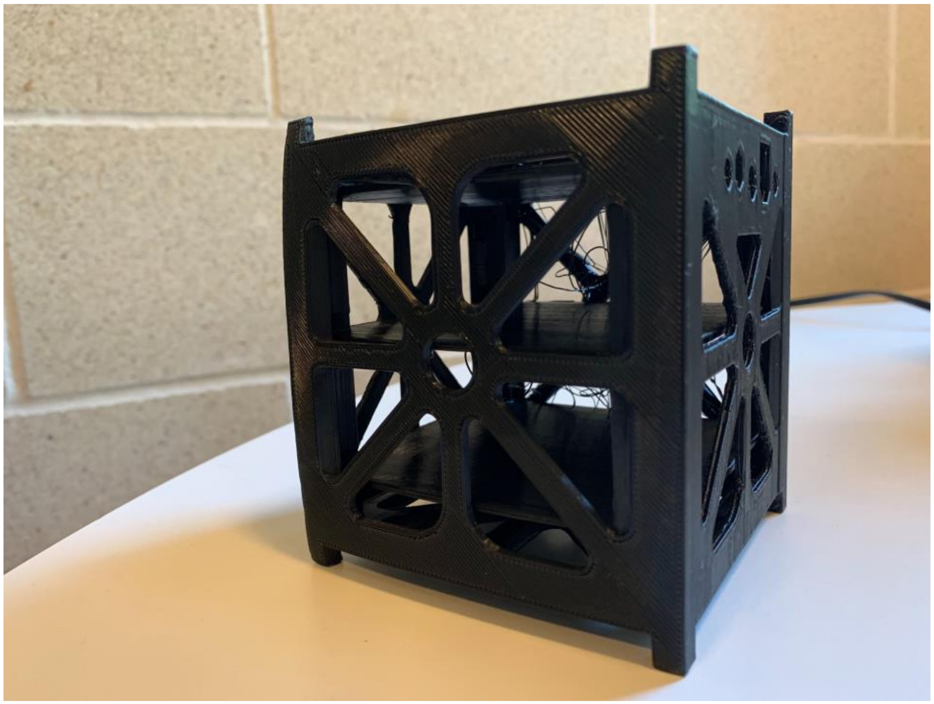


Figure 7: SolidWorks Model of CubeSat

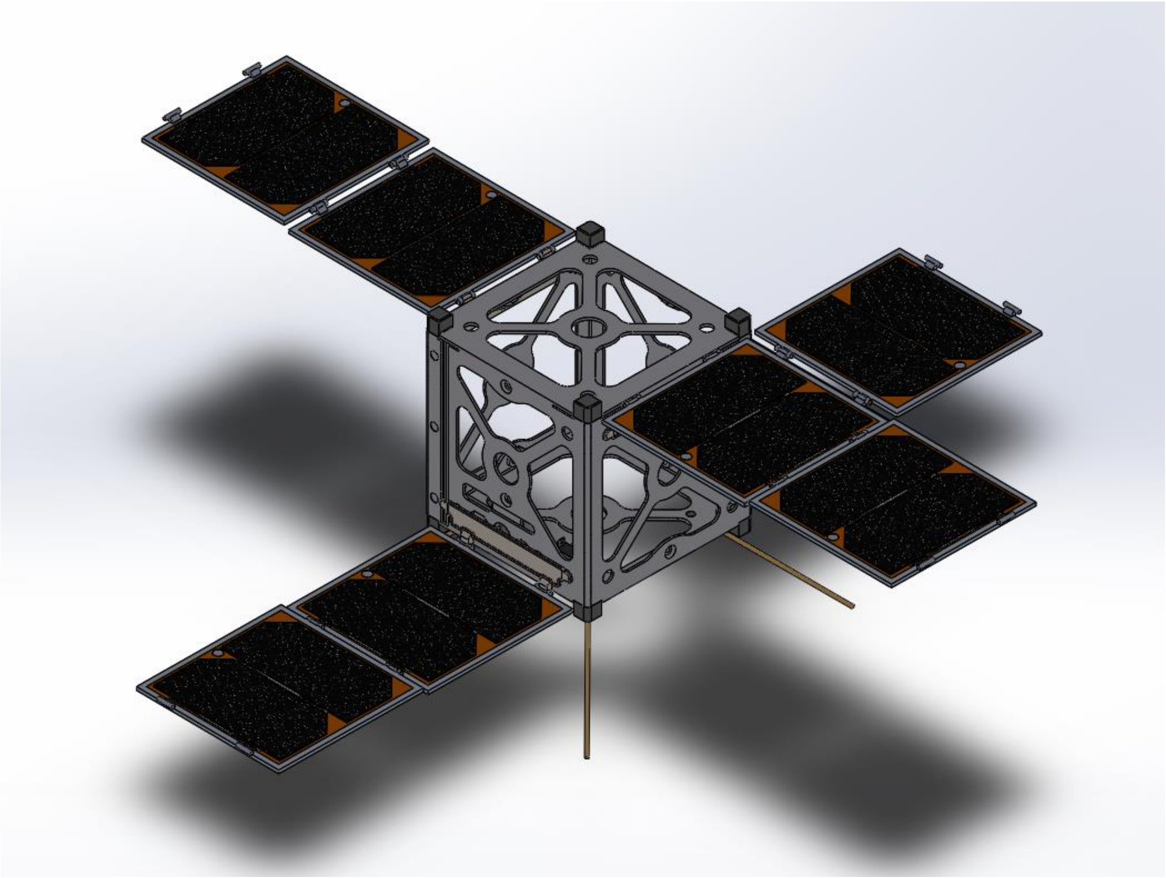


Figure 8: EUV radiation data flow chart

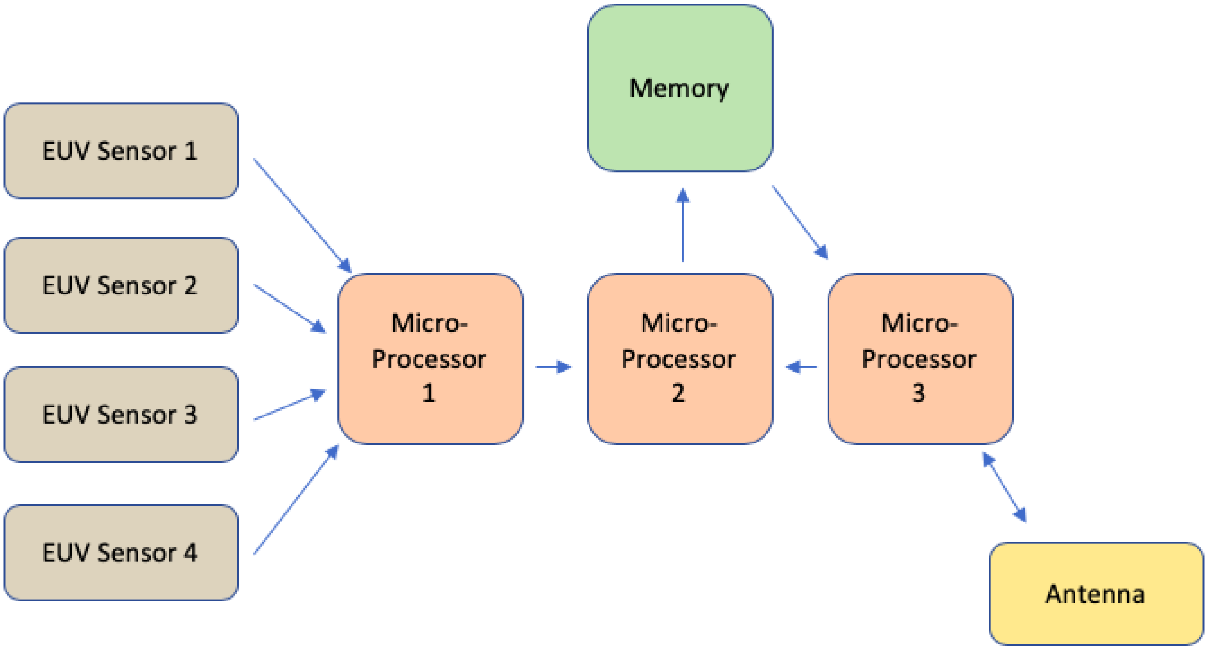


Figure 9: NASA's Vee Model of Engineering Design [6]

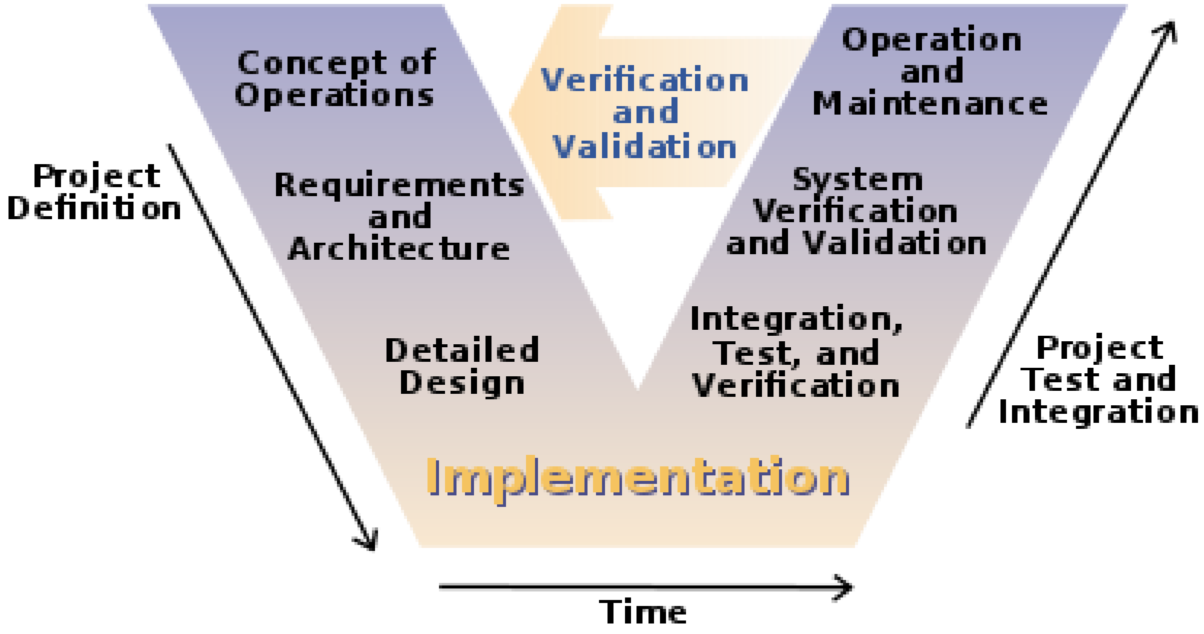


Figure 10: NASA's Spiral Process Model of Analytical Engineering Design Processes [6]

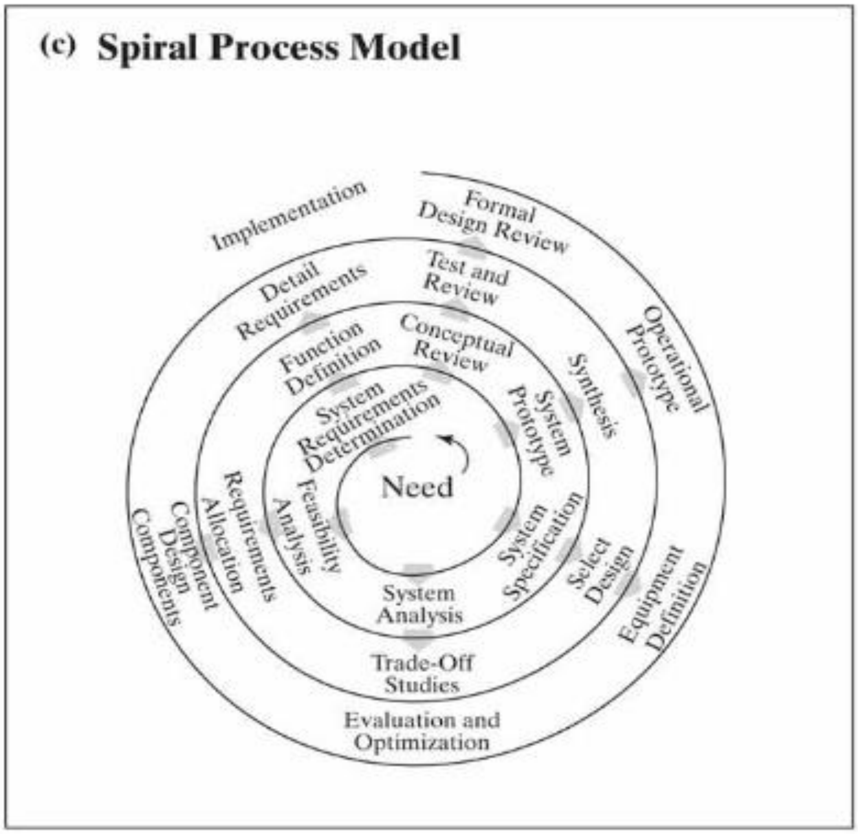
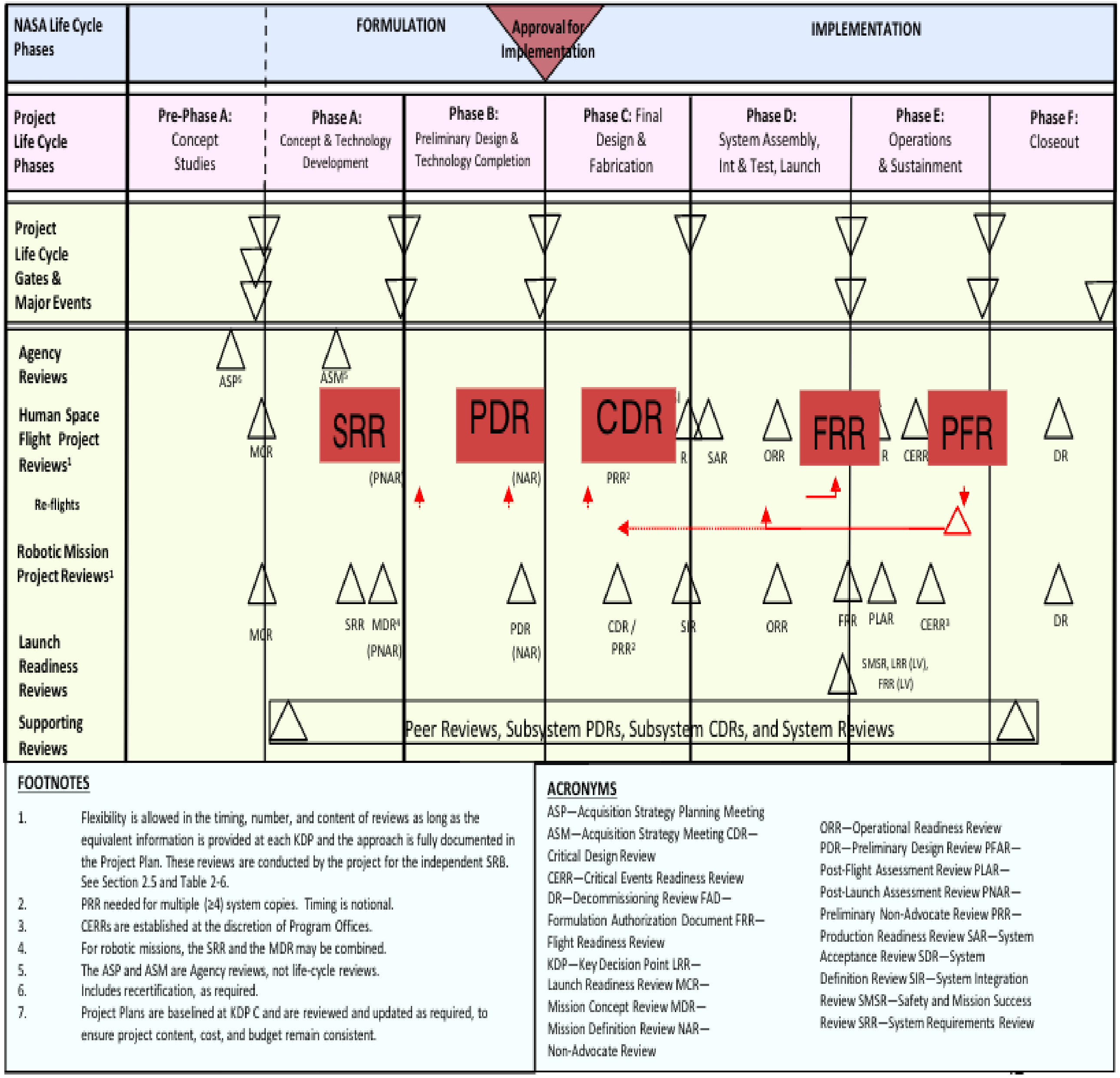


Figure 11: NASA's Program and Project Lifecycle Model [6]



FOOTNOTES

1. Flexibility is allowed in the timing, number, and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan. These reviews are conducted by the project for the independent SRB. See Section 2.5 and Table 2-6.
2. PRR needed for multiple (≥4) system copies. Timing is notional.
3. CERRs are established at the discretion of Program Offices.
4. For robotic missions, the SRR and the MDR may be combined.
5. The ASP and ASM are Agency reviews, not life-cycle reviews.
6. Includes recertification, as required.
7. Project Plans are baselined at KDP C and are reviewed and updated as required, to ensure project content, cost, and budget remain consistent.

ACRONYMS

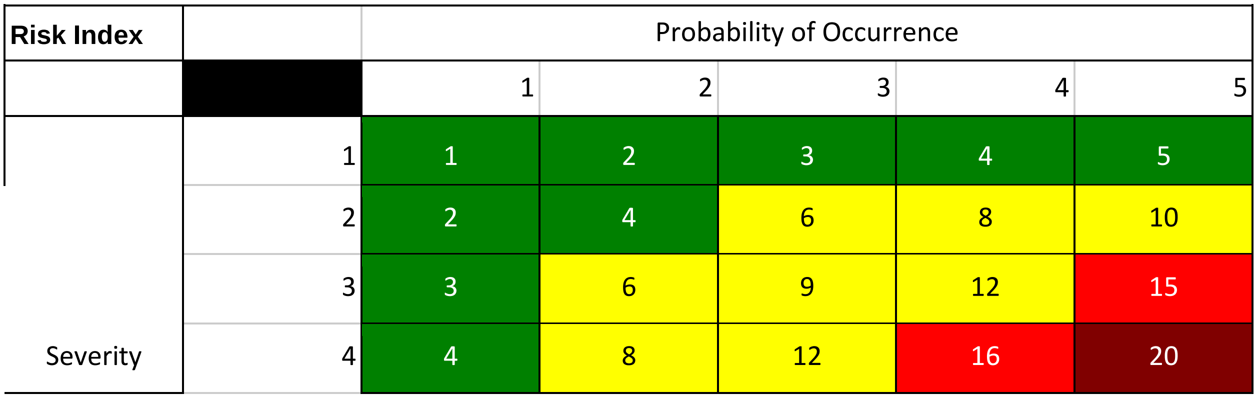
ASP—Acquisition Strategy Planning Meeting
ASM—Acquisition Strategy Meeting CDR—
Critical Design Review
CERR—Critical Events Readiness Review
DR—Decommissioning Review FAD—
Formulation Authorization Document FRR—
Flight Readiness Review
KDP—Key Decision Point LRR—
Launch Readiness Review MCR—
Mission Concept Review MDR—
Mission Definition Review NAR—
Non-Advocate Review
ORR—Operational Readiness Review
PDR—Preliminary Design Review PFAR—
Post-Flight Assessment Review PLAR—
Post-Launch Assessment Review PNAR—
Preliminary Non-Advocate Review PRR—
Production Readiness Review SAR—System
Acceptance Review SDR—System
Definition Review SIR—System Integration
Review SMSR—Safety and Mission Success
Review SRR—System Requirements Review

Figure 12: FMEA (Failure Modes and Effects Analysis) of SEDS Rice CubeSat

Failure Modes Effects and Analysis - OwlSat

Potential Failure Mode	Cause(s)	Effect(s)	Probability of Occurrence (1-5)	Severity (1-5)	Risk Index	Acceptable ?	Mitigation Plan
Solar panel fails to deploy	Antenna misalignment, panels get jammed	Lack of power to CubeSat	2	5	10	Yes	Testing deployment method of the solar panels as well as the antennae, have multiple panels to have a higher degree of redundancy
Antennae fail to deploy	Internal antenna fails to operate, antennae get jammed, ground station unable to upload to satellite	Data cannot be downloaded / uploaded from CubeSat	2	5	10	Yes	Testing internal antenna within the CubeSat structure to ensure no communication interference from the structure, have multiple antennae to have a higher degree of redundancy
EUV Sensor failure	Too much / too little power, bad calibration, faulty sensor	EUV data cannot be measured	1	3	3	Yes	Testing EUV sensors with multiple EUV wavelengths, have 4+ sensors to increase redundancy, can use UV data from public NASA data and combine with our GPS/accelerometer data
GPS failure	Antenna misalignment, Too much / too little power	CubeSat position cannot be measured	1	3	3	Yes	Testing GPS to ensure accuracy and ability to communicate with the antennae system on the CubeSat, can use position data from public NASA data which could be combined with our UV/accelerometer data
Sun Sensor(s) failure	Too much / too little power, bad calibration, faulty sensor	Sun cannot be located, may result in solar panel inefficiency	1	2	2	Yes	Testing sun sensors' functionality, have 2+ sun sensors to increase redundancy, passive attitude system will allow the satellite to still point generally towards the sun
Accelerometer failure	Too much / too little power, bad calibration, faulty	Cannot measure acceleration	1	3	3	Yes	Testing accelerometer before integration, having multiple accelerometers for

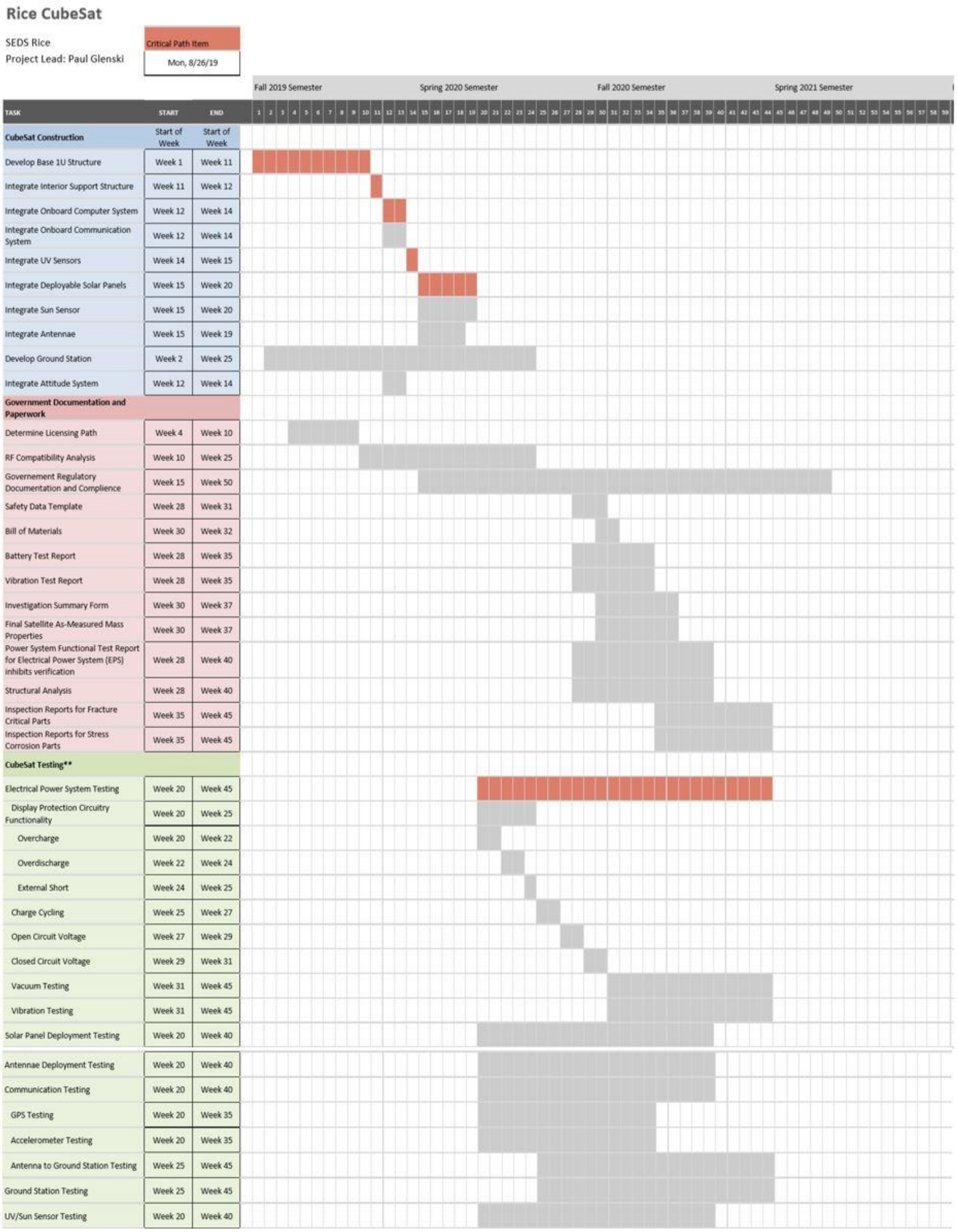
	accelerometer						redundancy, GPS can supplement acceleration measurements
Attitude system failure	Magnetic field interference, too much / too little power	CubeSat orientation cannot be controlled, UV/sun sensors and solar panels will not be pointing at the Sun, can lead to whole system shutdown	1	5	5	Yes	Extensive testing of the attitude system using simulations to mimic Low Earth Orbit
Communications failure	Antenna misalignment, too much / too little power	Data cannot be downloaded/uploaded from CubeSat	2	5	10	Yes	Testing of the communications system, having multiple antennas for different data transfers, testing of ground station
Losing track of satellite	Antenna misalignment, ground station misalignment	Data cannot be downloaded/uploaded from CubeSat	1	5	5	Yes	GPS system and antennas will be extensively tested, ground station communication with CubeSat will be extensively tested
Radiation degradation of CubeSat electronics	Materials not suited for LEO radiation levels	Electronics stop functioning	1	5	5	Yes	Coat all electronics with radiation protection, simulating electronics' life span when exposed to LEO levels of radiation
Radiation degradation of CubeSat structure	Materials not suited for LEO radiation levels	Structure will fail	1	5	5	Yes	All structural materials will be radiation-resistant, heat testing on structure, simulating structure's life span when exposed to LEO levels of radiation



Risk Index		Probability of Occurrence				
		1	2	3	4	5
	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
Severity	4	4	8	12	16	20

	5	5	10	15	20	25

<u>Figure 13:</u> SEDS Rice OwlSat Gantt Chart of Project Life



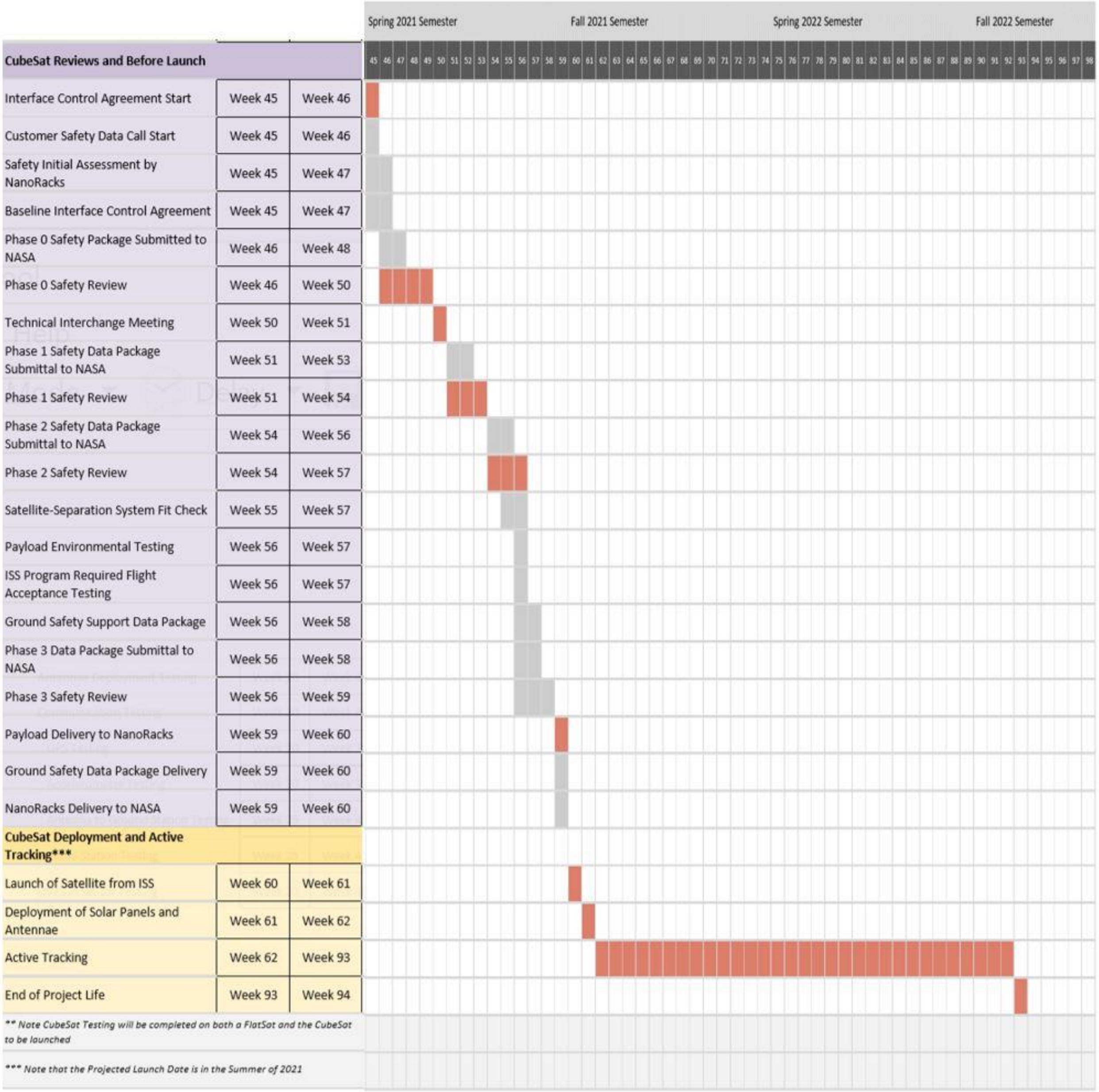
Rice CubeSat

SEDS Rice
Project Lead: Paul Glenski

Critical Path Item
Mon, 8/26/19

Fall 2019 Semester
Spring 2020 Semester
Fall 2020 Semester
Spring 2021 Semester

TASK	START	END
CubeSat Construction	Start of Week	Start of Week
Develop Base 1U Structure	Week 1	Week 11
Integrate Interior Support Structure	Week 11	Week 12
Integrate Onboard Computer System	Week 12	Week 14
Integrate Onboard Communication System	Week 12	Week 14
Integrate UV Sensors	Week 14	Week 15
Integrate Deployable Solar Panels	Week 15	Week 20
Integrate Sun Sensor	Week 15	Week 20
Integrate Antennae	Week 15	Week 19
Develop Ground Station	Week 2	Week 25
Integrate Attitude System	Week 12	Week 14
Government Documentation and Paperwork		
Determine Licensing Path	Week 4	Week 10
RF Compatibility Analysis	Week 10	Week 25
Governement Regulatory Documentation and Complience	Week 15	Week 50
Safety Data Template	Week 28	Week 31
Bill of Materials	Week 30	Week 32
Battery Test Report	Week 28	Week 35
Vibration Test Report	Week 28	Week 35
Investigation Summary Form	Week 30	Week 37
Final Satellite As-Measured Mass Properties	Week 30	Week 37
Power System Functional Test Report for Electrical Power System (EPS) inhibits verification	Week 28	Week 40
Structural Analysis	Week 28	Week 40
Inspection Reports for Fracture Critical Parts	Week 35	Week 45
Inspection Reports for Stress Corrosion Parts	Week 35	Week 45
CubeSat Testing**		
Electrical Power System Testing	Week 20	Week 45
Display Protection Circuitry Functionality	Week 20	Week 25
Overcharge	Week 20	Week 22
Overdischarge	Week 22	Week 24
External Short	Week 24	Week 25
Charge Cycling	Week 25	Week 27
Open Circuit Voltage	Week 27	Week 29
Closed Circuit Voltage	Week 29	Week 31
Vacuum Testing	Week 31	Week 45
Vibration Testing	Week 31	Week 45
Solar Panel Deployment Testing	Week 20	Week 40
Antennae Deployment Testing	Week 20	Week 40
Communication Testing	Week 20	Week 40
GPS Testing	Week 20	Week 35
Accelerometer Testing	Week 20	Week 35
Antenna to Ground Station Testing	Week 25	Week 45
Ground Station Testing	Week 25	Week 45
UV/Sun Sensor Testing	Week 20	Week 40



CubeSat Reviews and Before Launch		
Interface Control Agreement Start	Week 45	Week 46
Customer Safety Data Call Start	Week 45	Week 46
Safety Initial Assessment by NanoRacks	Week 45	Week 47
Baseline Interface Control Agreement	Week 45	Week 47
Phase 0 Safety Package Submitted to NASA	Week 46	Week 48
Phase 0 Safety Review	Week 46	Week 50
Technical Interchange Meeting	Week 50	Week 51
Phase 1 Safety Data Package Submittal to NASA	Week 51	Week 53
Phase 1 Safety Review	Week 51	Week 54
Phase 2 Safety Data Package Submittal to NASA	Week 54	Week 56
Phase 2 Safety Review	Week 54	Week 57
Satellite-Separation System Fit Check	Week 55	Week 57
Payload Environmental Testing	Week 56	Week 57
ISS Program Required Flight Acceptance Testing	Week 56	Week 57
Ground Safety Support Data Package	Week 56	Week 58
Phase 3 Data Package Submittal to NASA	Week 56	Week 58
Phase 3 Safety Review	Week 56	Week 59
Payload Delivery to NanoRacks	Week 59	Week 60
Ground Safety Data Package Delivery	Week 59	Week 60
NanoRacks Delivery to NASA	Week 59	Week 60
CubeSat Deployment and Active Tracking***		
Launch of Satellite from ISS	Week 60	Week 61
Deployment of Solar Panels and Antennae	Week 61	Week 62
Active Tracking	Week 62	Week 93
End of Project Life	Week 93	Week 94

*** Note CubeSat Testing will be completed on both a FlatSat and the CubeSat to be launched*

**** Note that the Projected Launch Date is in the Summer of 2021*

Figure 14: Forces that Act on Object in Earth Orbit[15]

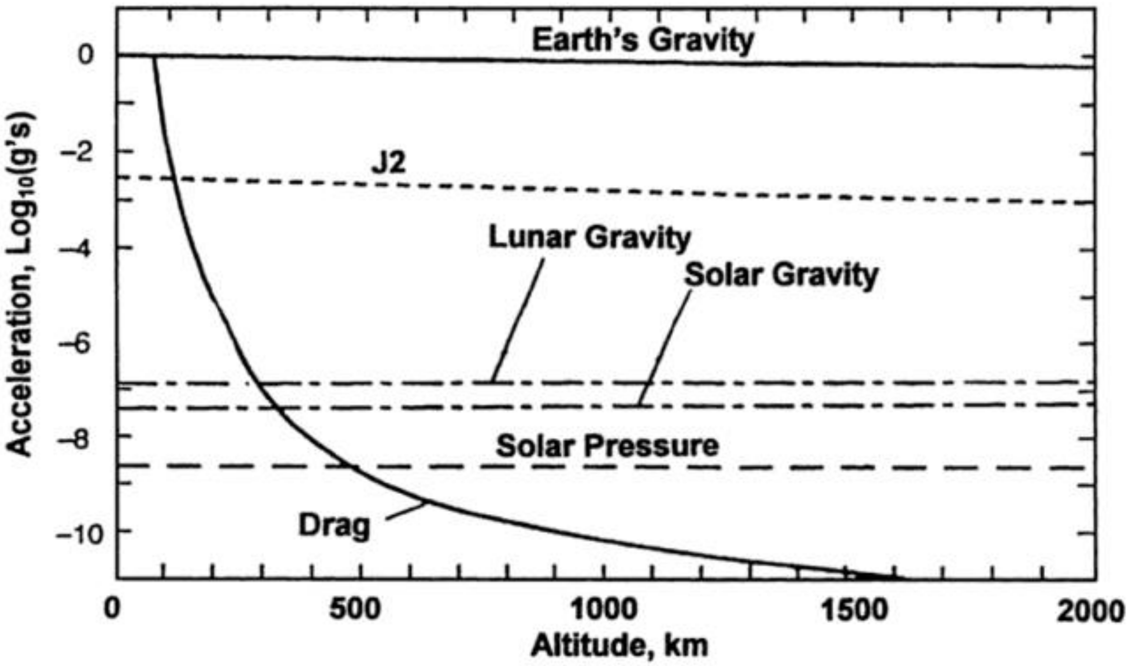


Figure 15: Lifetime of a Given Object with Respect to Given F10.7 index[16]

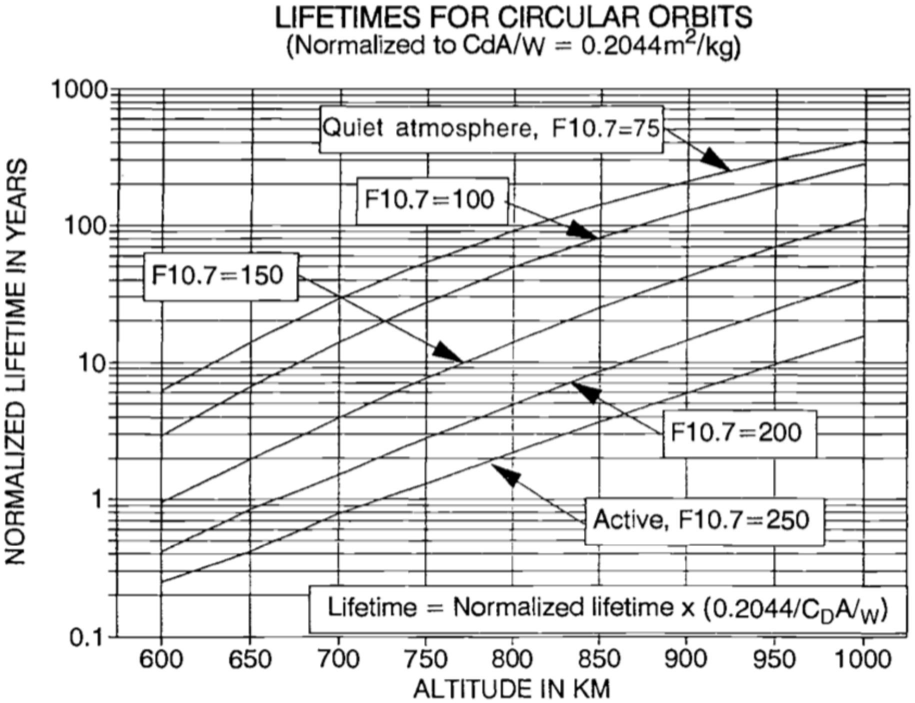


Figure 16: Drag Coefficient Change with Respect to Altitude and Shape[18]

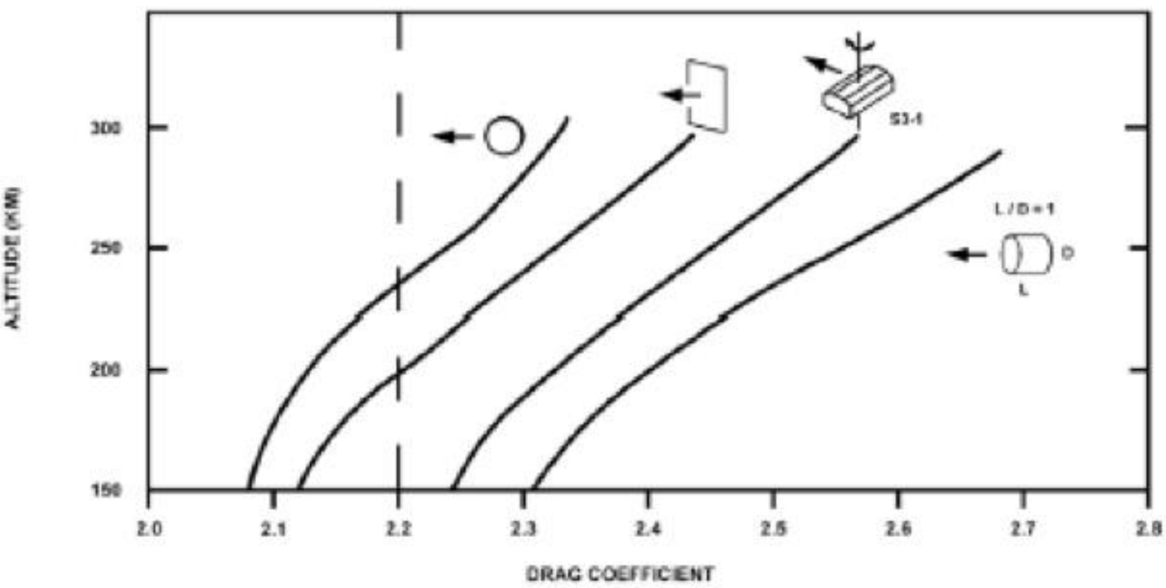
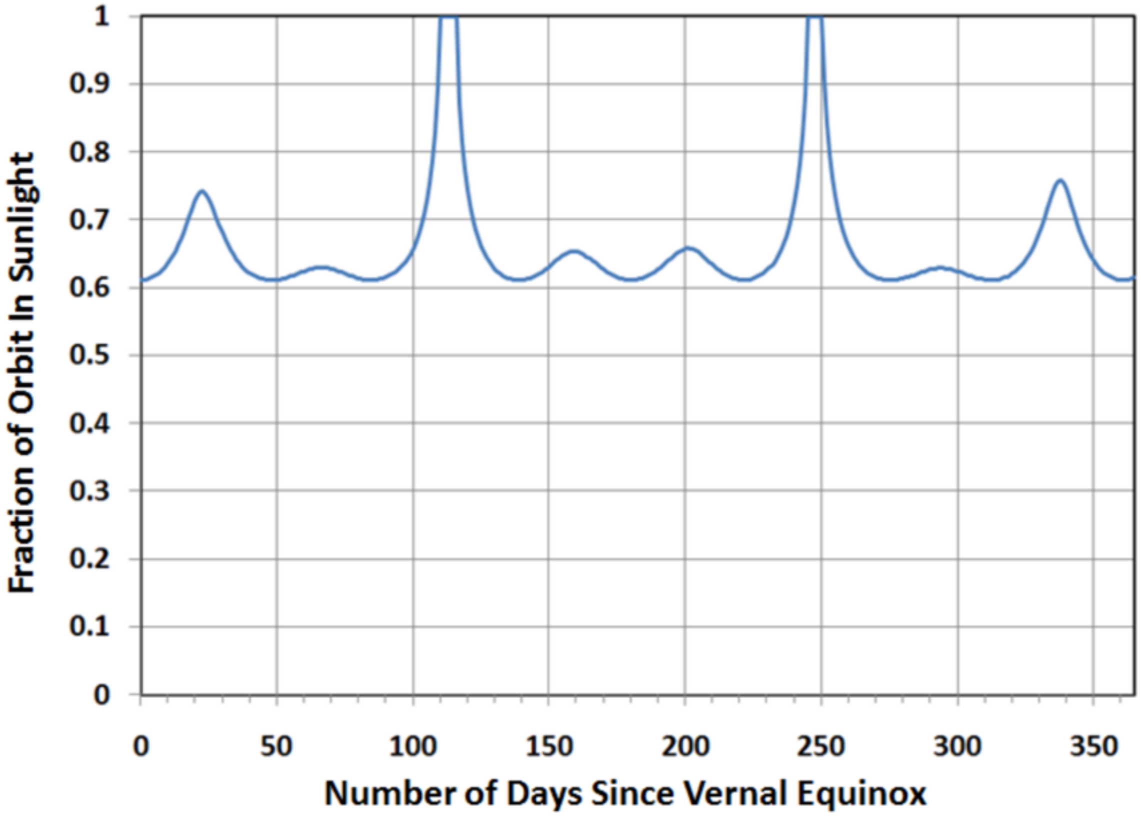


Figure 17: Fraction of Orbit in Sunlight During a Year on ISS Orbit



LETTERS OF COMMITMENT

Letter of Mentor Commitment

I, David Alexander fully commit myself to serve as a mentor for Rice University's Chapter of the Students for the Exploration and Development of Space Organization in its quest to design, construct, launch, and monitor a 1U CubeSat.

Signature:

Date: 4/27/19

Letter of Mentor Commitment

I, Stephen Bradshaw, fully commit myself to serve as a mentor for Rice University's Chapter of the Students for the Exploration and Development of Space Organization in its quest to design, construct, launch, and monitor a 1U CubeSat.

Signature: SJ Bradshaw

Date: 04/27/2019

Letter of Mentor Commitment

I, Nicolas Espinosa, fully commit myself to serve as a mentor for Rice University's Chapter of the Students for the Exploration and Development of Space Organization in its quest to design, construct, launch, and monitor a 1U CubeSat.

Signature:

Date: 4/27/2019

Letter of Mentor Commitment

I, Susanna Fragoso, fully commit myself to serve as a mentor for Rice University's Chapter of the Students for the Exploration and Development of Space Organization in its quest to design, construct, launch, and monitor a 1U CubeSat.

Signature: SFRAGOSO.

Date: 4/27/2019