Optical Night Sky Brightness Measurement

NOVA: Night-time Optical Visibility Assessment

ENG 4000

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Team 24

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Acronyms, Abbreviations and Definitions

The following table serves as a collection of the abbreviations used throughout this report.

Table 1 - Abbreviations

Term	Definition
NOVA	Night-time Optical Visibility Assessment, Name given to the payload
NOVA team	Group of Individuals working on the Capstone Project
OBC	On-Board Computer
TBC	To Be Confirmed
TBD	To Be Determined
ICD	Interface Control Document
I2C	Inter-Integrated Circuit
RSOnar III	The main payload
RSOnar II	The previous mission
SQM	Sky Quality Meter
SNR	Signal-to-Noise Ratio
FPS	Frames per Second
MCU	Micro-Controller Unit
RSO	Resident Space Object (i.e. space debris)
DFM	Design For Manufacturing

1.0 Executive Summary

This document outlines the NOVA sub-payload design for the RSOnar III balloon satellite mission. As one of three capstone teams with payloads on the balloon satellite, NOVA has a unique goal that is primarily aimed at improving the imaging quality for the main payload. The previous mission RSOnar II captured 20 thousand images during dusk and dawn that were too noisy to detect any RSOs.[1] This is why NOVA is an integral part of the RSOnar III mission; our goal will be to optimize imaging to make high SNR sky brightness measurements and maintain the same viewing angle and similar FOV as the PCO Panda 4.2 sCMOS camera on the main payload to image the same portion of the sky. This will not only allow more accurate background subtraction and calibration for RSO detection but also allow an easy way to distinguish between RSOs and cosmic rays.

The NOVA payload is divided into six subsystems that include mechanical, environmental, computational, electrical, scientific, and software. This is to ensure that the mission could be effectively broken down into smaller work packages, enabling more efficient collaboration and organization amongst the team.

At the heart of the NOVA scientific subsystem is the ZWO asi120mm mini CMOS camera[2] paired with the Raspberry Pi 6mm wide field lens[3]. This will enable high SNR imaging; but only at a moderate resolution, as it is not desirable for NOVA's purpose and will lower the SNR the higher the resolution for a given sensor size. This will be paired with the Beagleboard BeagleBone Black Industrial OBC [8] and a 1 tb micro SSD to ensure a robust and capable computational subsystem.

For a balloon mission reaching heights of 40km, there is a unique range of thermal, radiation, pressure, and vibrational environments a payload will experience. This document outlines NOVA's extensive environmental testing and management plan to ensure the integrity of data and the survivability of our sub-payload. Thermal management techniques include things like mylar, heatsinks, foam insulation, resin coating, and sufficient thermal coupling to the chassis. Due to the short mission duration, radiation protection will only be implemented on the software side to ensure the integrity of all data collected as it is more of a long-term issue in terms of spacecraft survivability. Extreme pressure ranges are to be mitigated with resin coating, as well as careful choice of components that are known to survive within these temperature ranges.

Alongside all mitigation plans, the NOVA team has an extensive testing and integration plan. This includes vacuum testing, cold chamber testing, vibrational testing, component-level testing, and system-level testing. This will ensure all potential risks associated with the extreme range of atmospheric conditions can be handled by NOVA.

2.0 Requirements

The NOVA payload has an extensive list of requirements that are broken into subsections and numbered to organize the requirements so we can ensure each has an appropriate impact on our design choice. These categories include Electrical, Environmental, Mechanical, Computational/Storage, Scientific, Safety and compliance, Operational Flexibility, Data integrity, Power, and Software. Each requirement has its rationale and verification to ensure each requirement can be verified and aligns with the mission objectives.

Table 2 - Requirements

Section	Req ID	Reference	Requirement Statement	Rationale	Verification
Electrical (1)	1.1	[1] Section 5.2.1	The payload shall receive a 5V ± 0.5V DC unregulated power supply from the main payload's Power Distribution Unit (PDU).	Integration with the main payload's PDU ensures stable power delivery and reduces the need for additional resources.	Verify that the power input is within the 5V ± 0.5V range by measuring the voltage at connection points between the main PDU and payload.
Electrical (1)	1.2	[1] Section 5.2.1	All payload wiring shall use wire gauges that conform to CSA standards for current-carrying capacity and signal quality	CSA wire gauge standards minimize the risk of overheating and ensure consistent current flow.	Confirm that wiring conforms to CSA standards by cross-referencing wire gauge with expected current ratings and capacities.
Electrical (1)	1.3	[1] Section 5.2.1	The payload wiring length shall be minimized and configured according to CSA standards, to maintain signal integrity and reduce resistive losses.	Managing wire length according to CSA standards limits voltage drops and signal degradation, which is	Measure wiring lengths and inspect configuration to ensure adherence to CSA standards for minimal resistive losses.

				critical for maintaining the accuracy of transmitted data.	
Electrical (1)	1.4	[6] , Section 4.1.2	The payload wiring shall include shielding that meets CSA standards to protect against electromagnetic interference (EMI)	Shielded wiring reduces EMI risks that could affect data transmission and the stable operation of other payloads.	EMI Testing: Test shielding effectiveness by measuring EMI susceptibility in operational environments, and verifying compliance with CSA standards.
Electrical (1)	1.5	[6] , Section 4.1.2	The payload shall implement grounding practices in accordance with CSA-STRATOS-MAN-0012, Section 4.1.2	Grounding prevents EMI, protects against ESD, and ensures stable electrical performance, which is essential for data integrity and safety of the payload and mission.	Verify grounding continuity and measure resistance to ensure CSA-compliant grounding across all payload components.
Environmental (2)	2.1	[6], Section 6.3	The payload shall operate nominally at altitudes between sea level and 40 km, ensuring continuous image data collection under variable atmospheric pressure.	Allows continuous operation through changing atmospheric pressures during ascent.	Altitude Testing: Simulate conditions in a vacuum chamber to test for operational capability across pressure ranges. - or Analysis: Computational model simulating

					pressure changes from sea level to 40 km to assess component resilience.
Environmental (2)	2.2	[6] , Section 6.3	The payload shall maintain continuous imaging capability in a temperature range between -30°C and +50°C.	Ensures functionality across the temperature range expected during high-altitude flights.	Thermal chamber testing and thermal profile simulation to confirm operational capability within a temperature range
Environmental (2)	2.3	[6] , Section 6.5	The payload shall incorporate thermal coupling to the chassis to maintain optimal operational temperatures across all components.	Maintains temperature consistency, which is crucial for reliable imaging and data collection.	Inspect thermal coupling and confirm all components achieve optimal temperature.
Environmental (2)	2.4	[1] Section 5.3.5	Where necessary, thermal insulation, heat sinks, or other passive cooling methods shall be integrated to ensure all components remain within operational temperature limits.	Protects sensitive components from extreme temperature variations, particularly during prolonged exposure.	Analysis: Thermal simulation to verify insulation and cooling systems maintain components within temperature limits.
Environmental (2)	2.5	[6] , Section 6.1	The payload shall include error-correcting algorithms and hardware-based protections to mitigate the effects of	Protects data integrity and system reliability under radiation exposure.	Analysis: Radiation simulation to model payload susceptibility and error-correction effectiveness

			high-altitude radiation exposure.		
Environmental (2)	2.6	[6] , Section 6.5	The payload shall be able to meet its performance requirements under prolonged exposure to UV radiation and low-pressure conditions typical of the stratosphere without degradation of performance.	Ensures payload durability and functionality under stratospheric conditions.	Analysis: UV and low-pressure simulation to assess performance resilience under environmental stresses.
Environmental (2)	2.7	[6] , Section 6.5	The payload shall have anti-condensation measures to prevent moisture buildup during rapid changes in altitude and temperature.	Protects sensitive electronics from moisture-related damage during ascent or descent.	Analysis: Testing in controlled environments with varying humidity and temperature to simulate mission conditions. This may involve observing the effectiveness of materials like resin coatings
Mechanical (3)	3.1	[1] Section 5.4	The payload shall be designed to fit within a right triangular prism with a side length of 14.14 cm, hypotenuse of 20 cm, and depth of 10 cm, corresponding to Bay 2 of the primary payload platform.	Ensures compatibility with spatial constraints of the payload platform.	Analysis: CAD fit simulation within specified dimensions for Bay 2.
Mechanical (3)	3.2	[1] Section 5.4	The payload mounting system shall maintain the camera's alignment at 45	Provides optimal camera alignment for	Analysis: Finite Element Analysis (FEA) simulation for alignment

			degrees relative to the main payload platform throughout the mission, ensuring precise imaging.	accurate data capture.	stability under mission dynamics.
Mechanical (3)	3.3	[1] Section 5.3.6	The payload shall meet its performance requirements while under the vibrational loads experienced during launch and ascent typical of stratospheric balloon missions, including random vibration and mechanical shock.	Protects payload integrity and functionality under mechanical stress.	FEA simulation and vibration test to confirm durability during launch and ascent.
Mechanical (3)	3.4	[1] Section 5.4	The payload shall be constructed using materials and structural reinforcements that ensure mechanical stability while minimizing weight, as per CSA/NASA payload weight restrictions.	Balances structural stability with weight restrictions for optimal performance	Analysis: FEA simulation to verify compliance with structural and weight standards.
Mechanical (3)	3.5	[6] , Section 5.1	The payload shall stay under 500g in total mass.	Complies with weight limits, reducing stress on the main platform for stability during launch.	Measure payload mass prior to integration, confirming it meets the 500g requirement.
Computational/Storage (4)	4.1	[1] Section 5.1.1	The onboard computing system (OBC) shall be capable of performing continuous image	Supports real-time data processing and error correction for	Test OBC under full data load and error correction for continuous operation.

			processing while simultaneously handling error correction algorithms and data storage management.	reliability	
Computational/Storage (4)	4.2	[1] Section 5.2.1	The storage system shall be sufficient to accommodate at least 780 minutes of continuous image data, taking into account the selected camera's resolution, image format, and bit depth.	Ensures storage capacity for the full mission duration without data loss.	Analysis: Calculate required storage based on camera settings; test for 780-minute data capacity.
Computational/Storage (4)	4.3	[6] , Section 4.4.4	The storage system shall support non-volatile storage mediums to prevent data loss in case of power interruptions or failures.	Protects against data loss from unexpected power disruptions	Simulate power failure to confirm data retention in non-volatile storage.
Computational/Storage (4)	4.4	[1] Section 5.1.1	The computational system shall include redundant fault tolerance capabilities, ensuring data integrity and continuous operation under adverse conditions.	Increases system resilience, ensuring data preservation during potential faults.	Analysis: Fault tree analysis to evaluate redundancy and fault tolerance for data integrity and continuous operation.
Scientific (5)	5.1	[1] Section 5.2.1	The selected camera shall provide imaging capabilities for a minimum of 780 minutes of continuous data collection, matching the operational time of the primary scientific payload.	Ensures imaging capability covers the full mission duration for complete data collection.	Continuous operation test of the camera in lab environment to confirm 780-minute duration.

Scientific (5)	5.2	[6] , Section 6.5	The camera's quantum efficiency across the visual wavelength spectrum shall be characterized and calibrated before the mission to ensure accurate sky brightness measurements.	Accurate sky brightness measurements require known quantum efficiency across wavelengths.	Conduct spectral calibration to characterize quantum efficiency across the visual spectrum.
Scientific (5)	5.3	[6] , Section 6.5	The camera shall have a high enough sensitivity to detect and measure sky brightness efficiently, even under low-light conditions.	Allows accurate sky brightness measurements under varying light conditions.	Test camera's sensitivity in a controlled low-light setting to confirm adequate brightness detection.
Scientific (5)	5.4	[1] Section 5.2.1	The camera resolution shall be chosen to optimize the signal-to-noise ratio (SNR) while allowing for the detection of stars within the images, balancing image resolution and sensor size.	Ensures image quality and SNR are sufficient for detecting stars and measuring sky brightness.	Analysis: Optical resolution and SNR simulation to determine optimal resolution for star detection and brightness.
Scientific (5)	5.5	[6] , Section 6.5	The camera system shall include dark current and flat-field calibration procedures to account for sensor noise and variations in detector response.	Corrects for sensor noise and variations, improving data accuracy.	Perform dark current and flat-field calibration in the lab to ensure calibration procedures are effective.
Scientific (5)	5.6	[1] Section 5.2.1	The payload shall be able to distinguish between sky brightness and	Distinguishing between sky brightness and stars is	Analysis: Image processing simulation to confirm the

			resolvable stars to ensure the scientific validity of sky brightness measurements.	necessary for accurate data interpretation.	camera's ability to separate sky brightness from star signals.
Safety and Compliance (6)	6.1	[6] , Sections 5.1.1 and 5.2.5	The payload shall comply with all safety standards specified by CSA and mission partners to ensure safe integration, deployment, and recovery.	Compliance with mission safety standards prevents damage to the payload and reduces risks to other components or systems.	Review documentation to confirm adherence to CSA and other relevant safety standards.
Safety and Compliance (6)	6.2	[1] Section 5.2.1	The payload shall include overcurrent protection circuitry to prevent component damage due to unexpected power surges.	Protects sensitive electronics and ensures the stability of power consumption across mission phases.	Test payload circuitry under power sure conditions to confirm effectiveness of overcurrent protection.
Operational Flexibility (7)	7.1	[1] Section 5.1.1	The payload shall support remote reconfiguration of data collection parameters (e.g., image resolution, frame rate) via the onboard computing system.	Allows adjustments in data collection settings based on real-time observations, optimizing data quality and storage use.	Perform a remote reconfiguration test to verify successful modifications of data parameters.
Operational Flexibi	7.2	[6] , Section 5.3	The payload shall include a failsafe mode that maintains	Increases mission success	Simulate system faults to verify transition into and

lity (7)			minimal operation functions if primary components encounter faults.	likelihood by enabling basic data collection or system preservation in case of a primary system fault.	operation of failsafe mode.
Data Integrit y (8)	8.1	[1] Section 5.1.1	The payload shall implement checksum verification for all stored data to detect any data corruption during storage or transmission	Ensures data integrity, allowing corrupted data to be identified and potentially corrected.	Verify checksum functionality by intentionally altering sample data to test corruption detection.
Data Integrit y (8)	8.2	[6] , Section 4.4.4	The payload shall include redundant data logging capabilities.	Redundancy in data storage provides a backup in case of primary storage failure.	Verify data is consistently logged to multiple storage locations, confirming redundancy.
Power (9)	9.1	[1] Section 5.2.1	The payload shall have a maximum power consumption of 4.0 W during full operational modes.	Ensures that the payload remains within the power budget allocated by the mission.	Measure power draw under full operational modes, ensuring peak consumption does not exceed 4.0 W.
Power (9)	9.2	[6] , Section 5.2	The payload shall incorporate power-saving modes that reduce power consumption during non-critical data collection phases.	Extends operational time by conserving power when full functionality	

				is not required.	
Softwa re (10)	10.1	[6] , Section 4.1.2	The software shall control and synchronize data acquisition across the camera and OBC to align with mission objectives.	Ensures data is captured in a coordinated manner, aligning with mission goals for consistent observations.	Validate synchronization accuracy through simulation tests and confirm time-stamped alignment in recorded data.
Softwa re (10)	10.2	[1] , Power System Requirem ents	The software shall include error-correcting codes and checksum verification to ensure data integrity during storage and prevent corruption from radiation exposure.	Ensures data reliability in high-radiation environments, preserving mission-critic al data accuracy.	Test error correction algorithms under simulated bit-flip scenarios to confirm effective correction.
Softwa re (10)	10.3	[6] , Section 4.3	The software shall manage data storage efficiently, employing compression algorithms to maximize storage capacity within the mission constraints.	Optimizes limited storage space, enabling retention of essential data for the entire mission duration.	Confirm data storage capacity and retention through simulation, verifying compression effectiveness.
Softwa re (10)	10.4	[6] , Section 4.1.1	The software shall regulate power consumption, prioritizing critical functions to maintain total usage under 4W.	Ensures compliance with strict power limits, avoiding battery drain and extending mission operation time.	Conduct power profiling to ensure that the software remains within the 4W power limit under various operating conditions.

Software (10)	10.5	[1] Internal Telemetry Requirements	The software shall log telemetry and diagnostic data, including camera and OBC status, memory usage, and error events, for post-mission analysis.	Provides insights into mission performance, enabling evaluation and improvements for future missions.	Verify telemetry logs during simulated mission operation, confirming data accuracy and completeness.
Software (10)	10.6	[1] Section 5.1.1	The software shall implement a watchdog timer and transition to a safe mode if critical errors are detected, preserving data integrity while maintaining basic functionality.	Increases mission resilience by allowing recovery from system freezes or malfunctions.	Test watchdog functionality by triggering simulated errors, confirming system stability in safe mode.

3.0 Baseline Design

The primary objective of the NOVA payload is to collect night sky brightness measurements in the visible spectrum to effectively filter noise and calibrate the imaging systems of RSOnar III. The mission aims to improve data collection of resident space objects by achieving high signal-to-noise ratio (SNR) imaging, enabling more precise measurements of the night sky brightness from a 40 km altitude [4]. The NOVA payload is designed to achieve a series of technical objectives that ensure the successful collection of calibration data for RSOnar III. First, the mission will focus on utilizing a high quantum efficiency, and low readout noise camera capable of capturing continuous images over a minimum of a 13-hour mission duration [5]. This imaging process will be facilitated by the Beagleboard BeagleBone onboard computer (OBC) to manage exposure times, error correction, and saving images to the onboard micro SSD [5]. Additionally, the mission aims to enhance overall data collection by allowing clear distinction between RSOs and cosmic rays due to multiple cameras imaging the same area of the sky. These measurements will establish a baseline for calibrating the RSOnar III payload, thereby improving its optical accuracy in detecting and tracking RSOs [4]. The mission will collect data during dusk, dawn, and night phases, demonstrating the payload's capability for continuous monitoring and calibration [4, 5]. This multi-phase data collection marks a significant advancement over previous missions, which were limited to nighttime measurements.

3.1 Feasibility Assessment

The NOVA payload prioritizes a feasible design that can be efficiently manufactured within our constrained timeline. Prioritizing commercially available off-the-shelf components, ensures accessibility, reliability, and compatibility amongst components, mitigating many of the risks associated with manufacturing and custom hardware development. One major issue we foresee is with the timeline for ordering these components. With the current strike with Canada Post, it may take much longer than expected to receive key components. Our team will carefully monitor this before ordering any components to ensure that the method of delivery will not be affected by the Canada Post strike.

The internal mechanical subsystem will be manufactured by the NOVA team with the use of the Lassonde machine shop from standard-sized commercially available aluminum 6061 and has been designed and CAD modelled with this in mind. We have also secured access to a 3D printer and started making a prototype model to ensure our design can be assembled before any manufacturing occurs.

Even with commercially available components and design for manufacturing in mind, there are still known risks associated with our design choices and the nature of the mission itself. The table below aims to outline the known risks and highlight our mitigation strategy.

3.2 Electrical

The NOVA sub-payload will be provided with power directly from the PDU of RSOnar 3. This includes the BeagleBone black industrial OBC with the 1 TB micro SSD, as well as the ZWO ASI120mm mini camera. Power will be provided directly to the OBC, and the micro

SSD and camera will be powered through the OBC to minimize power draw to maintain within our 4W power limit during peak activity.

The payload requires standard electrical connections provided by the RSOnar mission's main power management system. These connections will maintain minimized wire length, and use wire gauge and shielding that adheres to CSA standards as per electrical requirements 1.2, 1.3 and 1.4. The diagram below shows the NOVA sub-payload location within RSOnar 3's electrical design.

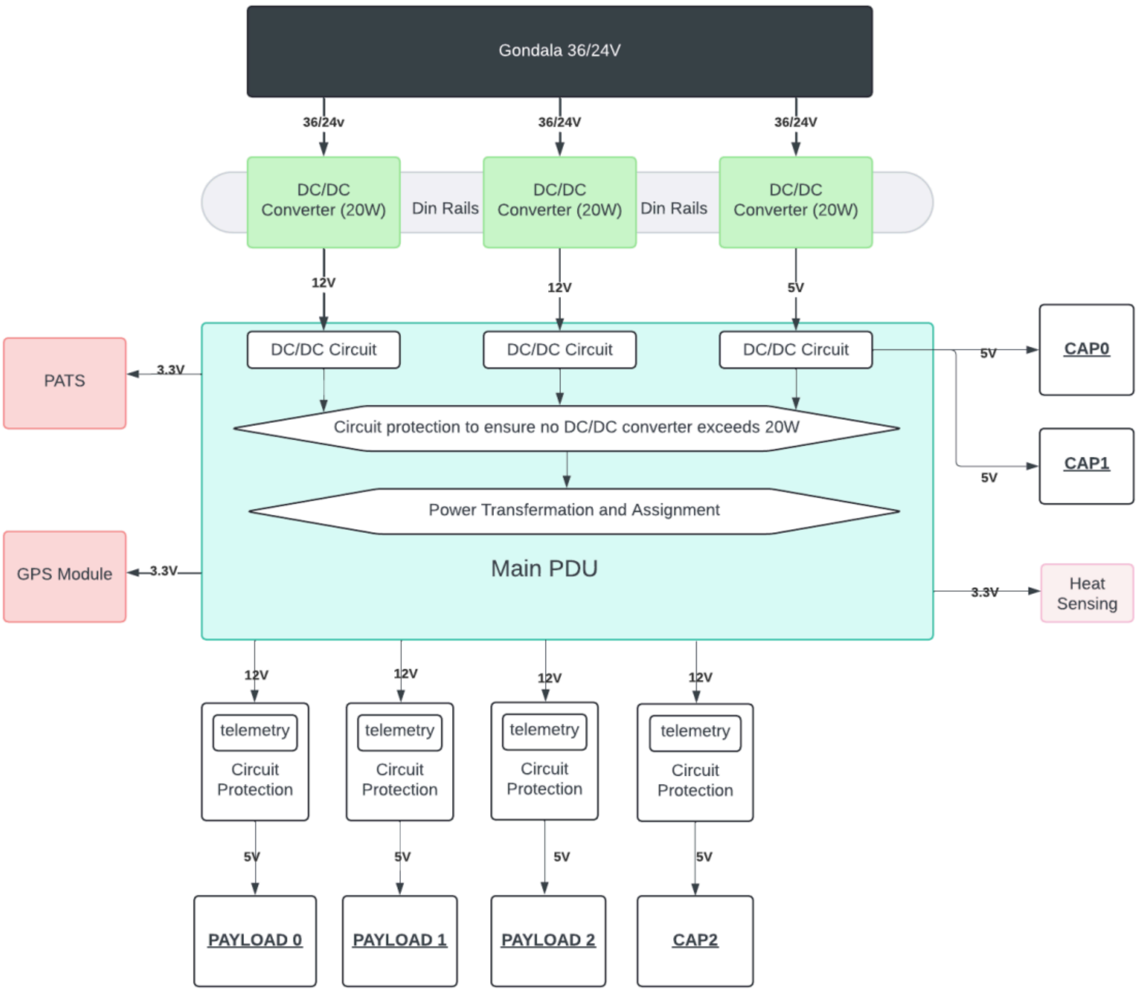

Figure 1 - Shows where payload's power is provided from RSOnar III (Cap 2) [1]

NOVA's electrical design will ensure efficient and reliable continuous imaging for a minimum of 780 minutes. By using the main payload's robust PDU and ensuring all connecting wires adhere to strict electrical standards, NOVA will be able to operate efficiently and effectively at 5V within the budget of 4W as per requirements 1.1 and 9.1.

3.3 Environmental

The NOVA payload must be designed to endure the extreme conditions encountered during the mission's ascent and descent, with temperatures ranging from -30°C to +50°C as specified in requirement 2.2. While the OBC was selected to meet this temperature range, other components, such as the camera, were not due to budget constraints. To mitigate this risk, a trade study was conducted to identify the most effective thermal management strategy.

The study evaluated foam insulation, resin coatings, and multilayer Mylar based on criteria including thermal performance, mass, durability, outgassing risk, and cost. The findings recommend a multi-layered approach, starting with Mylar insulation as the first layer for external thermal regulation. Mylar's lightweight, high reflectivity and low outgassing make it ideal for shielding against radiant heat and UV radiation. This will be complemented by resin coatings for internal components, providing durability, thermal stability, and protection against condensation and outgassing.

Foam insulation was ruled out due to its high outgassing potential and vulnerability to UV degradation, despite its thermal resistance. By integrating Mylar and resin, the thermal management system addresses both external and internal payload requirements, ensuring functionality and reliability throughout the mission.

Figure 2 - Mylar covering for NOVA payload

3.4 Mechanical

The NOVA sub-payload will be housed within the far right bay of the triangular prism alongside 2 other NOVA sub-payloads. The payload shall be mounted within the bolt pattern shown as per requirement 3.1. This follows a 50 mm by 50 mm square, spaced evenly apart at 36.75 mm, placed along a centerline on the bottom panel. The mounting allows the camera to maintain a viewing angle of 45 degrees as per requirement 3.2. We have been informed that we can also mount to the side panels of the chassis if needed. Vibration testing will be conducted to determine whether the use of these anchor points for the camera will increase image quality by lowering interference from vibration.

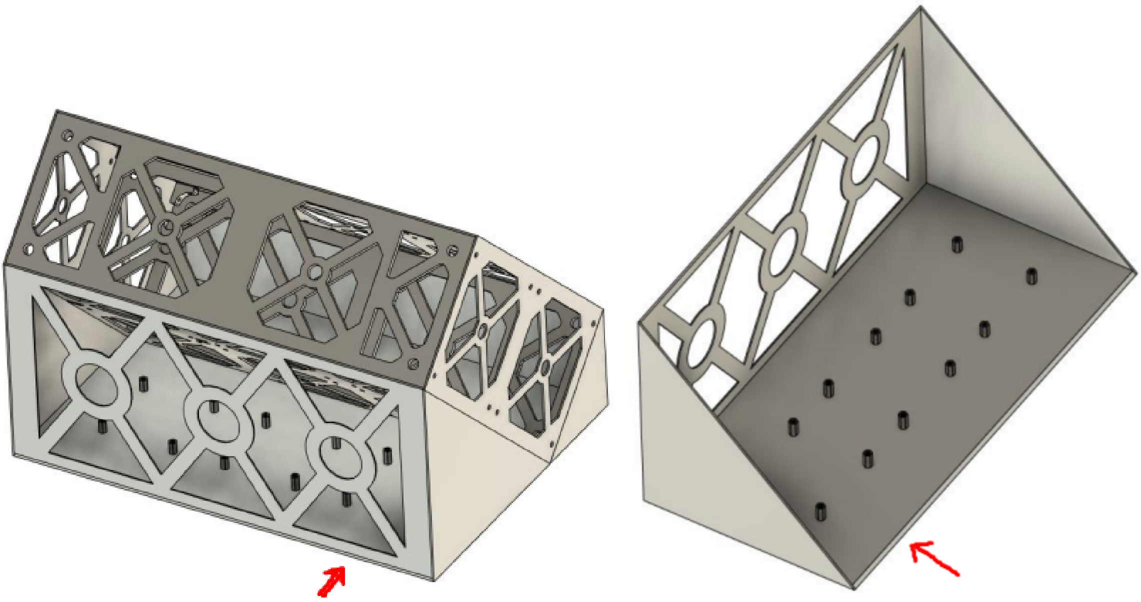

Figure 3 - RSOnar III Chassis with mounting points for 3 capstone sub payloads [7]

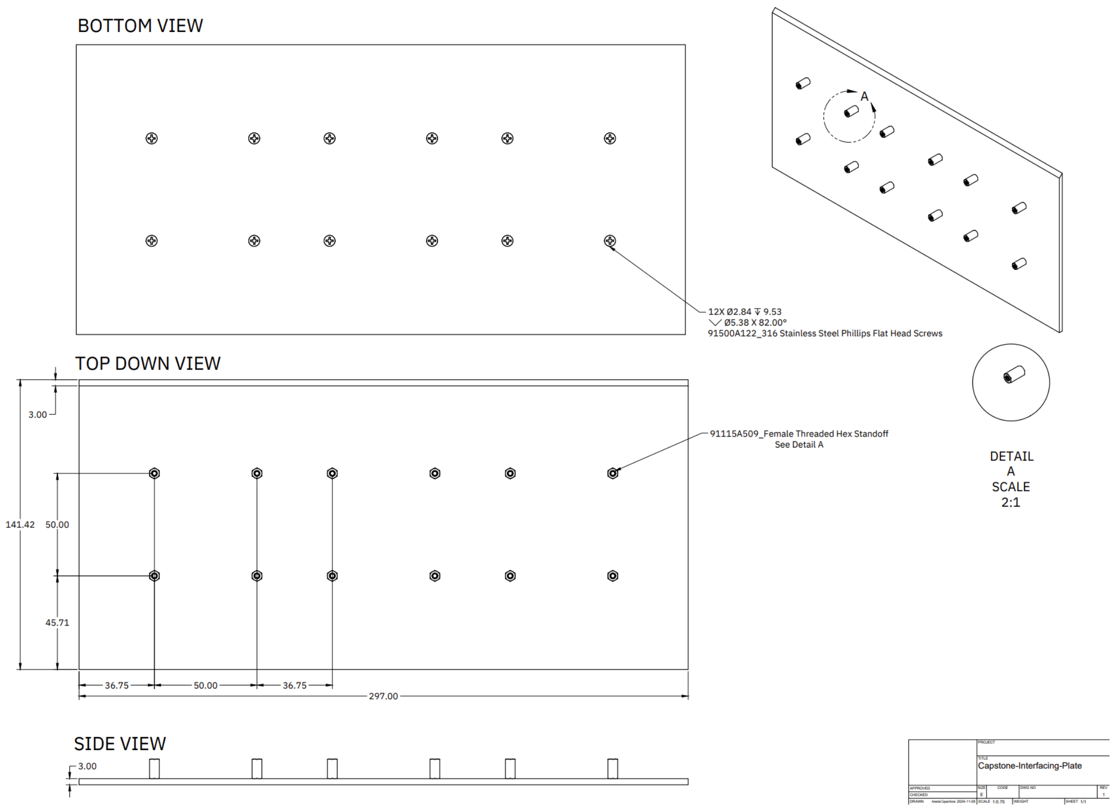

Figure 4 - RSOnar III drawing for mounting points [7]

A dedicated camera mount has been designed to maintain a consistent frame of view throughout the 40-hour mission. To ensure its structural integrity and reliable performance under dynamic conditions, vibration analysis will be conducted as part of the testing process. Additionally, the OBC will be mounted at a 90-degree angle relative to the base plate and the camera. This configuration minimizes cable overlap, reducing the risk of induction currents, while also serving as the central processing unit and control hub for NOVA's operations.

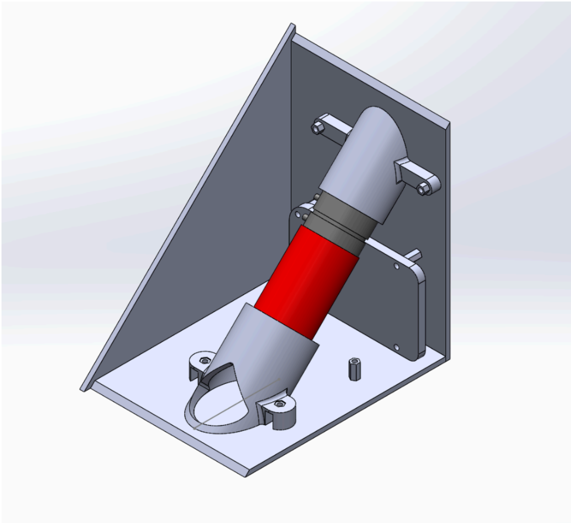

Figure 5 - Final Assembly of the payload peripherals as viewed from a 45-degree angle.

The design utilizes eight standoffs to securely mount both the camera and the OBC. Two of these standoffs are also used by RSOnar III to attach R3 to the main STRATOS payload. This dual-purpose approach introduces redundancy into the design, as the opposing forces within the standoffs increase friction, effectively preventing any unwanted shifting of the R3 payload during operation and ensuring enhanced stability throughout the mission.

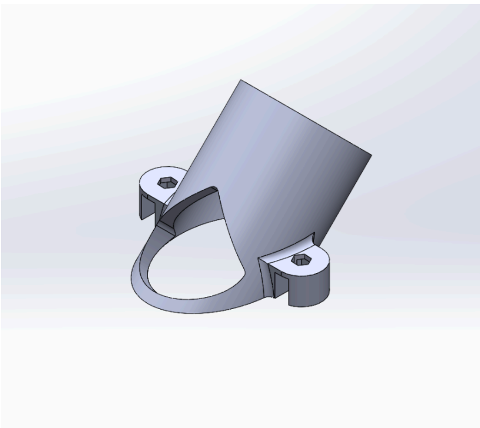

Figure 6 - Bottom Mount for the camera

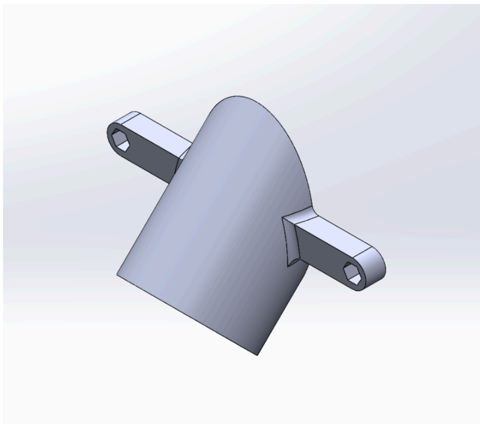

Figure 7 - Top Mount for the Camera

The bottom mount of the camera serves as a device that holds the camera in place while simultaneously maintaining an angle of 45 degrees to ensure a constant field of view. A cavity has been added into the design of this mount towards the bottom to allow for cables taking signals to and from the camera and be used for data analysis upon conclusion of the launch and descent phase of NOVA.

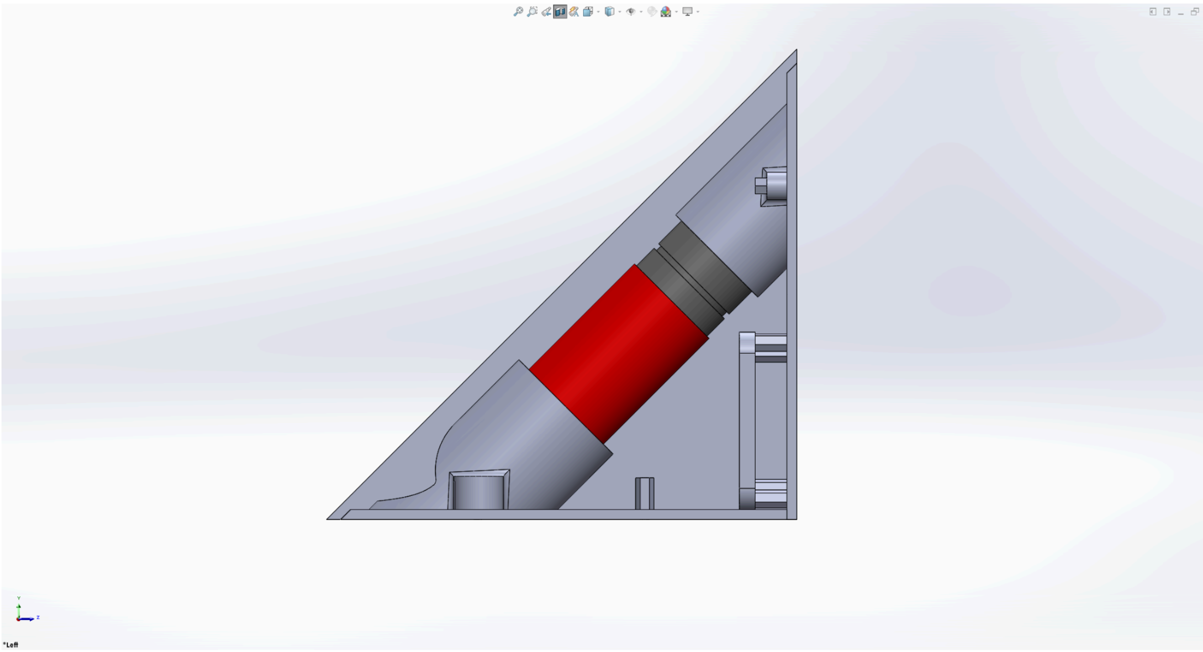

Figure 8 - Side view of the final assembly of the peripherals of NOVA

Finally, changes to the R3 structure have also been requested to allow for proper mounting of the peripherals. These additional holes allow for mounting hardware to be installed which will be crucial during the life of the mission.

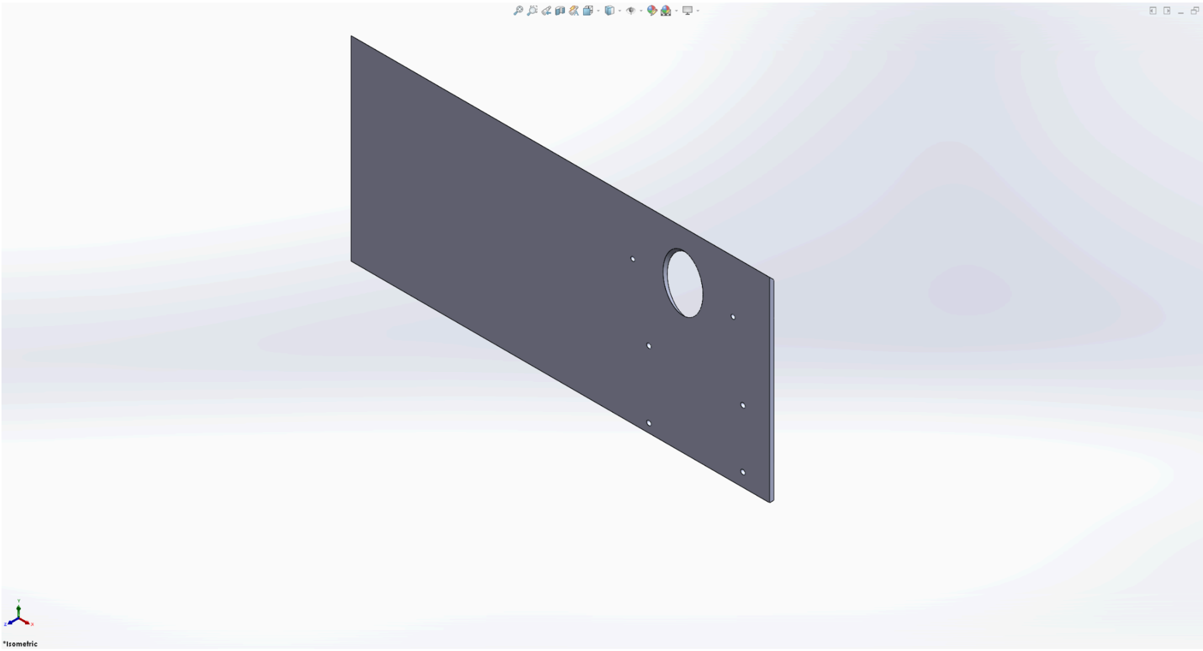

Figure 9 - Required cavities on the back plate of the R3 Structure

Please note that the hole diameters match the hole diameters seen above are the same as the mounting points as defined by the Capstone Interfacing document [7]. An additional hole has been requested to allow for the camera to have a clear field of view during our operation. The top mount of the camera also restricts the camera FoV to only view the outside and not be affected by the LEDs present on our OBC.

Please note that the SolidWorks Part and Assembly files are present within the Appendix for reference if needed.

3.5 Computational

At the heart of NOVA's computational system is the Beagleboard BeagleBone Black Industrial. With a 1GHz ARM Cortex-A8 chip and an operational temperature range of -40°C to +85°C, we are confident it will be able to handle the computational load and environment that is expected of the NOVA payload.

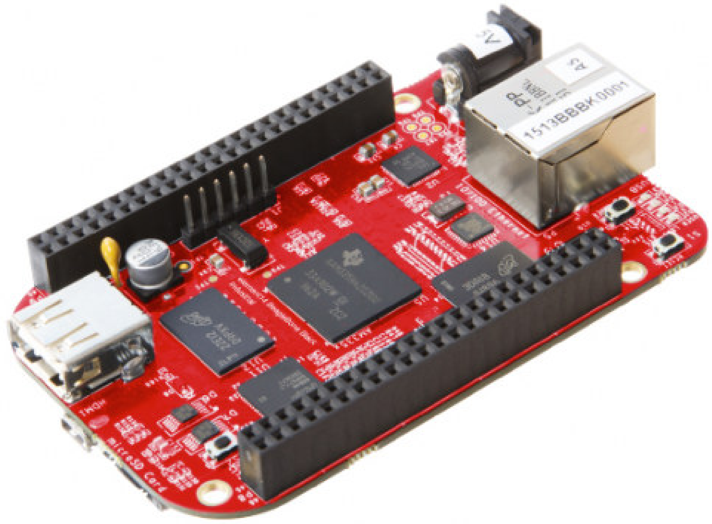

Figure 10 - Beagleboard BeagleBone Black Industrial OBC [8]

3.6 Scientific

NOVA's scientific payload consists of the ZWO ASI120mm mini camera and the Raspberry Pi 6mm WWide-angleLens.

Figure 11 - Camera and Lens [2] [3]

For our purpose of night sky brightness measurements, a high quantum efficiency and a low camera readout noise are key parameters. This makes the camera the driving factor in the scientific subsystem, with the lens choice being driven by our choice of camera. Key parameters for the camera are shown below:

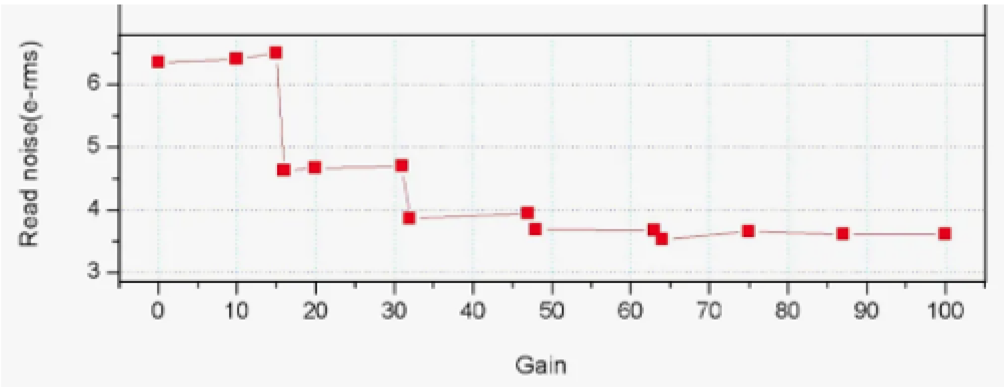

Figure 12 - Camera gain vs Read noise [2]

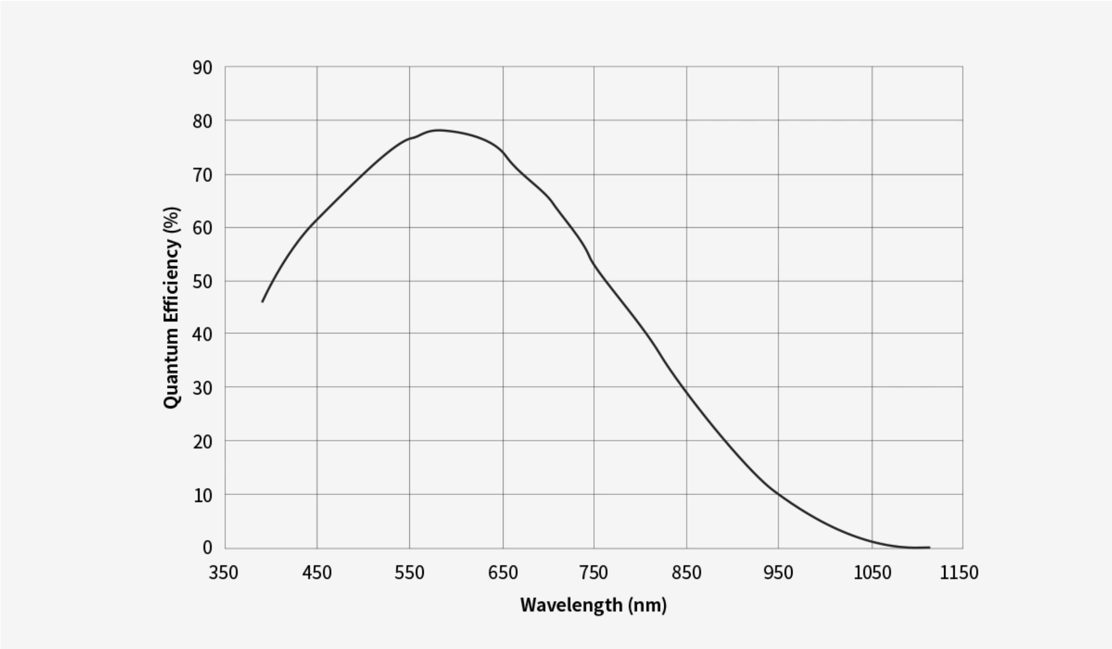

Figure 13 - Camera Quantum efficiency vs wavelength [2]

To ensure the camera-lens combination meets the mission requirements, the focal length of the lens was strategically chosen to match closely to the Field of View (FOV) of the main payload optical system of 29.7 by 29.7 degrees as follows:

$$FOV = 2 \cdot \arctan\left(\frac{SensorDimension}{2 \cdot FocalLength}\right)$$

For the ZWO ASI120MM Mini camera, which has a sensor size of 4.8 mm × 3.6 mm, the vertical dimension of the sensor is 3.6 mm. Substituting the desired vertical FOV of 29.7∘ into the formula and solving for the required focal length:

$$FocalLength = \frac{SensorHeight}{2 \cdot \tan\left(\frac{VerticalFOV}{2}\right)} = \frac{3.6\,mm}{2 \cdot \tan\left(\frac{29.7^\circ}{2}\right)} \approx 6.78\,mm$$

This calculation shows that a lens with a focal length of approximately 6.78 mm is required to achieve the desired vertical FOV. However, commercially available lenses include a 6 mm lens, which is the closest option that maintains the required vertical FOV. Using a 6 mm lens results in the following vertical FOV:

$$VerticalFOV = 2 \cdot \arctan\left(\frac{3.6\,mm}{2 \cdot 6\,mm}\right) = 2 \cdot \arctan(0.3) = 33.4^\circ$$

This slightly exceeds the required vertical FOV, which is acceptable for the mission. Consequently, the horizontal FOV will be larger due to the sensor's rectangular shape. For a 6 mm lens, the horizontal FOV is calculated as:

$$HorizontalFOV = 2 \cdot \arctan\left(\frac{4.8\,mm}{2 \cdot 6\,mm}\right) = 2 \cdot \arctan(0.4) = 43.6^\circ$$

This larger horizontal FOV is a necessary compromise to maintain the vertical FOV alignment with the main payload. The 6 mm lens thus provides the closest practical solution, balancing the mission's scientific objectives and available hardware options. An alternative is to use adjustable lenses, which are considered in the trade study, although they come with other potential issues.

3.7 Software

The software architecture for the NOVA payload aims to build upon the proven design from RSOnar II [1], utilizing Armbian, a lightweight Linux distribution, chosen specifically for its minimal resource requirements and power efficiency. The primary control software integrates the ZWO SDK [2] for camera operations with our custom data management system for continuous image capture and storage.

The operating system and control software are designed to run on the BeagleBone Black Industrial, interfacing directly with the ZWO ASI120mm mini camera through the SDK. This configuration allows for precise exposure control and data acquisition while maintaining power consumption below our 4W limit as per requirement 9.1. The system implements three primary exposure modes - 5s, 10s, and 15s - to match the main payload's imaging cadence [4], enabling synchronized data collection for accurate brightness measurements. For the operating system, we will also need to consider its resilience to damage and data corruption, as it will be used in a high-altitude environment.

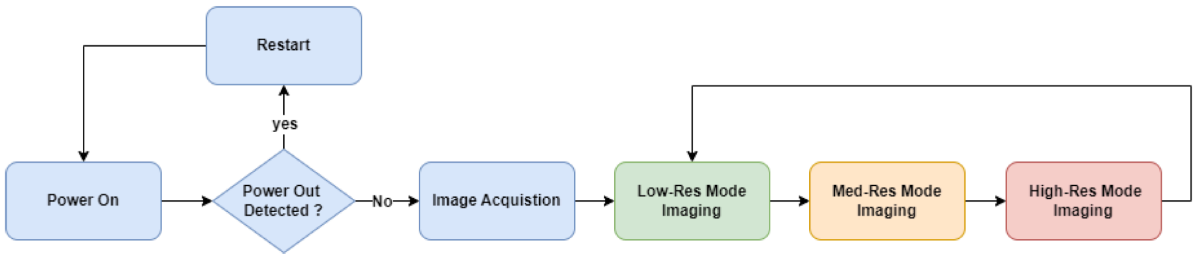

Figure 14 - Software architecture diagram showing data flow between components [1]

4.0 Baseline Design Compliance Analysis

The NOVA payload will go through extensive testing to ensure all subsystems comply with CSA regulations to ensure mission success. This includes:

Component-level testing

Each component will go through testing to assess the performance metrics such as response times, power consumption and compatibility. By identifying and addressing issues at the component level we can prevent failures before system level testing.

Vibration testing

Vibration testing will simulate the environment at the altitude of 40km that the components will experience during launch, operation, and landing impact. This will ensure all parts can withstand the vibrations without structural integrity issues.

Vacuum Testing

This test will evaluate the performance and survivability of components in a vacuum. This ensures that they function correctly in the harsh environments they will be exposed to during the mission.

Cold Chamber Testing

This test will assess the system's performance in sub-zero temperatures. This is critical to ensuring that the components remain operational and do not freeze or malfunction in the atmospheric conditions at the desired altitude.

4.1 Electrical

With the electrical design being provided by the RSOnar 3 team, we are confident that it will comply with CSA standards. Our only concern is ensuring our system functions with 5V under 4W during peak processes to comply with mission requirements 1.1 and 9.1. We are confident that the NOVA payload will comply with all electrical design requirements.

4.2 Environmental

The key failure point within our environmental subsystem is the extreme temperature range present in the atmosphere between 0 and 40 km heights. We are confident that our extensive thermal management and testing plan will ensure our payload meets all requirements. We have been working with the RSOnar team and have confirmed that the entire payload including all sub payloads will be encased in mylar, as well as coated with resin. On top of the thermal plans of the RSOnar team, the NOVA sub-payload team will also include closed-cell polyethylene, heatsinks, and internal mylar on key components. With this extensive thermal management plan, cold chamber testing, and key components such as the OBC that is designed to withstand this temperature range, we are confident that the thermal management plan will ensure the functionality of the NOVA sub-payload.

4.3 Mechanical

The mechanical design of NOVA ensures structural integrity, precise alignment and reliability under extreme conditions while adhering to the mass and spatial constraints. Usage of Aluminum 6061 ensured the low weight of the payload itself while providing us with the required strength for our operation. Our camera, ZWO ASI120MM Mini, has been mounted at an angle of 45 degrees from the base which is critical for imaging accuracy. The design of the mount for the camera also accounts for the vibrations that may take place during launch and descent and restrict movement within multiple axes to have a constant image field of view. To ensure the proper manufacturing of our designed mounts, we have ensured that all members of the NOVA team have been provided with the necessary machine shop training to account for DFM Standards as well. A major concern for our payload is the vibrations that occur during the launch and descent which will be simulated pre-launch through Vibration analysis alongside, Thermal Vacuum testing and Cold Chamber testing.

4.4 Computational

The main concern within our computational system is the ability to stay under 4W during peak imaging to comply with requirement 9.1. We are confident from our trade studies and research, as well as approval from mission supervisors that the BeagleBone Beagleboard black industrial will comply with all other requirements. Another concern is the integrity of our image data saved on the SSD in the event of thermal shock upon landing. Resin coating along with proper vibrational testing will ensure the integrity of data in this event.

4.5 Scientific

Both cold chamber and vacuum testing will be conducted while imaging, at the highest frequency expected during our mission. This approach ensures that the camera meets the required performance standards under the harsh environmental conditions it will face. Specifically, the tests will validate the camera’s ability to capture high-quality optical data on night sky brightness with minimal noise and consistent accuracy, even in extreme cold and low-pressure environments. The imaging data collected during these tests were analyzed for resolution, signal-to-noise ratio, and calibration stability, confirming that the payload can deliver precise measurements necessary for atmospheric and celestial studies. These tests also ensure the camera’s readiness for extended operation during the mission, aligning with the scientific objectives of the payload.

4.6 Software

The selection of Linux as our operating system was justified through many factors. As it has many variations, it yields the necessary drivers and tools for our hardware while minimizing overhead processes. This is critical for maintaining our 4W budget as per requirement 9.1, with an expected power draw of approximately 1.8W during normal operations based on similar implementations in stratospheric missions [4][5].

The implementation of the three different exposure times of 5s, 10s, and 15s is in direct support of our mission's scientific objectives by making sure we can maintain consistent data collection intervals, ensure synchronization with the main payloads imaging and provide flexibility for varying light conditions. We must also enable direct comparison with RSOnar IIIs primary camera data collection. Our state-machine architectural approach is designed to provide predictive behaviour during mood transitioning, clear operational states for system monitoring, efficient resource management, and defined error recovery procedures.

The ZWO SDK implementation is due to its compatibility with our camera hardware and its ability to provide efficient image data handling, its direct access to camera parameters and its built-in error-checking capabilities. This is also the reason we are using C++ as our coding language of choice, as the SDK is written in this language and it has the most benefits when it comes to image-capturing software implementation.

5.0 Trade Study Identification

5.1 Electrical

Trade studies were not conducted on Electrical design. This was a predefined portion of our mission before capstone, and we were required to use a pre-designed power distribution unit from within the main RSOnar payload. Providing our power unit that meets the rigorous standards of the CSA is not within the budget of our mission, hence receiving power from the main payload is the best and only viable option. We are to provide them with the connection type, and they are to provide the proper connections that meet CSA standards and provide 5V at a maximum of 4W for our OBC, which will be powering the camera.

5.2 Environmental

The purpose of this thermal case study is to evaluate and recommend effective thermal insulation and regulation methods tailored to the NOVA payload. By analyzing established practices in the aerospace industry, including the use of foam insulation, Mylar, and resin conformal coatings, this study seeks to provide a comprehensive strategy for managing internal and external payload temperatures. This framework will enhance the durability and efficiency of the NOVA payload's electronic components, ensuring mission success while maintaining compliance with environmental requirements.

Defining Temperatures and Impact:

1. **External Temperature Range:** Between -30°C and +50°C, requiring robust insulation to prevent external conditions from adversely affecting payload functionality.
2. **Internal Temperature Regulation:** Maintaining a controlled range critical for the operation of electronics, particularly the camera and OBC. Proper regulation prevents performance degradation due to temperature fluctuations.

Applications to NOVA Payload: These methods ensure sensitive electronics such as the ZWO ASI120MMMini camera and BeagleBone Black Industrial OBC operate efficiently. Thermal coupling, insulation, and coatings will maintain the necessary internal temperature stability, directly supporting mission objectives.

5.2.1 Candidate Thermal Solutions

5.2.1.1 Foam Insulation

Description: Foam insulation provides thermal resistance by minimizing heat transfer. Common materials include closed-cell polyethylene foam.

- **Advantages**:
  - Excellent thermal resistance.
  - Lightweight and offers vibration damping.

- **Disadvantages**:
  - High outgassing potential in vacuum environments, risking contamination.
  - Degrades under UV exposure, reducing long-term reliability.
- **Specific Details**:
  - Thermal Performance: ~0.03 W/(m·K) thermal conductivity.
  - Mass: Lightweight (<5 g/cm^3 depending on thickness).

5.2.1.2 Resin Coating

Description: Resin coatings, such as Parylene or silicone-based, are applied directly to electronic assemblies to protect against environmental stressors.

- **Advantages**:
  - Minimal outgassing; suitable for vacuum environments.
  - Durable under UV exposure and mechanical stress.
  - Enhances thermal coupling.
- **Disadvantages**:
  - Slightly heavier than foam insulation.
  - Requires precise application techniques.
- **Specific Details**:
  - Thermal Performance: Conductivity depends on the material (e.g., 0.1–0.2 W/(m·K)).
  - Mass: Adds ~10–20 g per square meter of coverage.

5.2.1.3 Mylar Insulation

Description: Mylar, a polyester film, is used in multilayer insulation (MLI) systems to reflect radiant heat and shield against UV radiation.

- **Advantages**:
  - Extremely lightweight.
  - Proven performance in aerospace missions.
  - Low outgassing.
- **Disadvantages**:
  - Fragile under mechanical stress; requires secure mounting.
- **Specific Details**:
  - Thermal Performance: Reflectivity >95%; conductivity negligible due to multilayer design.
  - Mass: ~1.4 g/m^2 for 25-micron thickness.

5.2.2 Trade-Off Analysis

Table 3 - Trade-Off Analysis

Criteria	Foam Insulation	Resin Coating	Mylar	Preferred Option
Thermal Performance	Excellent resistance to heat transfer.	Good; enhances heat dissipation with coupling.	Reflects radiant heat effectively.	**Depends on purpose**
Mass Impact	Lightweight.	Slightly heavier than foam (but marginal).	Extremely lightweight.	**Mylar**
Outgassing Risk	High; significant testing required.	Minimal; highly vacuum-compatibl e.	Minimal; proven vacuum performance.	**Resin or Mylar**
Durability	Degrades under UV and vibration stress.	Highly durable and resistant to UV and mechanical stress.	UV-resistant but fragile under vibration.	**Resin**
Ease of Integration	Moderate; requires careful placement.	Moderate; requires precision application.	Simple application but needs secure mounting.	**Equal**
Cost	Low material cost but testing adds expense.	Moderate upfront cost.	Low material cost; minimal additional testing.	**Mylar**

5.2.3 Evaluation and Scoring

Table 4 - Evaluation and scoring of Trade-Offs

Criteria	Weight	Foam Insulation	Resin Coating	Mylar Insulation
Thermal Performance	25%	4	4	4
Mass	15%	5	3	5
Durability	20%	2	5	3
Outgassing Risk	20%	2	5	5
Cost	20%	4	3	4

Total Score	100%	**3.25**	**4.2**	**4.0**

5.2.4 Recommended Solution

Given the mission's environmental conditions and CSA/MDA requirements:

1. **Primary Solution**: **Resin Coating**
   - Provides durability, vacuum compatibility, and protection against condensation and UV radiation.
   - Ensures structural reinforcement and thermal coupling for key components like the camera and onboard computer.
2. **Supplementary Protection**: **Mylar**
   - Applied as an external layer to enhance UV and radiant heat shielding.
   - Offers lightweight additional protection but requires careful integration to prevent tearing.
3. **Avoid Foam Insulation**:
   - Outgassing risks and UV degradation make foam unsuitable for this mission, despite its thermal resistance.

The recommended solution is a combination of resin coating and Mylar insulation, which aligns with CSA and MDA requirements for vacuum compatibility, UV resistance, and thermal management. This approach ensures the payload can operate reliably in the extreme environmental conditions of a stratospheric mission.

5.3 Computational

The OBC and storage are the core of NOVA's processing and data handling. Very careful consideration needs to be done when choosing these components. Many factors go into choosing the best OBC and this trade study aims to evaluate different choices based on the defined criteria. These will not only impact the reliability of the payload but also the quality and amount of data we obtain. The OBC must be capable of efficiently processing and storing large amounts of data while keeping a low power draw, and maintaining a stable temperature for a long duration of continuous imaging. To ensure the OBC design meets all of these requirements, the following parameters need to be considered:

Size and weight(10%)- Must be minimized to adhere to all payload constraints.

Cost(20%)- The chosen OBC must be as cost-effective as possible while still ensuring all operational requirements are met.

Power consumption(20%)- It must operate within the available power budget of 4W at 5V while providing power to the camera and storage device.

Temperature range(20%)- The OBC must be able to operate within the -30°C to +50°C with the help of the thermal subsystem. The wider this range, the more reliable.

Computational power(15%)- The OBC will need to be able to handle the throughput of image processing and error correction algorithms. This will be a continuous image file stream over a long duration.

Software/ Programmability(15%)- The OBC needs to be able to support custom software, as well as programming environments that our team is familiar with.

With these parameters in mind, a trade study was conducted where several different OBCs were compared.

Table 5 - OBC Comparison Chart [9] [10]

OBC	Processor	Expected load Power Draw	Weight	Size (L x W x H)	Temp Range	Programmability	Cost
Beagle Bone Black Industrial	ARM Cortex-A8 @ 1 GHz	~3W	37g	86 x 54 x 12 mm	-40°C to +85°C	Linux (Debian), Python, C, C++	~$110
PIC32 MZ OBC	PIC32MZ M14K @ 200 MHz	~1.5W	120g	144 x 101 mm	-40°C to +85°C	C, C++, Assembly, FreeRTOS, Micrium OS	~$100
NanoPi Neo H3	ARM Cortex-A53 @ 1.5 GHz	~2W	22g	40 x 40 mm	-20°C to +70°C	Linux (Armbian), Ubuntu Core, FriendlyWrt	~$50

Each of the OBC's considered above are rated on a scale from 1 to 5 for each of the 5 defined criteria to determine the best OBC choice.

Table 6 - OBC decision matrix

Criteria	**Weight (%)**	**BeagleBone Black Industrial**	**PIC32MZ OBC**	**NanoPi Neo H3**
Size and weight	10	4	2	5
Cost	20	2	3	5
Power Consumption	20	3	5	4

Temperature range	20	5	5	3
Computational power	15	5	2	2
Software/ Programmability	15	4	1	3
Total	100	3.75	3.25	3.65

Although the PIC32MZ has the lowest power draw, it has the most complex programming environment, and it is much larger, heavier, and slower than the other options. So it was ultimately not chosen. With the reliable temperature range, low weight, and small size, the BeagleBone Black Industrial ended up just being the best choice. With the temperature range of the atmosphere being the most challenging failure point in this project, the extra price and power draw of the BeagleBone is a worthwhile tradeoff that ultimately led us to choose it for the OBC on the NOVA payload.

5.4 Scientific

This study focuses on 12-bit cameras available within a budget of 300 CAD. We prioritized astronomical guide cameras because they emphasize high quantum efficiency and low readout noise, which are key factors for detecting faint stars in low-light conditions. These cameras can detect subtle changes in brightness without the added cost of high-resolution sensors found in other high-end cameras, which are unnecessary for our purposes. These specifications aim to select a camera that maximizes scientific value for obtaining highly accurate sky brightness measurements while remaining cost-effective. For the lens choice, this study focuses on 6mm commercially available lenses under 125 CAD. The focal length of 6mm was chosen because it's the closest available focal length to match the 6.8mm focal length that achieves a FOV of 29.7mm without an adjustable lens. This is the FOV of the Main payload camera that we will be supporting with our brightness measurements for better calibration. Each criterion is weighted according to its importance with respect to the mission objectives and requirements, reflecting the level of priority each imposes on the camera design.

- **Quantum Efficiency (QE) (20%)** - A key scientific parameter influencing the camera choice.
- **Readout Noise (15%)** - The second key scientific parameter driving the camera choice.

- **Power Consumption (15%)** - With a low power budget of 4 watts, there is an important trade-off between computing power and camera power, making this a critical parameter.
- **Physical Dimensions (5%)** - Our physical dimensions provide ample room, so as long as the camera size is reasonable, this is a less important factor.
- **Operating Temperature Range (10%)** - While important, acceptable cameras that can operate in the expected atmospheric temperature range are generally outside our budget. We plan to mitigate this with thermal design to allow a cost-effective camera that provides useful scientific measurements.
- **Mass (5%)** - The total mass is expected to stay well below 500 g if the camera weight is reasonable, making this a lesser priority.
- **Cost (25%)** - The most important factor given the budget constraint. Key scientific features, such as high quantum efficiency and low readout noise, increase camera costs, making cost a primary factor.

The following cameras were assessed based on the evaluation criteria outlined above, ensuring traceability to the mission requirements:

Table 7 - Camera comparison [2]

Feature	ZWO ASI120MM Mini	ZWO ASI220MM Mini	QHY5L-II Mono
Quantum Efficiency (QE)	79%	92%	74%
Readout Noise	4.0 e to 6.5 e	0.6 e to 3.2 e	4 e to 6.5 e
Power Consumption	0.8W (160mA at 5V)	0.8W (160mA at 5V)	0.64W
Physical Dimensions	36mm x 61mm	36mm x 61mm	31mm x 70mm
Operating Temperature Range	-5°C to +45°C	-5°C to +45°C	-40°C to +50°C
Mass	60g	60g	51g
Cost (CAD)	200	350	200

Each camera is scored based on how well it meets each criterion in alignment with mission requirements (see Requirements Table). This scoring matrix reflects both the absolute suitability and the trade-offs necessary for each camera model.

Table 8 - Weighted scoring matrix for camera choice

Criteria	Weight	ZWO ASI120MM Mini	ZWO ASI220MM Mini	QHY5L-II Mono
Quantum Efficiency (QE)	20%	4	5	3
Readout Noise	15%	3	5	3
Power Consumption	15%	5	5	5
Physical Dimensions	5%	5	5	4
Operating Temperature	10%	3	3	4
Mass	5%	4	4	4
Cost	25%	5	0	5
Total Weighted Score	100%	**4.00**	**3.25**	**3.85**

Each criterion is weighted according to its importance with respect to the mission objectives and requirements, reflecting the level of priority each imposes on the lens design.

- **Aperture (f-stop) (25%)** - A key optical parameter that influences the lens's ability to gather light and maintain clear imaging in low-light conditions.
- **Optical Quality (25%)** - Ensures the lens provides sufficient resolution to distinguish stars and measure sky brightness accurately, which is critical for achieving scientific objectives. Adjustable lenses generally have a lower optical quality than fixed FOV lenses.
- **Mass (10%)** - The total mass of the payload is expected to stay well within the overall limit of 500 g.
- **Physical Dimensions (10%)** - The lens while attached to the camera must fit within the specified payload geometry. While spatial constraints are manageable, ensuring compatibility is still necessary.
- **Cost (30%)** - The most important factor given the budget constraint. Balancing optical quality with affordability is essential to meet both scientific and financial requirements.

The following lenses were assessed based on the evaluation criteria outlined above, ensuring traceability to the mission requirements:

Table 9 - Lens comparison [3]

Feature	Raspberry Pi 6mm Wide Angle Lens	FA 6mm Machine Vision	ZWO 2.8-12mm f/1.4 Adjustable Lens
Aperture (f-stop)	f/1.2	f/2.0	f/1.4
Focal Length	6 mm	Adjustable 6 mm	Adjustable (2.8 mm to 12 mm)
Lens Type	Fixed	Fixed	Varifocal
Compatibility	C-Mount	C-Mount	CS-Mount
Weight	53 g	34.5 g	55 g
Size	30 x 34 mm	26.8 x 23.5 mm	42 x 32 mm
Cost (CAD)	Approximately 45 CAD	Approximately 110 CAD	Approximately 50 CAD

Each lens is scored based on how well it meets each criterion in alignment with mission requirements (see Requirements Table). This scoring matrix reflects both the absolute suitability and the trade-offs necessary for each lens option.

Table 10 - Weighted scoring matrix for lens choice

Criteria	Weight	Pi 6mm Wide Angle Lens	FA 6mm Machine Vision	ZWO 2.8-12mm f/1.4 Adjustable Lens
Aperture (f-stop)	25%	5	2	4
Optical Quality	25%	4	5	2
Mass	10%	3	5	3
Physical Dimensions	10%	4	5	3
Cost	30%	5	2	5
Total Weighted Score	100%	**4.45**	**3.35**	**3.6**

This trade study determined that the ZWO ASI120MM Mini is the most suitable camera for our stratospheric balloon mission aimed at measuring optical night sky brightness. Although the ZWO ASI220MM Mini has higher quantum efficiency and lower readout noise, the price increase of 150 CAD for only a 13 percent improvement in quantum efficiency limits its suitability for our mission objectives. It was included to give stakeholders a clear idea of the key trade-offs between price and performance. The QHY5L-II Mono has a better operational temperature range but falls short in technical performance compared to the ASI120MM Mini. Overall, the ASI120MM Mini offers a balanced solution that meets the mission's primary requirements, balancing technical capability, cost-effectiveness, and environmental suitability.

For the lens choice, the Pi 6 mm wide-angle lens was the clear winner. Although it is the cheapest of the 3, it has a fixed focal length of 6 mm which means fewer moving parts compared to the adjustable lens. It also had the largest aperture for collecting light. Although it was not the smallest and lightest, we can avoid using the 5 mm spacer due to it being the only CS mount lens of the 3.

Based on this analysis, the **ZWO ASI120MM Mini** and **Pi 6 mm wide angle lens** are the recommended choice for our mission. To ensure reliable operation in the expected environmental conditions, thermal management solutions are required to mitigate the camera operating temperature limitations, as specified in Requirements ENV-02 and ENV-04. Likewise, Vibrational testing is recommended to ensure all adjustment screws on the lens will maintain focus for the full mission duration. Additionally, it is required that we take proper Flats and Bias images near the flight date to ensure the scientific team can properly calibrate the images for scientific use.

5.5 Software

The software case study was done in two parts so that there was enough research into the many software components we would be using for the NOVA project. The first thing we focused on was finding the appropriate operating system as this would need to be able to run on our OBC of choice and be able to work with the other hardware components in our system. We looked mainly at four different operating systems, Armbian, Linux, Pi Lite and FreeRTOS. Our main areas of concern were the compatibility of the operating system with our hardware and software, the power consumption of the OS and the learning curve related to operating systems due to us having not known them before.

Table 11 - Decision matrix for candidate operating system

Criteria	**Armbian**	**Linux**	**Pi Lite**	**FreeRTOS**
Hardware/Software Compatibility	4	**5**	3	4
Power Consumption	**5**	2	2	**5**
Learning Curve	3	4	**4**	3
Total Score	12	11	9	**12**

The case study revealed that it would be ideal for us to continue with either FreeRTOS or Armbian as our OS of choice for this project. Although they seem to be the better choice, due to our familiarity with **Linux** kernels, we will be going with that for now with the idea of possibly moving towards FreeRTOS if possible. If we can complete our requirements easily, we might take this leap to make our project more efficient and effective.

The second thing we needed to consider for our software case study was the language that we would be choosing to code our image-capturing software in. We had different criteria for these such as its data acquisition capabilities, compatibility with different OS and hardware, power efficiency, memory allocation efficiency and learning curve as again we are not completely familiar with all of these languages.

Table 12 - Decision matrix for candidate Coding Language

Criteria	**C**	**C++**	**Python**	**Java**
Data Acquisition	5	**4**	3	3
Compatibility with Hardware and OS	5	**5**	4	4
Power Efficiency	5	**4**	2	3
Memory Efficiency	5	**4**	2	3
Learning Curve	1	**4**	4	4
Total Score	21	**21**	11	13

From this case study, we were able to understand that **C++** would be the best candidate for coding language for creating a much more capable and efficient image-capturing software. Although there is a tie between C++ and C, we have opted for C++ because the syntax is more familiar to our software engineers and is more compatible with our camera. It is also able to do more than regular C taking care of some of the hard work. Due to one of our group members being proficient in Python, we will be using that to create an example attempt at the software so we can get a feel for the way we want our final software to function and we can get preliminary testing on our other components as well.

6.0 Sustainability and Unintended Consequence Analysis

The NOVA design incorporates a thorough review to ensure sustainability and mitigate potential unintended consequences, with careful consideration given to its environmental impact and compatibility with broader mission objectives. The payload design aligns with the United Nations Sustainable Development Goals (UN-SDGs), particularly Goal 12: Responsible Consumption and Production, by utilizing lightweight, commercially available components and maintaining a low power consumption of just 4 watts. This design minimizes resource usage while ensuring efficient operation, reflecting a commitment to responsible engineering practices. Thermal management solutions, such as multi-layer Mylar insulation and resin coatings, have been implemented to protect the payload in extreme conditions.

These materials provide effective thermal regulation without relying on substances with high environmental risks, ensuring durability and reliability throughout the mission.

To address potential unintended consequences, such as material outgassing or heat generation that could interfere with other sub-payloads, the NOVA design has been subjected to rigorous testing protocols. These include vacuum, vibration, and cold chamber testing to simulate high-altitude conditions and identify risks that could compromise the mission. Collaboration with the RSOnar III team has further ensured thermal and mechanical compatibility, reducing the likelihood of interference or integration issues during deployment. These efforts align with Goal 9: Industry, Innovation, and Infrastructure promoting sustainable innovation in the design and implementation of scientific payloads.

Beyond its operational considerations, the NOVA mission contributes to broader societal and environmental objectives. The high-quality data it collects will support external stakeholders, including astronomical researchers and environmental advocacy groups, in advancing their studies on light pollution and atmospheric clarity. These efforts tie into Goal 13: Climate Action, as the data can inform strategies to mitigate artificial lighting's impact on the environment, and Goal 15: Life on Land, by fostering initiatives to protect natural ecosystems from excessive light pollution. By integrating sustainability into its design and proactively addressing risks, NOVA demonstrates a balanced approach that aligns with scientific, environmental, and operational objectives while contributing to the global goals outlined by the UN SDGs.

7.0 Project Management Updates

7.1 Work Breakdown Structure

Figure 15 - Work Breakdown Structure outlining the finished Work Packages

Please note that the boxes highlighted in green have been completed whereas the boxes highlighted in purple define our plan for the upcoming winter semester. This work breakdown structure provides us with a well-defined plan that allows us to successfully finish a working solution for our capstone project.

7.2 Gantt Chart

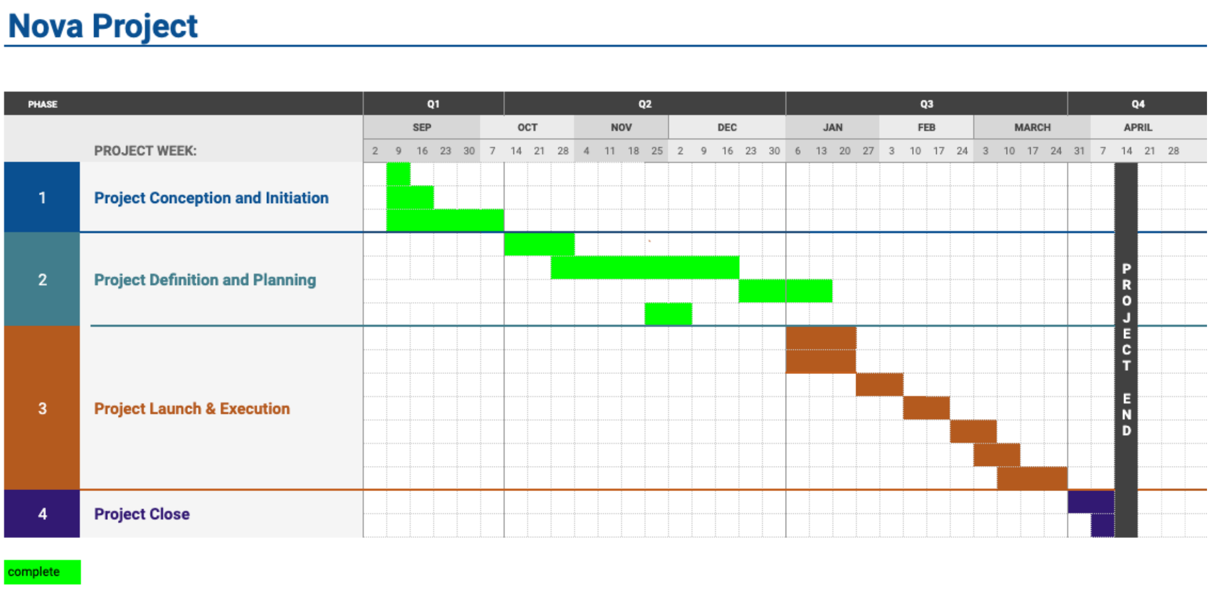

Figure 16: Updated Gantt Chart

The Gantt Chart has been updated to more accurately reflect the project's progress. Phases 1 and 2 have been completed (marked in bright green). Phase 3 has been extended to include more levels of testing.

Phases:

1. **Project Conception and Initiation**
    a. - Establish Communication Methods 0po
    b. - Define Team Roles and Responsibilities
    c. - Preliminary Research and Planning
2. **Project Definition and Planning**
    a. - Hardware Selection
    b. - Integration and Calibration Planning
    c. - Research Key Variables
    d. - Budget/Create BOM
3. **Project Launch and Execution**
    a. - Component Testing-
    b. - Implementation of Software
    c. - Subsystem Testing
    d. - System Testing
    e. - Interface Testing
    f. - Final Integration
    g. -Construction of NOVA

4. **Project Close**
    a. - Final Review and Preparation
    b. - Handover NOVA to RSonar Team

7.3 Bill of Materials (BOM)

Table 13 - Estimated material cost

Component	Estimated Cost (CAD)	Manufacturer	Notes
BeagleBone Black Industrial	~$110	BeagleBoard.org	Onboard Computer (OBC) for processing and control; industrial temperature range.
ZWO ASI120MM Mini Camera	~$225	ZWO	High quantum efficiency and low readout noise; meet scientific requirements for sky brightness measurements
Camera Lens	~$50	Raspberry Pi 6mm widefield	The camera needs some sort of lens to focus/ take images
Micro SD Card	~$50	SanDisk / Kingston	Needs to provide sufficient storage for image data; standard grade for cost reduction
Wiring Harnesses	~$20	undetermined	For powering components and data connections between components.
Insulation	~$20	undetermined	For keeping components within operational temperatures if needed
Aluminum 6061	~$50	undetermined	For the internal OBC and camera mount
Contingency	~$125	N/A	To account for fluctuating costs and currency conversions. These funds would be used as emergency cash and proper receipts will be provided upon usage.
Total	$ 650	N/A	This implies that we would be requiring approval of the budget from our faculty supervisor Professor Micheal Bazzocchi.

7.4 Risk Register

Table 14 - Risk register

ID	Risk	Impact	Likelihood	Mitigation Strategy	Status
1	**Thermal Failure**	High	High	Mylar, foam insulation, resin coating, thermal coupling, heatsink, cold chamber testing.	Active
2	**Vibration Damage**	High	High	Vibration testing. Use of durable materials. Rigid harnessing of project to payload. Resin coating	Active
3	**Radiation Interference**	High	High	Use of error correcting algorithms in the software when saving the data.	Active
4	**Schedule Delays**	High	High	Gantt Chart, Time buffers, Critical task prioritization, ensuring fast delivery times of components.	Active
5	**Power Constraint of 4W**	High	Medium	Parts chosen for the project with power usage in mind. Discussion with project leads if more power is required.	Active
6	**Payload Integration**	High	Medium	Work closely with the primary payload team. Use of Interface Control Document for specifications.	Active
7	**Component Failure**	High	Medium	Use of robust and highly reliable equipment and modules	Active
8	**Data Loss**	High	Medium	Use of non-volatile solid state storage. Have data loss protocol in place.	Active
9	**Over Budget**	Medium	Low	Budget reviews. Consider cheaper alternatives when possible while maintaining functionality.	Active

10	**Regulatory Compliance**	High	Low	Working closely with CSA to adhere to regulatory and safety compliance.	Active
11	**Camera Calibration Error**	High	Low	Will be using “Flats” and “Biases” to ensure that camera is calibrated well before flight. Testing will be done prior as well.	Active

8.0 Team Reflections

The following outlines the team members responsibilities as well as other factors that may influence their performance within the capstone project. It also serves as a summary of the ITP Feedback they have received and their future motives.

8.1 Harrish Elango

Role: Integration Lead

Responsibilities:

- Oversee software architecture, coding, and debugging processes collaboratively with the Software Lead.
- Ensure seamless integration and compatibility among all components.
- Coordinate integration testing to validate system performance under mission conditions.

Skills and Qualifications:

- Strong problem-solving abilities.
- Quick learner who applies new knowledge effectively.
- Proficient in troubleshooting integration issues and optimizing system performance.
- Adaptable team player, skilled in diverse technical environments.
- Familiar with coding practices across various software, hardware, and operating systems.

Motivation:

- Passionate about contributing to space exploration and technology advancement.
- Merge personal interests in technology and space into meaningful outcomes.

Fulfilling Team Gaps:

- Offer a holistic technical perspective to bridge gaps across disciplines and subsystems.
- Leverage a broad skill set to align the system with mission goals and team success.
- Support the team dynamically in any capacity to ensure collective achievement.

8.1.1 ITPMetrics Feedback

The feedback I received highlights my commitment, communication, and technical skills as key strengths that benefit the team. My dedication, positive attitude, and ability to fill knowledge gaps, keep things organized, and support well-informed decisions are appreciated. I'm glad my efforts to document decisions and maintain high standards have been valuable. I also see room to grow by taking on more leadership, such as facilitating brainstorming sessions and ensuring everyone has opportunities to contribute. This feedback motivates me to build on my strengths, step into more leadership roles, and continue driving high-quality, team-focused results.

8.2 Katia Kassabov

Role: Thermal and Environmental Lead

Responsibilities:

- Thermal management strategy
- Design and implementation of thermal protection solutions
- Conduct environmental tests and simulations
- Analyze environmental data

Skills and Qualifications:

- Experience with thermal and environmental simulation tools
- Knowledge of stratospheric conditions
- Experience with data analysis

Motivation:

- Passionate about space exploration and the challenge of designing space systems.

Fulfilling Team Gaps:

- Brings experience with data analysis and risk mitigation

8.2.1 ITPMetrics Feedback

The feedback I received emphasized several of my strengths, including my strong commitment, effective communication skills, and dedication to maintaining high standards in my work. At the same time, it also provided valuable insights into areas for growth, particularly encouraging me to take a more proactive approach in sharing my opinions and exploring different aspects of the project. Moving forward, I plan to build on my existing strengths by continuing to demonstrate commitment, clear communication, and attention to quality while actively seeking to enhance my engagement in discussions and decision-making processes.

8.3 Prajakta Lal

Role: Payload Design Lead / Scientific Analyst

Responsibilities:

- Documentation and Compliance
- Scientific Payload Development
- Data Analysis for atmospheric

Skills and Qualifications:

- Collaborative Approach
- Data Analysis and Interpretation

Motivation:

- Blending scientific exploration with practical solutions
- Challenge of conducting broader research in space science and designing a payload to capture data.

Fulfilling Team Gaps:

- Ensure we meet high standards for the quality of data during measurements and bridge any technical gaps in space science.

8.3.1 ITPMetrics Feedback

The feedback from my team is very encouraging, and I'm glad my organization and creative ideas are helpful. It's great to know my dependability and problem-solving skills are valued, as I genuinely enjoy supporting our success. The suggestion to speak up more is a helpful reminder to share my thoughts more often and actively engage in discussions. I also appreciate the note about my quiet nature sometimes seeming reserved, and I'll work on being more approachable. Exploring finances is a solid idea, and I'll look into it to expand my contributions. Overall, I'm grateful my efforts and positive attitude are recognized.

8.4 Gaurav Charan Moturi

Role: Software Lead

Responsibilities:

- Finding and choosing appropriate software solutions for project objectives with the integration lead

- Performance optimization of software solution
- Collaborate with other team members to align software development with mission requirements and constraints
- Documentation of code for project objectives

Skills and Qualifications:

- Experience working with FPGA and hardware connections
- Extensive knowledge of coding principles
- Great communication skills

Motivation:

- Passion for solving problems with technology and software solutions
- Bridges the gap in technical knowledge related to software integration and development

Fulfilling Team Gaps:

- Bring technical experience in FPGA
- Enhances team cohesion by promoting effective communication and collaboration

8.4.1 ITPMetrics Feedback

The feedback I received from my teammates was positive, emphasizing my willingness to contribute and my ability to create a collaborative and inclusive environment. I was commended for ensuring that everyone felt involved, effectively organizing the team, and proactively seeking external help when needed. Following my team's earlier suggestions, I took the initiative to delve deeper into the selected OBC's operations, conducting additional research and becoming more familiar with its software. As a result, my team's feedback has now shifted towards encouraging me to improve my focus on the implementation of the software for this project, highlighting this as an area for further growth.

8.5 Sarthak Sahai

Role: Project Lead / Systems Lead

Responsibilities:

- Act as the point of contact between the NOVA team and the Project Manager of R3
- Documentation and organization of all materials and resources.

Skills and Qualifications:

- 3D Modeling
- Experience with data analysis, prototyping and fabrication of materials

Motivation:

- Passionate and curious about Space engineering applications
- Eager to see the final outcome of the project

Fulfilling Team Gaps:

- Coordinating skills and resources
- Facilitating Communication
- Support

8.5.1 ITPMetrics Feedback

Reviewing through the ITPMetrics Feedback I understand that I've been a great help to my peers and have done a great job in researching and providing my team members with what they need. I have been told I tend to take on more tasks than I should which may negatively affect my mental health and need to emphasize the need to delegate tasks over taking more tasks upon myself.

8.6 Aiden Weatherbee

Role: Space Systems Engineer

Responsibilities:

- Camera and lens Trade study
- Thermal management plan.
- Mass, volume, and power budget.

Skills and Qualifications:

- Experience with several cameras for astronomical brightness measurements and telescope imaging.
- Experience employing vision camera code on multiple space-grade microcomputers.
- Experience on ESSENCE cubesat mission mechanical team (primary payload is a camera).

Motivation:

- Passion for space missions and astronomical imaging.

Fulfilling Team Gaps:

- Astronomical brightness measurement and camera knowledge.
- Space mission analysis and design skills.

8.6.1 ITPMetrics Feedback

After reading the new ITP metrics, it is clear that the team is even more happy with my efforts and guidance. From the last metrics I learned that I should further discuss my rationale for certain thoughts and questions more with the team before meetings with project supervisors and stakeholders to keep the team all on the same page. This time, I clearly improved from the feedback, as It mentioned this being a good trait of mine that the team is happy with. I plan to not make any changes in my performance or teamwork from here, as the feedback has no suggestions for improvement. This is reflected in the 4.8/5 rating.

9.0 Conclusions and Future Work

The NOVA Sub Payload has been designed to optimize brightness measurements for accurate calibration of the RSOnar III payload camera. By imaging in nearly the exact same location, and optimizing our camera and lens choice for a high SNR, we are confident that our payload will provide useful scientific data for the RSOnar III team.

The payload has also been carefully designed to withstand the extreme conditions present between 0 and 40 km altitude. This includes the temperature range and thermal shock, pressure range, increased radiation, and any mechanical shocks that may occur such as post-mission impact. As outlined, extensive testing will be conducted to verify all requirements are met, and that the NOVA payload can capture high SNR imaging data even in these extreme conditions.

The next step for the NOVA team is to obtain supervisor approval for all components we are purchasing so that we can submit the bill of materials outlined in this report. We can then order our components ensuring they are from sources that are not affected by the Canada post strike. We will simultaneously be completing a thorough software design that is based around the design of RSOnar II as it is a proven system design that has had success in the past. Once all components have been received, we can go ahead with manufacturing our internal mechanical structure at the Lassonde machine shop outlined in the mechanical design subsection that will be fixed to the RSOnar III balloon satellite.

After all subsystems have been constructed, the next step before integrating our subsystems into a single payload design is integrating our software design to conduct subsystem-level testing. This will allow the extensive verification process outlined in this document to be conducted to ensure that the NOVA payload will meet all requirements outlined in section 2. Once complete, the NOVA payload can be integrated and the thorough testing described in section 4 can be conducted.

10.0 References

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11.0 Appendices

Link to Gantt Chart: Capstone Gantt Chart

https://docs.google.com/spreadsheets/d/1AuGDyT_0Yqkz_e1kojHYcQUohy-Bnx89A45vnMMxkTc/edit?usp=sharing

Link to 3D Models: December 5th 2024

https://drive.google.com/drive/folders/1o2ILCYEm_qmwO38NgHXP4vXAGTat_-1s?usp=sharing

Link to Case Studies: Case Studies

https://drive.google.com/drive/folders/1pZBQQ4ZpdFk8WlVbMU__CNbK5Qom6ysU?usp=sharing