Mission SeaLion Integrated CubeSat Design Approach to Accommodate Mission Critical Payloads in a Low Earth Orbit

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ABSTRACT

In the dynamic landscape of space applications, CubeSats have emerged as pivotal platforms for scientific research, technological innovation, and educational endeavors. As the demand for small form factor satellites continues to rise, there is an increasingly critical need for a holistic and rapid development approach in the design of CubeSat structures and payloads. This research focuses on Old Dominion University's (ODU) integrated design approach of accommodating mission critical payloads in its second space mission, nicknamed Mission SeaLion. The 3U CubeSat class satellite mission is a partnership between ODU, the U.S. Coast Guard Academy (USCGA), and the U.S. Air Force Institute of Technology (AFIT). The goal of Mission SeaLion is to validate on-orbit – (i) an impedance probe, (ii) a commercial-off-the-shelf UHF Doppler payload, and (iii) a deployable composite structure (DeCS) experiment. Mission SeaLion is scheduled to be launched aboard Firefly Aerospace's small launch vehicle, Alpha, out of Vandenburg Space Force Base in Fall 2024. In development for Mission SeaLion is a novel multi-function drag enhancement and measurement system, which is encapsulated in the DeCS experiment. The integrated design approach to Mission SeaLion's satellite bus is characterized by its three primary payloads and the need to accommodate a 3-tier communication system including a software defined UHF radio as a Doppler payload, which is aimed at extending the U.S. Coast Guard's reception of distress calls beyond visual line of sight within the arctic circle. This paper describes the integrated design approach as well as the comprehensive framework utilized to seamlessly integrate peripherals and subsystems within mission space, power, and weight constraints. A significant section of the paper is dedicated to the design of a novel deployment mechanism as a technology enabler for NASA's in-space assembly and manufacturing program. The paper also describes in detail the design of a sheet-metal based CubeSat structure to accommodate a host of peripherals on the surface. As part of the discussion on the CubeSat structure, the paper also provides an insight into the design of custom configurations of surface mounted and deployable solar panels to ensure adequate power generation despite the absence of an attitude control system

INTRODUCTION

In the dynamic landscape of space applications, CubeSats [1-3] have emerged as pivotal platforms for scientific research, technological innovation, and educational endeavors. As the demand for small form factor satellites continues to rise, there is an increasingly critical need for a holistic and rapid development approach in the design of CubeSat structures and payloads. Old Dominion University's (ODU's) second space mission, nicknamed Mission SeaLion, is a 3U CubeSat class space mission. The goal of Mission SeaLion, which is a partnership between ODU, the U.S. Coast Guard Academy (USCGA), and the U.S. Air Force Institute of Technology (AFIT), is to validate on orbit, three space technology payloads:

a) an impedance probe.
b) a commercial-off-the-shelf UHF Doppler payload.
c) a deployable composite structure experiment.

Mission SeaLion is scheduled to be launched on board the Firefly Aerospace's small launch vehicle, Alpha, out of Vandenberg Space Force Base in Fall 2024. The deployable composite structure (DeCS) experiment, which is a custom payload designed and developed by ODU, is the encapsulation of the novel multi-function drag enhancement and measurement system (mDEMS). The Mission SeaLion CubeSat and the 3U CubeSat under development at Virginia Tech will be deployed through the XTERRA dispenser (Figure 1).

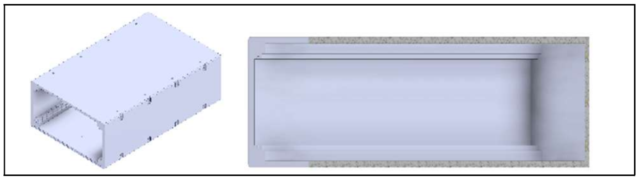

Figure 1: XTERRA Simplified Dispenser and its Internal Envelope

Both the teams will collaborate to show design integration of their respective space payloads in a single 3U CubeSat Mission. While much of the CubeSat bus development is based on commercial-of-the-shelf (COTS) systems, certain systems of the Mission SeaLion, including the ODU payload and the IP, are custom designed and developed. A 3-tier communication system, which is developed based on COTS systems, is critical for demonstrating the success of Mission SeaLion.

NASA’S IN-SPACE SERVICING, ASSEMBLY, AND MANUFACTURING AND THE DECS

NASA's ISAM program [4-6] is aimed at developing advanced technologies and capabilities to enable on-orbit assembly and maintenance of space structures. The program aims to significantly reduce the cost and complexity of future space missions by enabling the assembly of large space structures in orbit, and the repair and maintenance of existing spacecraft. The DeCS payload elaborately discussed in References [7-9] is an effort to make progress towards ISAM. There may be over 170 million pieces of debris smaller than 1cm, ~670,000 pieces with size ranging from 1cm-10cm and ~29,000 particles larger than ~10 cm [10-11]. Orbital debris may result in cascading impacts, ultimately leading to domino effect or the Kessler Syndrome [12]. The solutions elaborately discussed in Reference [13] are envisioned and researched to limit space debris and equip PNMSats with autonomous drag enhancing systems.

Deployable Mechanism Features

A compact, reliable, and flexible (based on mission requirements) deployable mechanism is designed for a wide range of applications and small satellite classes. Following are the essential features of DeCS:

a) Passive or active deployment
b) Volume approx. 1U (105 x 118 x 118 mm3)
c) Deploy monostable or bistable booms.
d) Modular (plug and play)

DeCS Deployment Sequence

The functional block diagram shown in Figure 2 describes the DeCS payload architecture. The description includes the functions of each component, the downstream functions that are affected when a component fails, the backups and redundancies that can be designed into the system to increase reliability in the event of failures occurring.

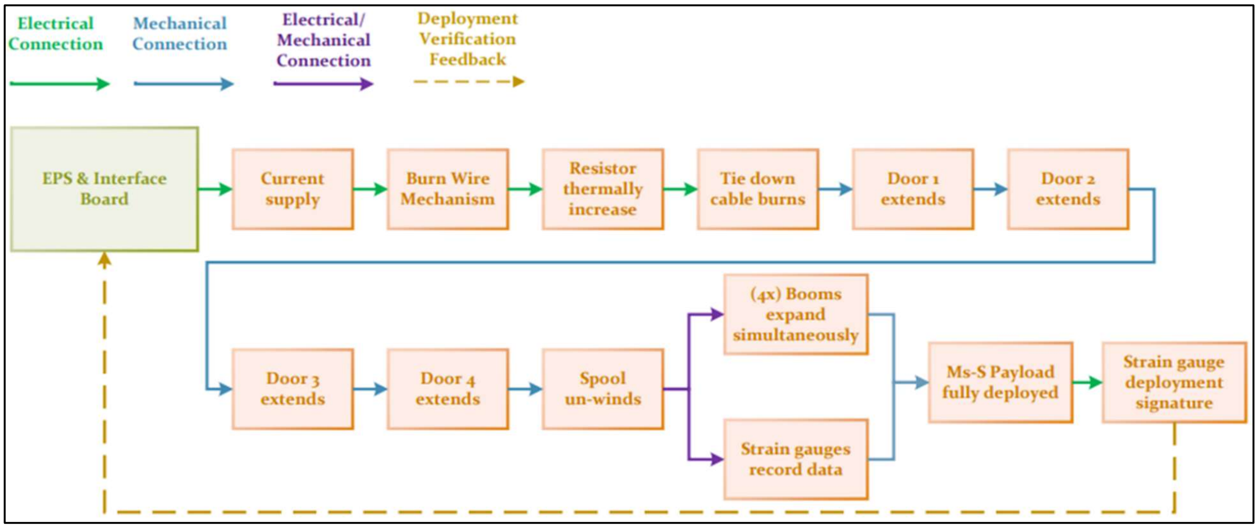

Figure 2: DeCS Functional Block Diagram

Components of the DeCS Design

The mechanical components diagram shown in Figure 3 demonstrates a logical arrangement of individual parts in the assembly. It also provides the assembly sequence for the whole mechanism. Enhanced versions of the diagram of the components can be used for the failure analysis. The structure with two side panels and two support panels, which is shown in Figure 4, is designed to serve as the foundation of the DeCS mechanism. The side panels include tab design, which act like rails during deployment. The center of the deployment structure is a spool that supported the ultra-thin, high-stiffness (UTHS) composite booms [8], which are guided by the two flanges (Figure 5). The spool is supported by the two bearings that are connected to the structure of the deployment mechanism. This design choice ensures that the UTHS composite boom could be deployed with precision and accuracy, while also remaining stable and secure throughout its operation. For smooth and effortless rotation during the deployment operation, the bearings are used to support the spool. The diameter of the spool is designed to be 50 mm, while the height of the spool without the flange is 64mm. This dimensions were derived from the critical bending radius of UTHS boom under pure bending [9].

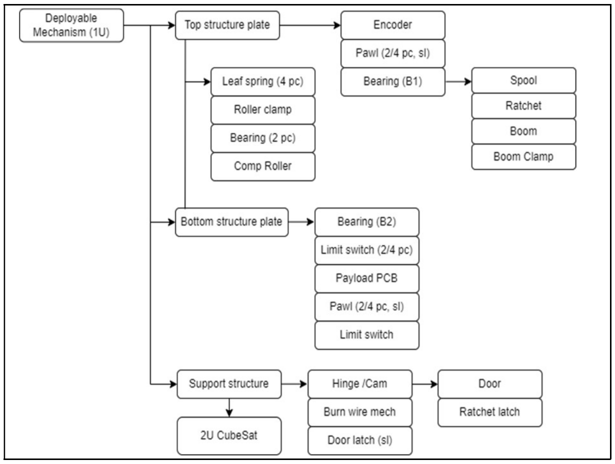

Figure 3: DeCS Component Block Diagram

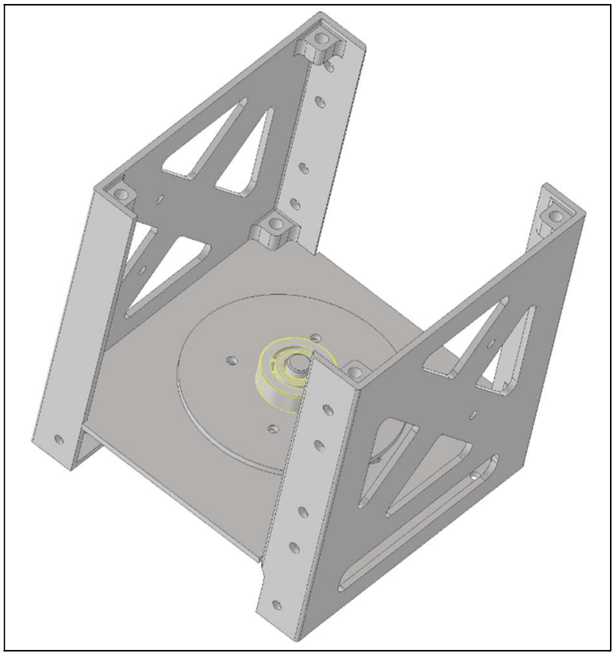

Figure 4: Deployable Mechanism Structure

To prevent blossoming during deployment, a unique curved design of the spring (Figure 6) is utilized to compress the UTHS composite boom onto the spool. This spring is designed to provide approximately linear force upon deformation, which was necessary for ensuring that the UTHS boom is compressed evenly and without blossoming under stored condition [14]. At the tip of the spring, a roller is included to provide frictionless contact with the UTHS boom. The spring is connected in a cantilever configuration with one side bolted to the side panel of the structure.

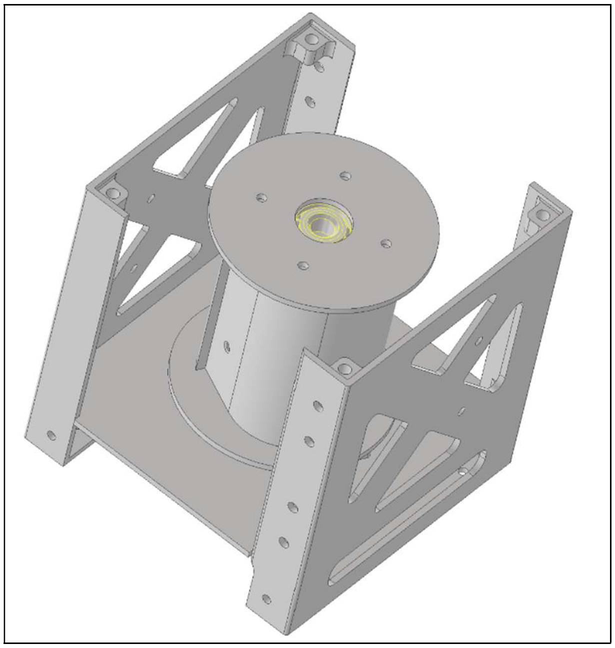

Figure 5: Center Spool Assembly with the Deployer Structure

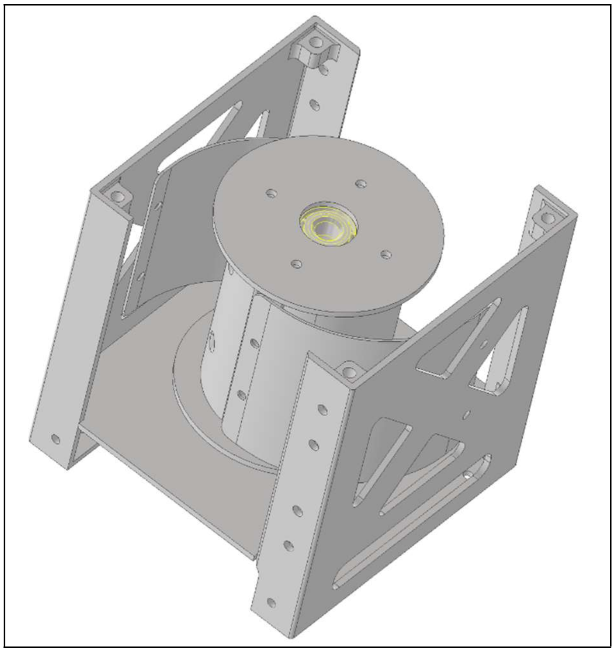

Figure 6: Curved Spring with Compression Rollers

The deployment mechanism is secured by two doors as shown in Figure 7, which are designed to keep the UTHS composite booms stowed. These doors could be triggered by a burn wire when latched or simply released when constrained by the dispenser. The burn wire provision for the latch is to ensure that the doors are released only when the deployment process is initiated. Upon burn wire activation or when jettisoned from the dispenser, the doors would open to allow the spool to uncoil and deploy the UTHS composite booms. This design choice is to ensure that the deployment mechanism does not accidentally deploy the UTHS composite booms.

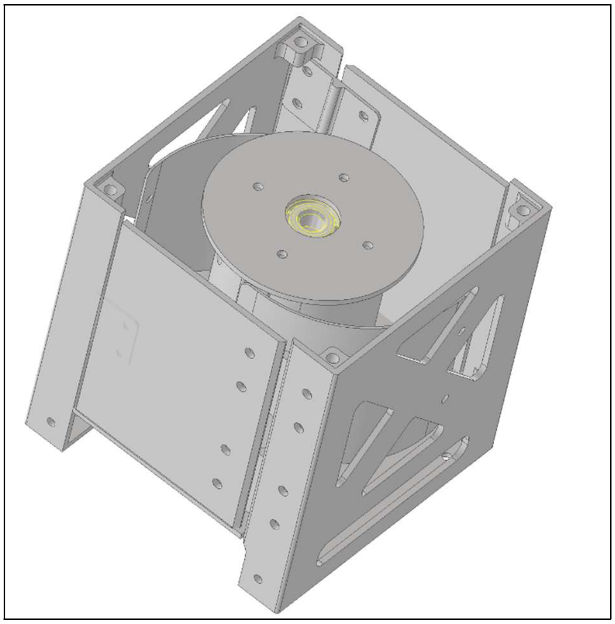

Figure 7: Door Assembly with Deployer Structure

Although not part of the current design, as the DeCS is a passive deployable mechanism, a burn-wire controlled spring-loaded lever can be used to synchronize the door deployment with unwrapping of the booms. Upon triggering the burn wire, lever is release the doors while holding the spool using two pawls. Once the doors reached 30°, the pawls were released ensuring the UTHS composite booms are deployed without the blossoming effect. This approach prevents adding any additional tip load during the deployment to the booms which can overpower the spring compression force and lead to blossoming.

This intricate design ensures that the deployment mechanism operates seamlessly and reliably, allowing for the successful deployment of the UTHS composite booms. The UTHS composite boom deployment mechanism is designed to hold a 2-meter-long boom and can be used for active deployment. It includes a feature for boom retraction in case of active deployment, which allows for the safe and efficient retraction of the boom when needed. This feature ensures that the mechanism could be used in a variety of deployment scenarios, making it a versatile and valuable tool for a range of applications. Overall, the UTHS composite boom deployment mechanism (Figure 9) is a sophisticated and well-designed system that enables the successful deployment of the UTHS composite boom, while also providing additional features for enhanced functionality and flexibility.

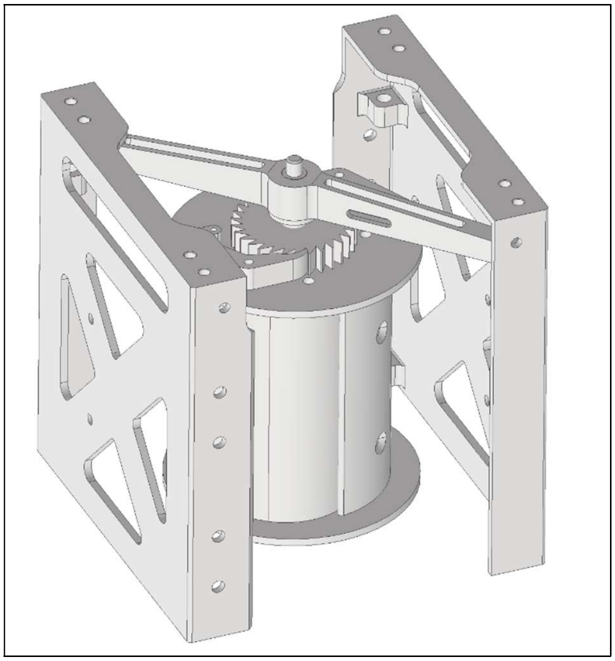

Figure 8: Pawl and Ratchet Assembly with Spring Loaded Lever

The DeCS is a low technology readiness level (TRL) design for pre-formed composite structures that can be wrapped around a cylinder and welded together to create a rigid, high-cross-section structure. This innovative approach to manufacturing space structures may be adopted for applications such as large-area solar arrays or antenna structures. The high packaging volume of these pre-formed structures also enables efficient space transportation. The DeCS design approach aligns with NASA's ISAM program, which aims to develop technologies and capabilities to enable in-space manufacturing, assembly, and servicing of large structures and systems. The ISAM program seeks to leverage the unique environment of space, including microgravity, vacuum, and extreme temperature conditions, to enable manufacturing and assembly processes that are not possible on Earth.

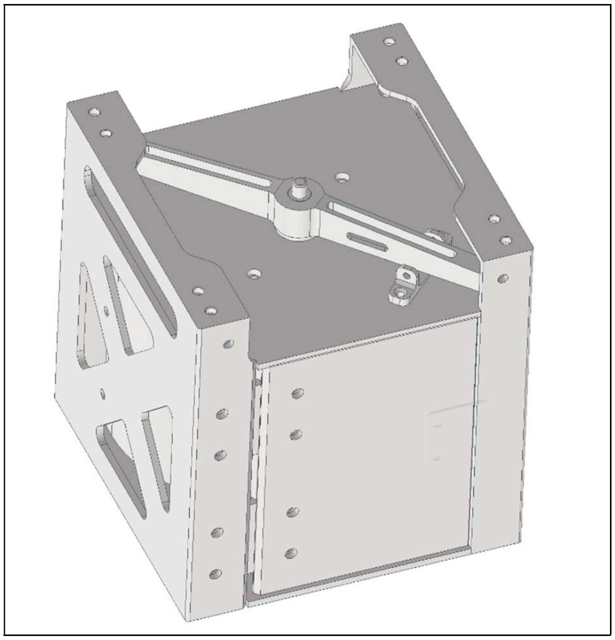

Figure 9: DeCS Full Assembly

Design, Fabrication, Qualification of UTHS Boom

A parametric study was conducted using MATLAB, on lenticular cross section boom with radius and arc angle as the variables, as shown in Figure 10. The optimal value to meet the mission requirements were determined to be 62mm flattening length and material limitations failure strain (Figure 11). The boom was designed to passively deploy, and single twill-weave carbon fiber material was chosen for fabrication due to its high strain capability without failure.

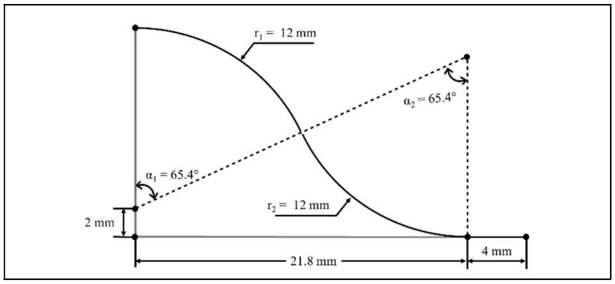

Figure 10: Quarter of Boom Cross-section

A two-stage curing with an inner vacuum bag was used to prevent two critical fabrication defects: providing uniform pressure on the inner surface of the lenticular shape and effectively reducing the matrix squeezing near the web. For the boom testing, large deformation bending was performed to analyze localized pure bending damage at the bending radius, which wass crucial for understanding folding deformation and damage during rolling (Figure 12). As shown in Figure 13, the eccentric buckling test was also performed to assess the coupled bending and compression behavior, revealing global structural bending under post-deployment loading conditions.

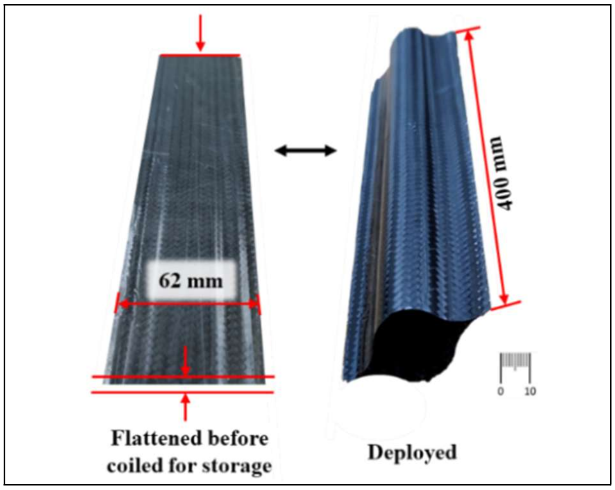

Figure 11: Flattened and Deployed Boom

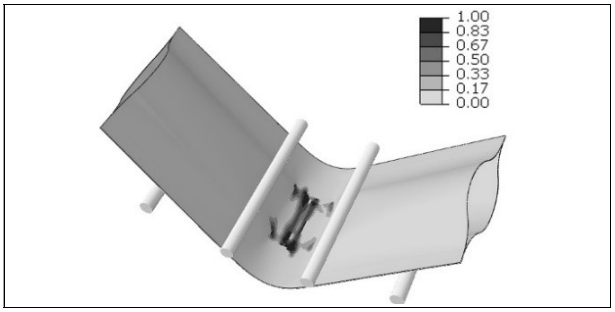

Figure 12: Large Deformation Under Pure Bending

Figure 13: Eccentric Buckling of UTHS Boom

The repetitive bending cycles with different concave sides of the boom revealed sub-critical damage for a critical bending radius of 13.86 mm. The buckling test for eccentricity of 36.5 mm and a length of 2 meters, a buckling tip load of 4-5 N was observed [9]. Vibration performance for the UTHS boom was also evaluated for a 400 mm length with a similar boom root condition to the deployment mechanism for a 65 grams tip payload, resulted in a resonance frequency of 20 Hz [8]. The valuable insights provided by this elaborated test contributes into the robust performance of the materials and reliable structures under various conditions. The findings contribute to the optimization of design parameters, ensuring that mission requirements are met while maintaining structural integrity and functionality. These results will be instrumental in guiding future developments and applications in this field.

THREE-TIER COMMUNICATION SYSTEM, COMMAND & DATA HANDLING, AND THE ELECTRICAL POWER SYSTEM

The integrated design approach to Mission SeaLion's satellite bus is characterized by its three primary payloads and the need to accommodate a three-tier communication system including a software defined UHF radio as a Doppler payload, which is aimed at extending the U.S. Coast Guard's reception of distress calls beyond visual line of sight within the arctic circle. The three-tier communication system consists of – (i) a GOMSpace AX2150 S-Band radio, (ii) a GOMSpace SDR UHF radio, and (iii) the Iridium L-Band radio from NSL. Each of these radios operate on a different frequency.

The GOMSpace radios offer CAN, I2C, and serial interfaces, while the Iridium L-band radio offers a serial interface. These devices are treated as separate entities in the operating software despite some having similar interfaces. This is a default requirement due to each being utilized for a specific set of operations, ensuring strict modularity rules. Also, having a single interaction method would render some capabilities useless [15]. The GOMSpace radios utilize the open-source CubeSat Space Protocol (CSP) [16] allowing plug and play functionality. Each of the devices is considered a node according to CSP. To communicate with the GOMSpace devices, data is sent and routed towards the node representing the device. The open-source libcsp [17] library provides all necessary implementations for the protocol to operate, exposing methods to send and receive data to/from nodes. These implementations are encapsulated within a set of concurrently running transmitter and receiver threads as part of the communications system module design of the flight software. The threads utilize these methods to downlink any data channeled by the flight software, and uplink any data from the ground station. The Iridium radio connects to an intermediate mesh of "Iridium Network" satellites. These operate as a relay of information between the radio and the ground station. The serial interface is used to operate and communicate with the device. Transmitting and receiving data is bound by protocols described in the "Interface Control Document" (ICD). The onboard flight software includes drivers that implement these protocols. As mentioned above, the transmitter and receiver threads then encapsulate these drivers, and operate them when communication is requested through this device. Figure 14 illustrates the operation of the three-tier system when downlinking data, where data is shown to be routed to the appropriate device based on user selection; most importantly, operational layers for each communication device. The opposite process is followed in the case data is to be uplinked to the CubeSat. The three-tier communication system is more elaborately discussed in Reference [18].

Flight Software Design Overview

The cohesive operation of the mission SeaLion CubeSat stems from a modular mission ConOps oriented software design. The focus of the design is on the concept of modularity, allowing for abstraction and low coupling of operational instructions on system hardware and its accompanying software. The design consists of five modules illustrated in Figure 15. These are: (i) Mission Scheduler, (ii) Sensors, (iii) Actuation, (iv) Power System, and (v) S-Band\UHF-VHF Comms. Each of these plays role in handling a functional aspect of the operation of the satellite, with the Mission Scheduler as the main entity and beneficiary of information facilitated by the other subsystems. To ensure strict modularity, each of these modules follow specific interface rules.

As the main receptables to the space environment, both the sensors and actuation modules tend to provide an encapsulation of any instruments the satellite is equipped with, while managing to report requested information in the case of the sensors module and providing commands for action in the case of the actuation module. Internal to the sensors module, this is achieved by introducing two blocks, one for fetching raw data i.e. analog signals, binary data, etc., with the other processing fetched raw data into a format usable by the spacecraft. The sensors module is limited to a single read-only concrete interface provided for each instrument with sensing functionality, meaning that data can only be requested. Multiple interfaces are allowed for obtaining different processed formats of the raw data. Conversely, the actuation module is limited to a write-only interface per actuator, as an actuation device is triggered for a certain action based on desired inputs. Multiple interfaces are allowed by the design in the case the same actuator implements multiple physical interfaces to carry out the same or extended actions. Inside of the actuation module, inputs from the external interfaces are converted to formats adhering to the physical interfaces of the actuators. The presence of these interfaces in both modules abstracts the hardware when utilized in other parts of the flight software. To conform to this separation of modules, elements of any instruments aboard the spacecraft are separated based on their sensing and actuation functions, despite being contained within the same device. Such design allows for the quick replacement of hardware offering the same functionality.

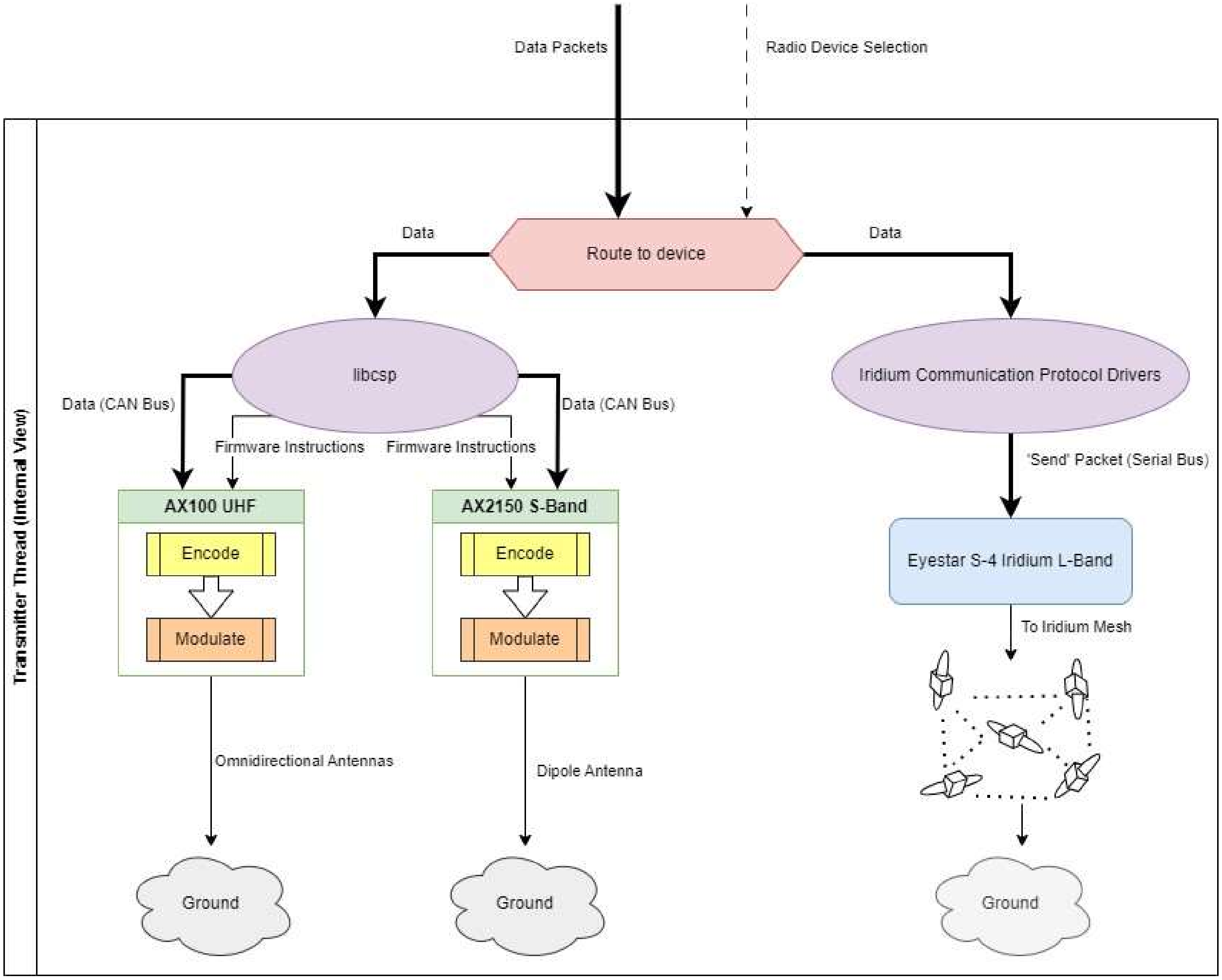

Figure 14: Transmitter Thread Downlinking Map [18]

The power system consists of the NanoPower P31u from GOMSpace, which interfaces with the body mounted and deployable solar panels to regular power and charge the NanoPower BPX battery module from GOMSpace. The NanoPower P31u is also capable of regulating power distribution to various CubeSat systems, including the mission payloads, through the CubeSat bus for efficient operation. This system incorporates the power control switches present on the interfacing circuitry, OBC, and daughter board. It implements an input-only access interface for all operations. All switching and modulation functionality is encapsulated within the NanoPower BPX module, which is controlled by the flight software and the Nanomind A3200 on-board computer from GOMSpace.

Responsible for all communications between the CubeSat and ground station, the S-Band\UHF-VHF Comms module houses the three-tier communication system mentioned previously. Of the main features of this module is that it allows for a multi-device expandable common interface offering the potential to add as many devices as required by the mission.

Having a single common interface provides a non-coupled relationship between implementation and usage. The provision of such separation necessitates the for routing between the common and device specific communication interfaces, for which this module implements. Three sections make up the communication subsystem: first is the transmitter thread, which is an independent concurrently running thread that is immediately accessible for transmitting any outgoing data from the CubeSat, second is the receiver thread, which is independent and runs concurrently as well to ensure the immediate receival of any uplinked data, the third is the function trigger, which interprets any telecommunication commands sent by the ground station, crafting them into new mission modes within the mission scheduler. Some function triggers such as pings are immediately executed, and any replies are immediately routed to the transmitter thread.

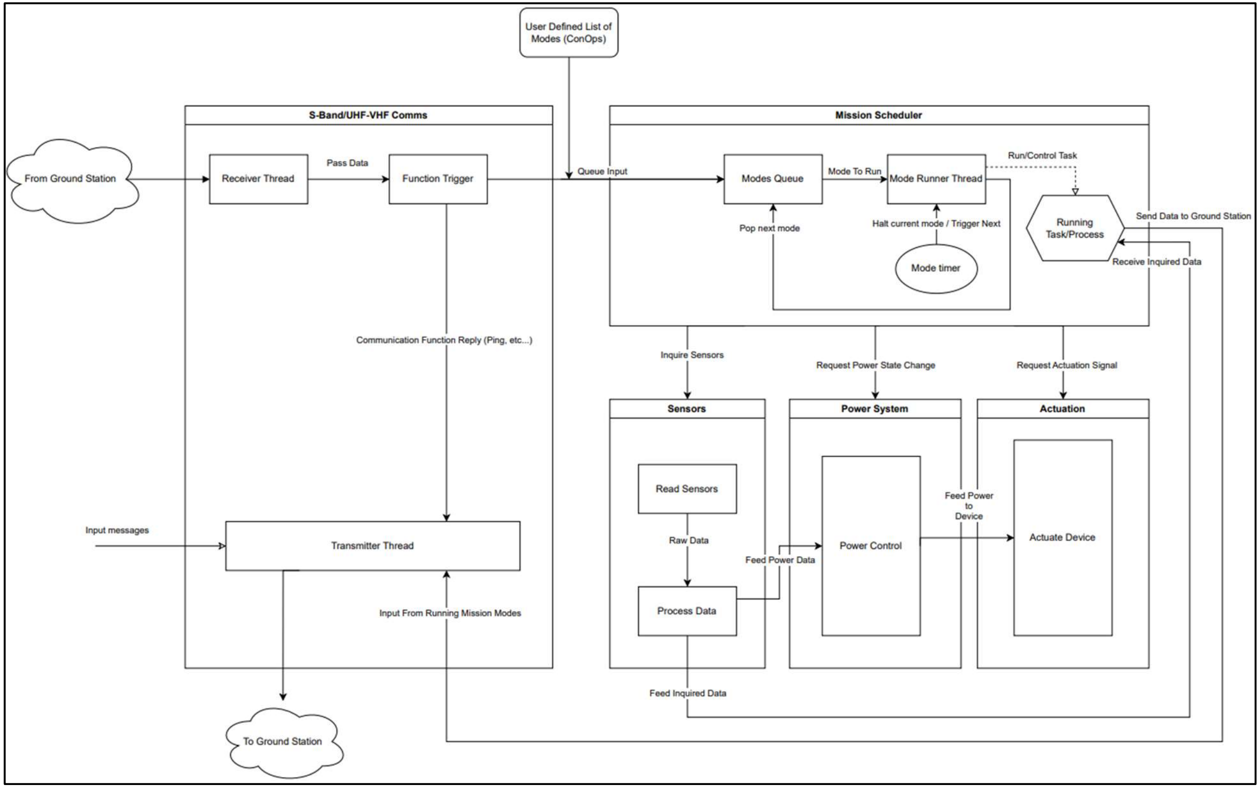

Figure 15: Overall Command and Handling Flight Software Architecture

At the core of the Mission SeaLion flight software is the mission scheduler. This mission scheduler organizes and prioritizes the various mission functions. It makes sure the correct execution of all modes and operations in the system in their organized order, therefore balancing the operation of the CubeSat. The mission mode scheduler is built upon two entities: (i) the modes queue, and (ii) the scheduling thread. Where the first is simply a FIFO (First In – First Out) queue which buffers the list of modes to be executed in a certain order decided by the mission CONOPS. The scheduling thread resembles the execution end of the queue, its responsibilities include running modes from the FIFO queue and ensuring the continuous running of the currently operational mode until the allotted mission mode time is exhausted. A mission mode is a custom entity that contains and describes certain operations to be executed within the operational timeline of the system. It is identified by an ID number, mode name, callback function, kill function, and a timeout limit. All needed mode operations are described within the callback function, which can utilize all the other modules of the software. Such design allows for the dynamic definition of any operations that need to be run during the lifetime of the CubeSat, without having to pre-define a mission state map. With the mission modes defined and buffered into the mission modes FIFO queue, the scheduling thread pops one mode at a time executes it by running the callback function and pushes it back to the head of the queue. The mission modes scheduler is further described in detail in [18].

Mission Interface Board

The mission interface board is designed to be the centralized collection hub for integrating the hardware components of the CubeSat. A 3D rendering of the interface board is shown in Figure 16. It performs the function of a collection hub for the NanoDock daughter board holding the NanoMind A3200 OBC and AX 2150 S-Band radio, the external ports of the OBC not exposed through the daughter board, the Eyestar S4 Iridium L-Band radio, and the impedance probe.

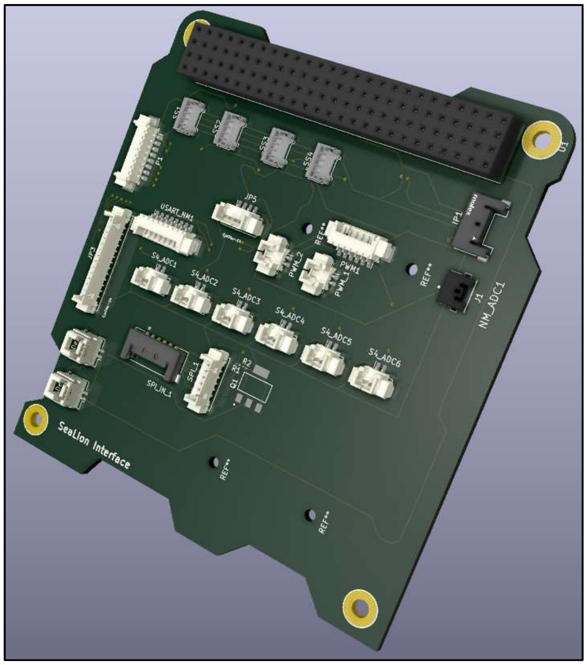

Figure 16: 3D Model of the Mission SeaLion Interface Board

This board exposes connection ports to allow for expanding the system with additional instruments. Based on the current design, it embeds the serial and input endpoint connections of the S4 Iridium radio exposing all six of its ADC interfaces. The USART connector interface of the daughter board, four connectors exposing the I2C bus of the satellite, two pulse width modulated outputs and two single-trigger payload deployment switches controlled by the OBC PWM port are accessible on the interface board. It also facilitates the connection for four independently switchable 5v drive switches controlled by the OBC GPIO ports, a connector to the OBC ADC to detect the Iridium radio busy line, the impedance probe instrument input port, and an SPI bus connection port for extending the system further when intended. The interface board is designed as per the PC-104 form factor and standard, thus including two 52 pin connectors which enable it to be plugged as part of the PC104 stack. It extends the functionality of existing hardware; however, no active components are included on the PCB. They are all passive thus requiring no firmware while still being controlled by the flight software.

Overall System Power Budget

The overall power budget of the Mission SeaLion CubeSat is summarized in Table 1:

Table 1: Overall Component Level Power Budget

Module	Power (mW)
Eyestar S4 Iridium Radio	1022
Nanocom AX2150 S-Band transceiver	4185
Nanomind A3200 OBC	182.4
Impedance Probe Payload	0.45
Nanosense M315 magnetometer	12.5
NanoPower P31u EPS	160
NanoPower BPX Battery pack	6064
Total	**11626.35**

There currently exists a total of six mission modes defined for the system. Table 2 shows each mission mode with its estimated runtime, and total power budget. Estimations are based on an approximate 98-minute orbital period.

Table 2: Mission Modes Power Budget

Module	Estimated Runtime (minutes)	Power Required (mW)	Total Power Consumption Per Period
Safe-hold Mission Mode	61.7	1204.40	74311.48
Mission Mode 1	10.0	1204.85	12048.50
Mission Mode 2	10.0	682.40	6824.00
Communications Mode	10.0	4185.00	41850.00
Solar Panels Deployment Mode	3.3	842.40	2779.92
Antennas Deployment Mode	3.0	842.40	2527.20
Total			**140341.10**

DESIGN OF THE MISSION SEALION CUBESAT STRUCTURE

As mentioned previously, the Mission SeaLion CubeSat is developed with a payload-centric approach to design. Two innovative payloads, a pair of Impedance Probe (IP) antennas and the DeCS serve as the driving design constraints for the design of the CubeSat structure. The CubeSat structure main constituents are the four sub-assemblies: (i) a self-contained PC104 stack, (ii) the DeCS housing, (iii) a sheet metal outer shell, and (iv) a set of deployable solar arrays. The four sub-assemblies serve a vital role in ensuring the missions successful operation.

PC104 Stack

The PC104 stack serves as the nervous system of the CubeSat and is responsible for supplying power and sending commands to the various systems carried aboard the CubeSat. The PC104 stack with its active and passive constituents is shown in Figure 2. At the top of the stack is the IP board, which is responsible for processing the data collected by the IP antennas and sending the data to the OBC through the interface board. As mentioned previously, the interface board serves as a central hub for all instrumentation interfaces and routes their data to the OBC for further processing. The NanoMind A3200 OBC is responsible for data handling, sending and receiving information between the ground station and the three-tier communication system.

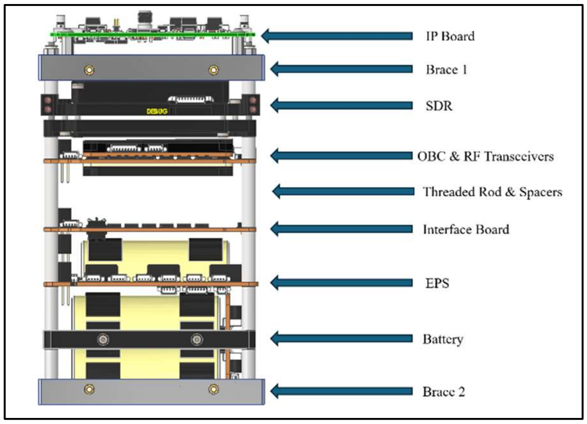

Figure 17: PC104 Stack Overview

The CubeSat power system is developed around the NanoPower P31U to distribute power and charge the NanoPower BPX batteries. The P31U will charge the battery pack via six individual channels, each supplied by a plane of solar cells. Furthermore, the P31U will house a remove before flight pin that will ensure all SeaLion systems remained powered off prior to the final integration with an XTERRA 3U dispenser [18].

Serving as the main source of structural rigidity to the SeaLion CubeSat, two of three internal braces are integrated within the PC104 stack sub-assembly. Each brace serves to prevent deformation to the sheet metal outer shell and anchor the threaded rods that run through each PC104 board. The braces shown in Figure 18 enable seamless integration of the PC104 stack to the outer sheet metal shell via the M3 holes located about their perimeters. Once fitted with threaded inserts, the M2.5 thread inserts enable the user to fully assemble the PC104 stack outside of the sheet metal shell. This maintains accessibility to all four sides of the stack during its assembly process and the routing of the satellites electrical harness. Furthermore, the cutouts in the center of each brace ensures that wires from other sub-assemblies can be routed internally within the structure into the PC104 stack. Once assembly of the stack is completed, it can be inserted into the sheet metal shell and secured from the outside with M2.5 screws. After integration with the sheet metal chassis, brace 2 has provisions to integrate CubeSat standoffs and a quad-monopole UHF antenna on its backplane.

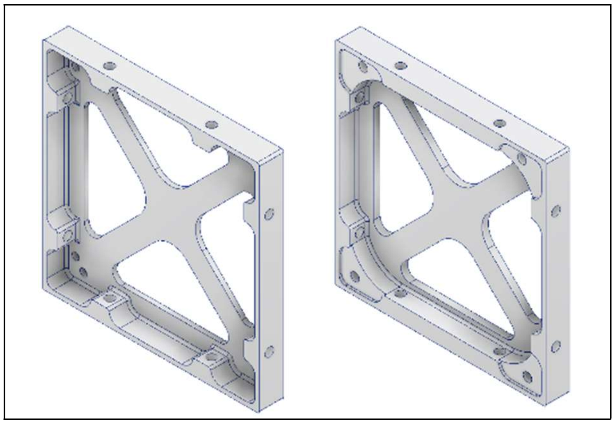

Figure 18: PC104 Stack Braces

Deployable Composite Structure Housing

Mission SeaLion's second sub-assembly takes the form of the DeCS 1U housing. The DeCS is responsible for constraining the deployment of ODU's composite boom. Figure 19 illustrates the location of each interior component of the DeCS. The DeCS consists of a central spool surrounded by four compressing rollers. These compressing rollers are pushed against the center spool by four leaf springs. The compressing rollers and their leaf springs serve two purposes: (i) enabling the DeCS to store elastic potential energy as the carbon fiber boom is wound into its stored configuration and (ii) preventing premature blooming of the wound boom within the DeCS housing by compressing the boom against the center spool. Once wound, a ratchet affixed to the bottom of the spool is then interfaced with a locking mechanism that is mounted on the housing's door; enabling the entire payload to be constrained via the friction pads' interface with the dispenser. The dispenser interface bypasses the need for a signal from the OBC to initiate deployment and instead uses the pad-dispenser interface to resist the spring force of the carbon fiber boom, enabling an immediate deployment once the CubeSat has been deployed from the dispenser. This process is made possible by the unique geometry of the boom, which stores potential energy in a stowed configuration.

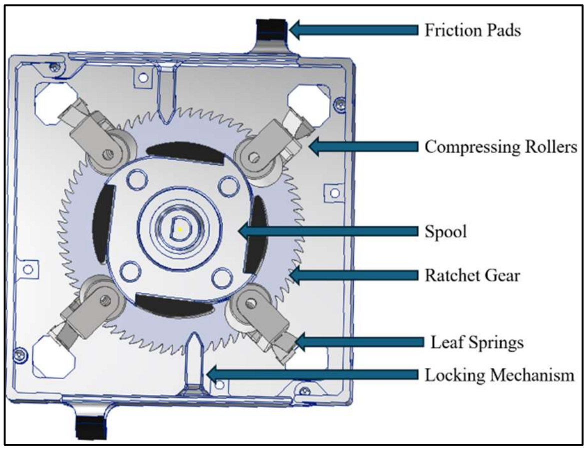

Figure 19: Top View of the DeCS Housing

Figure 20 depicts the mating of the DeCS housing and brace 3. Brace 3 enables the DeCS to integrate with the outer sheet metal shell in a similar manner to braces 1 and 2 through its 8 perimeter holes. However, instead of utilizing thread inserts, the utilization of a nut and bolt to join the sheet metal shell and 1U DeCS payload is used for added strength. This necessitates the installation of the DeCS housing prior to the PC104 stack.

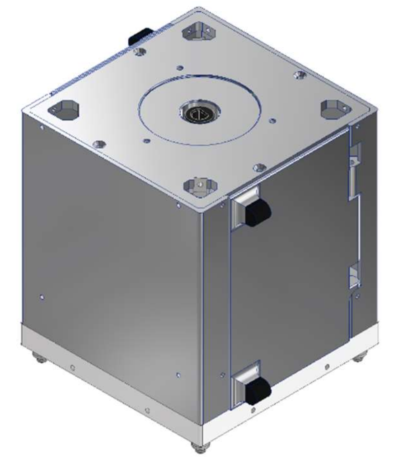

Figure 20: DeCS Housing and Brace 3

Sheet Metal Outer Shell

The sheet metal outer shell show in Figure 8 is the uniting structure of the CubeSat. The shell serves as a mounting point for the PC104 stack, DeCS housing, side panels and chassis-mounted instrumentation. To prevent cold welding upon deployment, the rails of the sheet metal shell undergo hard coat anodization.

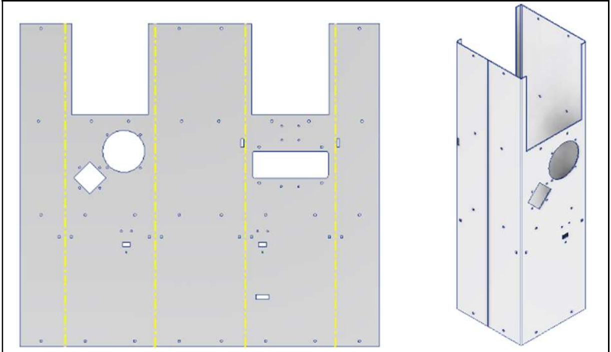

Figure 21: Sheet Metal Pattern and Folded Shell

The two sides of the sheet metal shell, highlighting all mounted instrumentation while omitting the side panels are shown in Figure 22. The sheet metal shell encapsulates the DeCS housing while cutouts allow the deployable doors to open freely. Mounted below the DeCS, and interior to the sheet metal shell, is a magnetometer and adjacent S-Band antenna. Due to the S-Band antenna's height, it was necessary to recess the antenna into the sheet metal shell to fit within the envelope deployer's dynamic envelope. The mounting bracket that enables the S-Band antenna to be recessed 3 mm within the sheet metal shell and fit within the envelope is also shown in Figure 22.

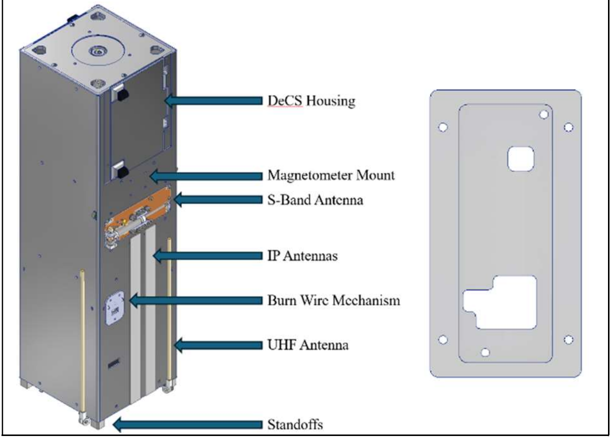

Figure 22: Sheet Metal Shell & S-Band Mounting Bracket – View 1

Mounted on the surface of the shell shown in Figure 22 are the two IP antennas. The IP antennas measure

180 mm in length and necessitate adjacent placement to be accommodated within the available space on the sheet metal shell. As shown in Figure 23, the adjacent empty surface and its opposing side will be occupied by surface-mounted solar panels and solar arrays detailed in the next section.

Figure 23: Surface-mounted Solar Panels

The burn wire mechanism, shown in Figure 22 and 23, and its routing holes will play a vital role in constraining the mounted solar arrays and UHF antenna. The burn wire mechanism provides a fastening point for the nichrome burn wire and the heating element required to initiate deployment, while the routing holes enable the wire to reach all 4 sides of the structure without interfering with the function of the CubeSat's corner rails. This ensures that the UHF antennas and solar cells mounted on the deployable panels are properly constrained throughout deployment, negating any risk of damage to either mission-critical components.

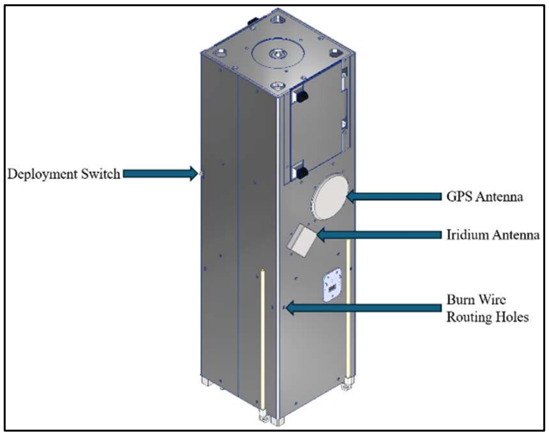

Figure 24: Sheet Metal Shell w/ Burn-wire Mechanism – View 2

Serving as an auxiliary means of communication with the satellite, the Iridium antenna ensures that the SeaLion team will have a reliable means of communication at any point of our orbit. Furthermore, the coupling of an Iridium antenna with a precision GPS allows the SeaLion satellite to be accurately tracked throughout its orbit.

Deployable Solar Array Configurations

The two configurations of the deployable solar panels (Figure 25) include a deployment along the length of the panel in a piano-style hinge and a deployment from the leading short edge. The configuration designis to that regardless of the SeaLion CubeSat's orientation, there will always be a set of solar cells capable of harvesting energy on-orbit.

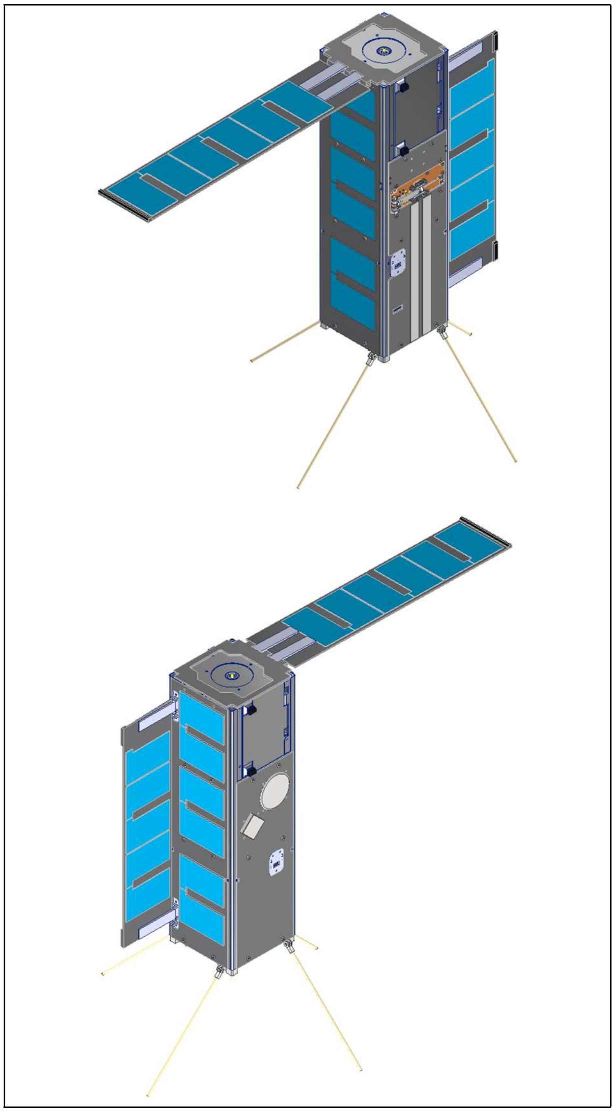

Figure 25: Deployable Solar Panels Configurations

Figures 25 and 26 illustrate how the combination of surface mounted solar panels and the deployable solar array ensure that every plane of the satellite is populated with solar cells. Custom developed hinges are used to attach the deployable solar panels to the CubeSat. Figure 26 shows the unique geometry that enables the spring loaded hinge to lock perpendicular to the CubeSat's surface.

Figure 26: Custom Developed Hinges

As the burnwire constraining the solar array is activated, double torsion springs fitted at the base of the hinge enact a moment that deploys the array. This deployment is then locked at 90 degrees through a physical interferance between the hinge body and its base. In addition to self-locking features of the hinge, a slope is designed into the bottom flange of the hinge body to enable the panels to pack in as small form factor. A CAD rendering of the Mission SeaLion CubeSat with deployed solar panels and the DeCS UTHS booms is captured in Figure 27. In this configuration, the CubeSat will experience the most atmospheric drag and at the same time generate adequate power to support all the mission operations.

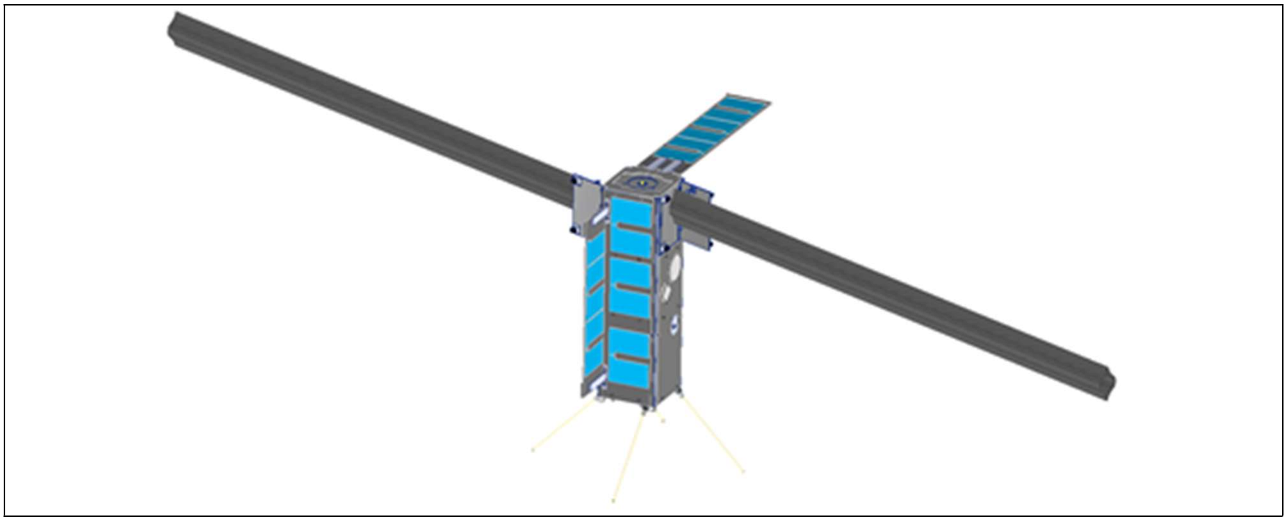

Figure 27: CAD Rendering of the Mission SeaLion CubeSat w/ Deployed Solar Panels and DeCS Booms

CONCLUSION AND FUTURE WORK

The overarching vision of Mission SeaLion project is to advance the TRL of its payloads and technological innovations to support NASA's ISAM program. The design of the Mission SeaLion CubeSat is largely frozen, and the team is working on the development. As part of the development, most of the flight hardware is either procured or being procured. The DeCS payload design is completed, and the mechanism is under development at both ODU and the USCGA. The UTHS booms, which have been rigorously researched and tested, are under development at ODU. The CubeSat structure is under development at the USCGA. Most of the flight hardware, which makes up the PC104 stack, is procured and/or fabricated, including a version of the mission interface board and the solar panels. The design of the flight software is mostly complete and ready to be deployed on the flight OBC.

The team is currently working on the development of flight solar panels to accommodate solar cells (CICs) from SolAero. An updated version of the interface board is under development to better accommodate the various flight hardware in the PC104 stack. The ground station needed to support S-band and UHF communications are under testing at the USCGA. The environmental qualification of the CubeSat is scheduled to be completed at ODU and USCGA. The mission is scheduled to be launched aboard Firefly Aerospace's small launch vehicle, Alpha, out of Vandenburg Space Force Base in Fall 2024.

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