Proceedings of the 2020 Annual General Donald R. Keith Memorial Capstone Conference
West Point, New York, USA
April 30, 2020
A Regional Conference of the Society for Industrial and Systems Engineering

EECSat: CubeSat Development

Sean Coyle, Roger Burk, and Alexander Kedrowitsch

Department of Systems Engineering
United States Military Academy, West Point, NY

Corresponding Author: sean.coyle@westpoint.edu

Author Note: Cadets Joseph Benden, Joshua Cox, Logan Marcsisin, Ethan McInturff, Sean Moriarity, and Charlie Wassaf are all 4th years students at the United States Military Academy who have immensely contributed to the success of the EECSat project. Each cadet is from the Computer Science, Information Technology, or Electrical Engineering Department. Although each cadet listed is not a coauthor to this paper, their work has driven much of the results found in this paper. Dr. Roger Burk, an Associate Professor in the Department of Systems Engineering, and Major Alexander Kedrowitsch, an Assistant Professor of Computer Science in the EECS Department, are the Capstone team's advisors and provided instrumental guidance and assistance to the cadet team in furthering the project.

Abstract: The EECSat, originally dubbed the Black Knight Sat, is a class of inexpensive and versatile nanosatellites called CubeSats that have the potential to further the United States and the United States Army's dominance in space. This system is driven by inexpensive and commercially available parts with the intent to allow the United States Army to possess the capability to launch highly capable and specialized payloads to space to complete an array of missions. Equipped with a Raspberry Pi, a small commercially available computer, the EECSat has the potential to conduct onboard computations in space for a fraction of the cost compared to other large-scale satellites making the EECSat unique. Additionally, the EECSat is being developed to be a bus driven design. The bus driven design, another unique attribute of the EECSat, will serve as the constraints and requirements for future payloads in order to pioneer a standardized satellite platform. The EECSat project focused extensively on stakeholder analysis, research, problem definition, requirement generation, interdisciplinary collaboration, and documentation of the novel idea called EECSat.

Keywords: EECSat, CubeSat, Raspberry Pi, Scrum, Sprint

1. Introduction

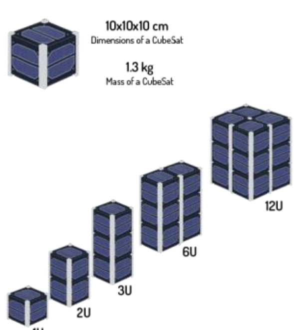

Figure 1. CubeSat Sizes and Configuration

In 1999, California Polytech developed a standardized class of nanosatellites called CubeSats. A class of satellite constructed with an arrangement of 10cm x 10cm x 10cm cubes not exceeding 1.3 kg in mass called units or U (Puig-Suari et al., 2000). These cubes are combined to build CubeSats of different sizes and configurations to conduct a wide range of missions (Figure 1). Since California Polytech's development of the CubeSat, teams across the world have constructed many variants of the CubeSat with unique payload functionalities. In 2016, the company Planet developed a CubeSat titled DOVE that monitors the health of the Earth through using a network of CubeSat called a constellation, advanced sensors, and cameras capable of transmitting live updates of conditions around the world (Dvaraj et al., 2017). In 2018, NASA launched the MarCo CubeSat that functioned in a supporting communication role for a larger mission conducting experiments on Mars (Klesh and Krajewski, 2015). Finally, by 2021, M-ARGO will be sent into deep space to identify the composition of asteroids for future space mining endeavors ("A&G Volume 59 Issue 5, Full Issue," 2018). CubeSats have surged in popularity over their larger scale satellite counterparts because of their smaller, lighter, and more inexpensive nature. These qualities increase accessibility and enable space development for academic purposes. The EECSat team has recognized the US Army's desire to further its role in the space domain and is working to achieve this by developing a novel inexpensive bus driven CubeSat.

This paper presents the EECSat team's pioneering work at the United States Military Academy in developing a CubeSat by presenting the EECSat team's problem definition, solution design, decision making, and solution implementation process. Furthermore, this paper will present the agile planning process called Scrum used to organize and manage the EECSat team. This paper will be viewed at a higher level enabling for limited technical knowledge in computer science, information technology, electrical engineering, space, and physics.

2. The EECSat

2.1 Overview of the EECSat

The EECSat is a break-away from the Black Knight Sat project. Black Knight Sat was a multi-year project focused on developing a CubeSat for the US Army. However, due to finding only a limited amount of information on Black Knight Sat's research the EECSat team had to start at the project at the beginning. This enabled the EECSat team to rebrand and properly define the EECSat problem and vision. As a team and communicating with the project owner, the EECSat team defined the problem - The United States Army needs an inexpensive and versatile satellite bus capable of being fitted with a variety of payload types that can be rapidly manufactured and deployed to conduct a wide range of mission sets and to support the United States' Operationally Responsive Space initiative. The Operationally Responsive Space initiative to design and develop low-cost, rapid-reaction payloads, buses, space lift and launch-control methods to meet joint military operational requirements for on-demand space support and regeneration ("Operationally Responsive Space (ORS)"). The EECSat team has set out to develop a CubeSat that meets the needs of each of the stakeholders.

2.2 The United States Interest in the Space Domain

With the growth of technology, newer domains such as the space domain have proven their relevance in supporting the battlefield and keeping leaders informed. Satellites located in orbit serve a multitude of functions to include communication and research. These satellites play a vital role in connecting, growing and sustaining nations' economies and way of life, especially the US. Protecting these assets are essential in maintaining the civilized way of life we foster today. The US has recognized the importance of protecting these assets and our way of life and is seeking to further its objective by establishing the Space Force ("U.S. Space Force Fact Sheet", 2020). The space domain is complicated and layered. The US needs a way to maintain peace and order in a region that was not readily available in early space flight history. The need for rapid response to threats and the need to get information communicated rapidly is essential. The US needs a means of rapidly deploying satellites as a means to meet this end ("U.S. Space Force Fact Sheet", 2020).

3. Product Development

3.1 Scrum Organizational Hierarchy

The EECSat project followed a prescribed agile process specific to software development called Scrum. The Scrum process was prescribed by the Department of Electrical Engineering and Computer Science at the United States Military Academy. The EECSat team was not permitted to use another format for project management, therefore it used this process of management and planning for two semesters. Scrum is designed for teams smaller in size, typically ranging in sizes between five to nine people. Members of the team possess titles to include the Product Owner, the Scrum Master and the Technical Experts (Cohn). The Product Owner is the key stakeholder of the project and is responsible for establishing the requirements and constraints of the product. The Scrum Master's role is to give direction to the team and ensure the team is productive. The Scrum Master acts as a liaison between the Product Owner, outside teams, and the technical experts. The technical experts are those individuals who are physically working on the software and electronics to make the Product Owner's vision a reality. Together, the Product Owner, the Scrum Master, and the Technical Experts define and develop a product.

3.2 Scrum Process

The Scrum process begins with developing a product backlog (Figure 2). The product backlog is a list of all the desired features that the product owner and the team vision the product to possess. The product backlog serves as a reminder to the team of the product owner's vision for different work cycles called Sprints. Sprints are two to four-week work cycles where tasks are completed to try to accomplish a specific focus. At the beginning of each Sprint meeting, a daily scrum meeting starts the workday. The daily scrum meeting enables each member to state what they have accomplished the last Sprint meeting, what they are going to accomplish that day, and any issues they are facing. At the end of a Sprint, a review presentation takes place. This is a presentation on all that was accomplished during the Sprint and all that has not been accomplished during that Sprint. Additionally, it serves to inform those who are interested in the focus of the future Sprint. Following the Sprint Review is the retrospection review, where the team conducts an after-action report, discussing what went well and what could have gone better (Cohn). The Scrum process was facilitated using an online application titled "Trello." Trello is an online application designed specifically for Scrum planning, enabling each member of the EECSat team to log hours and add tasks through one singular application.

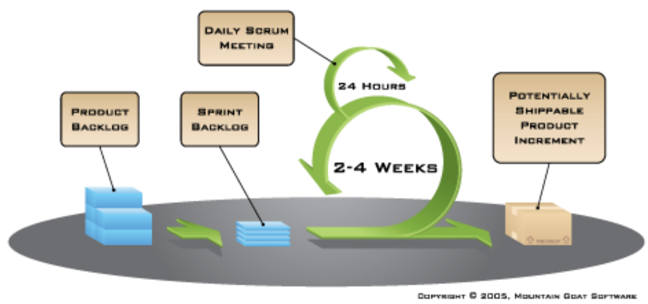

Figure 2. Scrum Process

3.3 Scrum and Systems Engineering

The Scrum management process was a unique learning experience. Typically, Scrum is used by software engineers. At the United States Military Academy through the Department of Systems Engineering the V-model, waterfall planning method, and the Systems Decision Process is used for the systems engineering approach in problem-solving and planning. Unlike these models, the expectation of Scrum was for each member to become immensely involved at all levels of the project, technical and managerial, as well as expect management to be extraordinarily open to changes. Unlike the waterfall method, V-model and the Systems Decision Process, the Scrum process is designed to adapt to rapid change. Scrum expects that a project can easily take an alternate approach to achieve a solution due to coding's nature. Adapting to this model was challenging because the system decision process cycled every week and there was no set date on completing a product. Although timelines were set, they served only as the motivation for the team to try and accomplish that task. However, due to novel coding and trying to integrate unlike hardware and software timelines went longer or shorter than expected. Nevertheless, the Scrum model accounted for this and allowed for future sprints to change objectives and adapt to any changes.

3.4 Research and Data Acquisition

When initiating the EECSat project a wide range and in-depth literature review was conducted to improve each member's understanding of CubeSats, space, Raspberry Pi, satellite design and achievements of previous Black Knight CubeSats and CubeSats at different academies. A library of literature was developed, and a literature review was conducted. The EECSat team reached out to the United States Air Force Academy (USAFA) to learn about processes and concerns our counterparts have developed and overcame. The EECSat team entered with a limited base knowledge of CubeSats and space. Through the EECSat's team's initial literature review they were better able to define the problem.

A part of data acquisition was done through experimentation. The EECSat is a unique concept that uses unconventional hardware and software that have conventionally not been tested in the harsh conditions of space. This led to the need to attain data by conducted self-led experiments. In order to gain an understanding of the hardware, the EECSat team was able to conduct a thermal chamber test. This enabled the EECSat team to study how certain hardware functioned under extreme temperatures. In the future, several tests will be conducted to include a vacuum chamber test, thermal-vacuum chamber test, vibration testing, and a weather balloon launch validation test. Each of these tests will be used to represent the environment of space to the best of their abilities, while also acting as the genesis of procedure design.

4. System Design

After conducting stakeholder analysis with the project owner, the EECSat during operation will maintain a low-earth orbit (LEO). A LEO orbit is between 300 km-1600 km. The desired projected orbit will pass-over West Point, New York antenna's range located on top of Bartlett Hall. The EECSat is expected to make several passes a day maintaining contact with Bartlett Hall's antenna for what is predicted as a maximum of 15 minutes long. It is desired that there be two-way communication between EECSat and the ground station. The frequency range used for communication will be UHF. UHF will enable data to be transmitted through Earth's dense atmosphere to both the ground station and the CubeSat. Altogether, the EECSat's desired life expectancy in orbit is six months. If EECSat is to remain operational for six months, it will serve as a proof of concept for where CubeSats can take space-capabilities of the US Army.

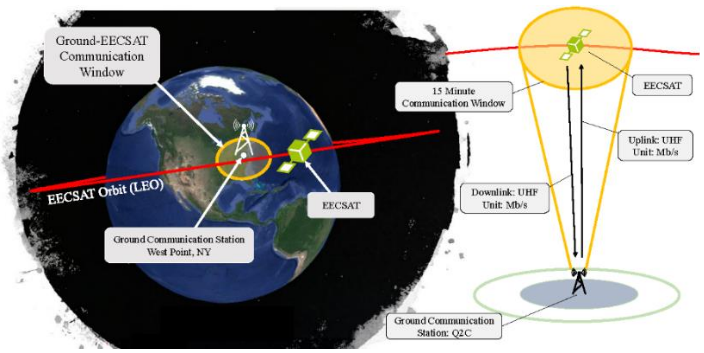

Figure 3. EECSat OV-1 Diagram

4.1 EECSat Subsystems

Within the span of the year, EECSat has determined that several sub-systems are required when constructing a CubeSat (Figure 4-2). Of these sub-systems, five sub-systems are the current EECSat focus given each of the team member's expertise. These five systems comprise: (1) Communication, (2) Command & Data-Handling, (3) Electrical Power Subsystem, (4) Attitude Determination & Control System, (5) and Payload. The thermal subsystem and the structural subsystem were not in the scope of this year's research, as a future team composed of mechanical engineers would investigate.

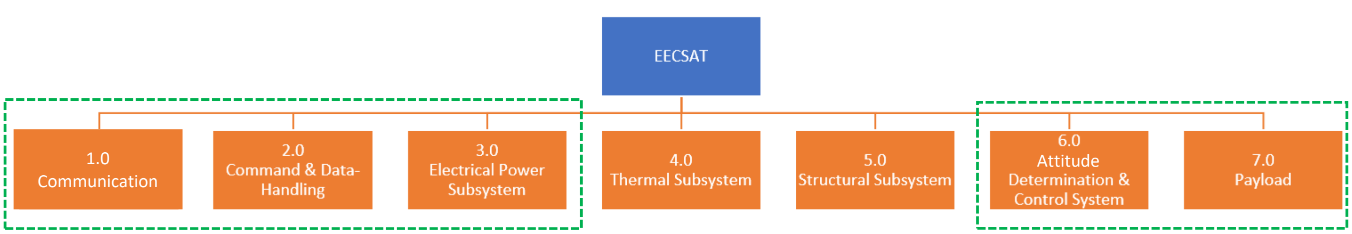

Figure 4. Functional Hierarchy of the EECSat

4.2 Communication

The Communication subsystem is responsible for transmitting and receiving information from the ground station. Communicating telemetry data, payload data, EECSat commands, and updates are essential processes that the communication subsystem is responsible for carrying out. In accomplishing this task, the project manager has required that the EECSat be equipped with an HamShield 1.0. The HamShield 1.0 is a VHF and UHF radio transceiver capable of sending and receiving digital packets of information to the ground station and the EECSat respectively. The HamShield is an open-source hardware and software system that enables collaboration with teams and individuals who develop modifications for the HamShield.

4.3 Command & Data-Handling

The Command and Data-Handling system is responsible for managing data on the CubeSat, carrying out commands sent from the ground station, managing onboard CubeSat operations, and routinely monitoring the health of the CubeSat. The component provided by the EECSat project manager to be the onboard Command and Data-Handling computer is the Raspberry Pi. The Raspberry Pi is a lightweight, versatile, and simple computer capable of completing the needed onboard calculations during flight. Additionally, the Raspberry Pi is an open source hardware and software enabling the EECSat team to collaborate and retrieve code for the Raspberry Pi's operation from online code repositories such as GitHub.

4.4 Electrical Power Subsystem

The Electrical Power Subsystem (EPS) has proven to be a challenging subsystem within the EECSat system. The EPS is responsible for powering the EECSat's hardware including any payload attached to the EECSat as well as monitoring the operation of the bus. An understanding of the EECSat's power needs, an understanding of the efficiency of power generation methods available, and an understanding of how current power reservoirs behave in space is necessary before the EECSat is launched into space. Initially, the EECSat project owner sought for the EECSat to be equipped with a GOMSpace NanoPower P31u electrical power supply system. However, poor documentation and the EECSat's inability to understand the complicated and layered software led to the EECSat team to come to the decision to abandon the GOMSpace component and leave the future decision of space hardened technology to future teams.

4.5 Attitude Determination & Control System

The Attitude Determination and Control system as the name implies conducts two functions. The first function is to determine the attitude of the EECSat. Attitude determination is conducted several ways by either surveying the Earth's horizon, observing visible constellations, using the sun or by using the Earth's magnetosphere. The second function is to control the attitude of the CubeSat. This is controlled by multiple means to include propulsion systems, momentum stabilizers, gravity-gradient stabilizers, or magnetic torquer rods. The EECSat team recruited the assistance of the United States Military Academy Physics and Nuclear Engineering (PANE) department by working with a team developing a magnet torquer satellite stabilizer system. The magnet torquer stabilizer operates by sensing the Earth's magnetosphere, inputting data into an algorithm, and output that information as a magnetic field from a magnetorquer orienting the EECSat.

4.6 Payload

The Attitude Determination and Control system being produced by the PANE Department is EECSat's first payload. EECSat has been working with the PANE Department to outsource a system essential to the EECSat to alleviate the burden of work on each team member and to recruit the assistance of a more experienced team. EECSat and the PANE Department have been working together, developing new standards of collaboration for future payloads. In the future, EECSat will be working with other teams developing payloads, growing the space-capabilities of the EECSat to meet the Operationally Responsive Space initiative.

5. Integration Testing

Unfortunately, due to unforeseen circumstances with the outbreak of the COVID-19 pandemic this year's expected integration test will be postponed indefinitely. After one and a half semesters, the EECSat team was planning on conducted an integration test using a weather balloon, a payload, and the United States Military Academy's ground station radio. The weather balloon served to simulate an orbit in which that the ground station would track the weather balloon's flight. The payload, consisting of a beacon, radio antenna, Raspberry Pi, Hamshield, camera, and necessary infrastructure would enable the payload to transmit data to and from the ground station and weather balloon. The camera would take still images every five minutes and a trained model on the Raspberry Pi would classify that image (i.e. harbor, baseball field, etc.). The classification would then be transmitted through the hamshield out of an antenna to the ground station. The classification would be received at the ground station and be compared to the flight in a post-mission review. As a result of the pandemic, the EECSat team has been focusing on the documentation of procedures and thinking for future EECSat teams.

6. Future Research and Conclusion

The EECSat team has been working diligently and learning every day. The nature of space is complex and understanding how to launch an object into space is challenging. However, the EECSat team is establishing the foundation for successors of the EECSat project at the United States Military Academy. Through establishing procedures and documenting research the EECSat team is ensuring the longevity of the EECSat project. Within the groups of future teams, the introduction of new domain experts to include mechanical engineers will enable the exploration of the thermal subsystem and the structural subsystem. Soon, the EECSat team will be conducting thermal-vacuum testing, vacuum testing, vibration testing, and a weather balloon launch. Each test is used to mimic the conditions of space to learn how commercially available parts operate in space conditions. The EECSat project is a multiyear project with the end goal of launching a CubeSat into orbit. It will require the effort of many experts and will require heavy collaboration. The EECSat project is a wonderful example of what people can accomplish through working together and collaborating to accomplish a common goal.

7. References

A Basic Guide to Nanosatellites. (2019, September 5). Retrieved March 3, 2020, from https://alen.space/basic-guide-nanosatellites/

"A&G Volume 59 Issue 5, Full Issue." *Astronomy & Geophysics*, vol. 59, no. ASTROG, Oct. 2018, doi:10.1093/astrogeo/aty237.

Andrew K., & Krajewski, J. (2015). MarCO: CubeSats to Mars in 2016. *Digital Commons*, Retrieved from: https://digitalcommons.usu.edu/smallsat/2015/all2015/16/

Cohn, M. (n.d.). Scrum Overview: Agile Software Development. Retrieved March 3, 2020, from: https://www.mountaingoatsoftware.com/agile/scrum/resources/overview

Puig-Suari, J. et al. (2000). *CubeSat Developments at Cal Poly: The Standard Deployer and PolySat*. Retrieved from: https://doi.org/10.1117/12.406645

Dvaraj, K. et al. (2017). Dove High Speed Downlink System. *Digital Commons*, pp. 1–9, 2017, Retrieved from: https://digitalcommons.usu.edu/smallsat/2017/TS7AdvTech2/8/

Operationally Responsive Space (ORS). (n.d.). Retrieved March 5, 2020, from: http://acqnotes.com/acqnote/careerfields/operationally-responsive-space-ors

U.S. Space Force Fact Sheet. (2n.d., March 31). Retrieved April 5, 2020, from: https://www.spaceforce.mil/About-Us/Fact-Sheet